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The Role of Commercial Space Transportation in an International Moon Village

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Abstract

The Director General of the European Space Agency has proposed that an international Moon Village be established as an appropriate and worthwhile follow-on to the International Space Station (ISS). This paper describes one possible implementation of the Moon Village, including specifically how commercial space transportation could support such an endeavor. It also provides some initial FAA perspectives on transportation safety that would be applicable to the project.

A successful Moon Village would involve both public and private sector entities, and would be focused on carrying out a number of different missions, including exploration, scientific research, technology development, in-situ resource extraction, and even tourism. Each participant would provide specialized contributions as part of a broad, interdependent coalition. A new lunar economic structure may evolve in which both governments and corporate entities would exchange goods and services.

Examples of basic products (goods and services) could include constructing and operating habitats; generating and distributing electrical power; providing food, water, and oxygen; supplying communications, navigation, and transportation services; and controlling and maintaining all of the necessary hardware and software. As the community grows, products would become more diversified, and could include health care, security, and leisure time activities.

To create a Moon Village and sustain it, transportation will be crucial. Transportation will be needed not only from the Earth to the Moon and back, but also across the lunar surface, and in support of operations in cis-lunar space. Because of the Moon's low gravity and the potential ability to use lunar resources to generate rocket fuel, the Moon may also prove to be an appropriate staging area for missions to Mars or other deep-space destinations. Based on recent experience by the United States in supplying cargo (and plans to transport crew) to the ISS, there would be a number of advantages in using vehicles owned and operated by the private sector in support of the Moon Village. For example, the use of commercial space services can result in lower costs, increased innovation, greater risk tolerance, the creation of new markets, and the identification of new sources of funding. These advantages could allow the Moon Village to develop more quickly and less expensively than would be possible using more traditional government acquisition techniques.

1. Introduction

In 2015, Dr. Johann-Dietrich Woerner proposed an international Moon Village as a next step in space exploration. The proposal by Dr. Woerner, then the head of the German Aerospace Center (DLR) and currently the Director General of the European Space Agency (ESA), is not a DLR or ESA program, but a personal idea for consideration as government agencies evaluate follow-on exploration activity after the International Space Station.

Instead of constructing a lunar base led by one nation, Dr. Woerner said a Moon Village would be a joint international effort where "different countries of the globe should bring in their special ideas, their special competence."[1]

A permanent base could be located on the far side of the Moon for astronomy, planetary science, resource exploitation and other purposes.

The U.S. Federal Aviation Administration's Office of Commercial Space Transportation (FAA/AST) has endorsed the idea of Moon Village and further proposed that private industry can play an important role. Industry could not only provide goods and services to support construction and sustainment of a Moon Village, but also carry out their own commercial objectives as a partner with governments.

This paper describes how commercial space transportation can play a role in one possible implementation of a Moon Village and includes some initial FAA perspectives on transportation safety that would be applicable to the project.

2. What is a Moon Village?

As described by Dr. Woerner, a Moon Village is a permanent lunar base that combines the capabilities of different space faring nations, whether it is through robotic or human contributions. The missions undertaken as part of a Moon Village could be scientific, or they could involve mining or even tourism. In most cases, participants would live and work in the same place.[2] [3] Activities would be carried out both by governments and by private industry.

While acknowledging the success of the construction and continued operation of the International Space Station, there is also a recognition that ISS won't be around forever. As nations discuss and plan extensions of ISS operations, there have also been proposals for expanding human and robotic presence in the Solar System and what could be done next at an international level. Possible destinations include Mars, asteroids, the Moon, and others locations. Each has potential advantages, and there is no single best answer.

The Moon is attractive for several reasons:

- The Moon is relatively close to the Earth, resulting in lower costs to reach it, more frequent launch windows, and reduced human safety risks;
- The Moon has natural resources, including surface and underground metals, minerals and water ice that can be extracted for multiple uses including sustaining a base and building new structures;
- The Moon can be a testbed for developing technologies that are applicable to more distant destinations, such as Mars or asteroids;
- The Moon would provide a stable platform for science, including telescopes for astronomy; and
- The Moon may be more technically feasible as a destination in the near-term, as compared to Mars, which would be more challenging.

The potential for near-term activity opens up opportunities to existing and potentially new spacefaring nations, increasing the appeal of global partnerships.

According to Dr. Woerner, "the advantage of the idea of Moon Village is that we don't need a big amount of funding at the beginning. We don't have to define everything and just… build a big structure. The idea is with different actors, different players worldwide… they look in their special capabilities, in their special interests, and they bring just their part into the idea. That means we can start with a small landing mission which many countries are already planning, up to a huge investment for instance for some radio telescope[s] on the far side of the Moon. So it's multiple uses by multiple users but a single place."[4]

One location for a base could be at the South Pole on the dark side of the Moon where there are strong indications of the presence of water, and which would be ideal for telescopes that point away from the Earth. The Moon and its orbit can also be a staging area or "pit stop" on the way to other solar system or deep space destinations.

3. Notional Phases of Moon Village Development

In order to characterize commercial roles in a Moon Village, it is useful to first identify a series of phases of development. Phases can be happening concurrently as original partners advance and new partners are added, depending on particular mission needs.

In keeping with a start small and simple philosophy, the following is just one possible growth scenario used to give a notional structure to a Moon Village:

- Phase 1: Partnership Planning;
- Phase 2: Exploration and Robotic Testing;
- Phase 3: Demonstration and Human Occupancy; and
- Phase 4: Mission Operations and Expansion.

Phase 1 activities might include planning and agreements on international partnerships and a basic establishment of roles and responsibilities based on specialty contributions. Because activities would be carried out both by governments and by commercial entities, there may be some areas with regulations that are inherited from existing providers and other areas without regulations (such as surface operations) that may initially start with fundamental practices or standards to enhance safety and interoperability.

All stakeholders will need to engage on standards. Existing multi-stakeholder organizations that could serve as models for Moon Village consensus standards include the International Telecommunications Union and the Internet Corporation for Assigned Names and Numbers.

Phase 2, in general, would focus exploration on direct planning for the location and establishment of a Moon Village, starting with robotic sensing from orbit and on the surface.

For some countries and potentially companies in the near term, various forms of Phase 2 may have already taken place (before Phase 1) through orbiting lunar mapping and sensing space probes, surface rovers, and other early commitments. Certainly, over 50 years of international Moon exploration including the Apollo program have already produced a large amount of data and experience that can be adapted for each phase.

Phase 3 would begin a focus on testing and demonstrating equipment for individual missions, human occupation, and resource exploitation as well as initial, temporary human excursions. This phase would also include activation of a transportation supply chain and the beginning of support goods and services for human and robotic activities.

Phase 4 would mark the start of a permanent Moon Village with establishment of continual human presence that moves to initial operations in science, resource exploitation, and expansion. It would also include a steady rate of cargo transported to and from the Moon at a pace that meets partner needs. This phase would mark the establishment of a small, interdependent community that would be ready for immediate growth as new partners arrive with new missions. Basic products and services would also be in place with regular user demand.

4. Measures of Success

A successful Moon Village would involve public and private sector entities carrying out their respective duties while working and living in the same location as a community.

Each participant would provide specialized contributions as part of a broad, interdependent coalition. These contributions could range from performing various missions to providing goods and services.

For example, missions could include: astronomy, surface exploration, scientific research, resource extraction, manufacturing (using lunar resources), and tourism.

At the same time, a series of basic products (goods and services) would available. Examples of basic products could include: constructing and operating habitats; generating and distributing electrical power; providing food, water, and oxygen; communications; navigation; transportation services to and from the Moon; and controlling and maintaining hardware and software. As the community grows, products would become more diversified, potentially including health care, security, rover repair depots, and leisure time activities.

A new lunar economic barter structure may evolve in which partners would exchange goods and services -- regardless of whether they were governments or private companies. Examples could include trading electrical power for an upgraded habitat, or telescope time for filtered water.

A key measure of success would be a gradual shift from relying solely on Earth originated supplies -- where applicable -- to living off the land. This could include growing food in greenhouses and using lunar materials for 3D printing of machinery or new habitats.

Another measure of success could be selling/trading products originating on the Moon back to the Earth, low Earth orbit residents, or outbound transportation services to Mars, asteroids or other destinations.

5. Commercial Partner Advantages

Ideally, a Moon Village would have commercial companies as full partners with governments. Goods and services offered would be independent of government support; government would be just another customer. At the same time, private industry would be just another participant with access to the collective benefits of a functional Moon Village.

Definitions of what commercial activity is and how to draw a line between government and the private sector can vary. One such definition can be found in the U.S. 2010 National Space Policy: "The term "commercial," for the purposes of this policy, refers to space goods, services, or activities provided by private sector enterprises that bear a reasonable portion of the investment risk and responsibility for the activity, operate in accordance with typical market-based incentives for controlling cost and optimizing return on investment, and have the legal capacity to offer these goods or services to existing or potential nongovernmental customers."[5]

The use of commercially provided goods and services by governments can offer several advantages including: lower cost, increased innovation, the opportunity for greater risk tolerance, the creation of new markets, and the identification of new sources of funding.[6] These advantages could allow the Moon Village to develop more quickly and less expensively than would be possible using more traditional government acquisition techniques.

For markets that are still maturing, just as commercial companies have partnered with government and expanded to independent operations in satellite communications since the 1960s, launch since the 1980s, and remote sensing since the 1990s, we should expect that there will be similar commercial partnering for Moon Village operations with the potential to transition to greater private investment risk and responsibility.

Use of commercially provided services can enable governments to focus their resources on accomplishing things in space that only governments can do.

6. Role of Commercial Space Transportation in a Moon Village: Earth to the Moon and Back

In the United States, the key role of commercial operators to provide cargo transportation services to and from the International Space Station (ISS), and soon, crew transportation services, is a model that could be applied to a future Moon Village.

NASA was able to provide incentives and opportunities to private industry to meet both government objectives (resupply) and commercial objectives (commercial satellite launch, in-space transportation, and space tourism). As part of this effort, companies contributed significant funding for system development.

For ISS Commercial Resupply Services missions, instead of overseeing vehicle design and using a traditional acquisition contract, NASA loaded its requirements into launch services contracts. Each commercial provider would decide how to meet those requirements. At the same time, NASA and the FAA worked together to resolve safety issues. Once selected, the launch service providers (SpaceX and Orbital Sciences [now Orbital ATK] were paid to deliver certain amounts of cargo to the ISS. Success of the program enabled NASA to hire a third service provider (Sierra Nevada Corporation) for the follow-on contract.

Transportation to and from the Moon Village would need to be done on a regular basis. A transportation architecture plan and barter or trade options would be established during Phase 1. The many needs of a Moon Village during Phase 2 would create opportunities for heavy-lift, medium, and small launch vehicle services, as well as new vehicle research and development.

Moreover, to increase base construction, cargo throughput, and occupant safety, multiple service providers would be needed. As a result, there is the potential for a new market for space transportation services to be created. Private companies are typically in an advantageous position to provide

services at lower cost and greater efficiency than government.

Although launches to the Moon can be done today (by both governments and commercial operators), vehicles that could perform soft landings on the Moon with the significant cargo required by a Moon Village would have to be developed.

Initially, expendable vehicles could be used during Phase 2 development. But eventually, for Phases 3 and 4, with lunar-produced products and crew rotation, lunar descent and ascent vehicles would ideally be reusable. Governments may be able to provide commercial incentives not only for Moon Village missions but also for separate commercial or other government missions that may not be directly part of Moon Village activity, such as in cis-lunar space or to support missions to asteroids or other planetary destinations.

In keeping with the Moon Village charter to grow with specialized contributors, a barter economy for launch and return space transportation services could be established. For instance, governments or commercial companies could purchase launch and return services, but instead of exchanging funds, they would trade for research time, access to facilities, or other infrastructure needs.

Barter arrangements have been successful between International Space Station partners, with launches of hardware (modules and supplies) being exchanged for equipment access and time to do research. One reason the European Space Agency (ESA) uses barters is to "avoid the need to make cash payments to non-Member States, and instead permit such budgets to be invested with European industry."[7]

7. Surface Operations

Although surface transportation and other surface habitat operations would appear to be different than space transportation, there are similar issues with respect to safety and the challenges of operating in the unique environment of space.

Organizations that prepare standards and regulations may find the similarities could be reason enough to address space transportation and surface transportation under a unified approach.

Entirely new vehicles built for lunar operations may have to be developed, ranging from rovers and mining vehicles to human transports.

Similar to space transportation, incentives, barters, and other arrangements could be used for the unique attributes of surface transportation in a Moon Village.

Infrastructure could include lunar road construction, navigation, repair and charging stations, and sites for launches and landings (lunar spaceports).

Habitats would need common interfaces for transfer of water, power, oxygen, and may be modular to provide flexibility for expansion. Detailed standards for life support and habitats that keep an entire community functioning may need to be reviewed and agreed on during Phase 1.

Furthermore, the Moon has unique properties that may require unique and detailed standards for human activity ranging from working in a vacuum with one-sixth gravity to cosmic and solar radiation.

Each of these areas would benefit from common standards and other practices to ensure interoperability between Moon Village partners.

One constant and unique aspect of human and robotic operations on the Moon will be dealing with surface dust. Over half the mass of regolith is comprised of abrasive particles less than 100 micrometers in diameter. According to geologist and former Apollo astronaut Harrison Schmitt, "the invasive nature of lunar dust represents a more challenging engineering design issue, as well as a health issue for settlers, than does radiation."[8]

Dust mitigation strategies and common rules will be needed. Each habitat air lock will have a dual purpose as a "dust lock" for removal of dust from spacesuits and equipment. "Continuous exposure of lungs and other internal organs to micron- and submicron-sized mineral and glass particles…may cause long-term health problems."[9]

People working outside will potentially be exposed to solar particle events, "warnings for which will only be on the order of half an hour."[10] Vehicles will need adequate protection or shelters may need to be pre-deployed. A solar particle event could last a few hours. Covering a habitat with 2 to 5 meters of lunar regolith can provide protection from external radiation.[11]

8. Commercial Moon Planning Today

Lunar plans underway by U.S. companies today can provide insight into future commercial missions and the kinds of activities that might take place in and near a Moon Village.

Google Lunar XPRIZE

There are 16 remaining teams in the Google Lunar XPRIZE competition out of 29 original entrants.[12] Prizes will be awarded to teams able to land a privately funded rover on the moon, travel 500 meters, and transmit back high definition video and images. A $20 million grand prize will be awarded to the first team to meet the prize objectives. The second place team will win $5 million. Additional prizes for completing specific milestones have a total value of $5 million.

Winning teams "must prove that 90% of their mission costs were funded by private sources. Teams have until the end of 2016 to announce a verified launch contract to remain in the competition and complete their mission by the end of 2017."[13] The prize was created in 2007 to incentivize space entrepreneurs to pursue affordable access to the Moon and other destinations.

Moon Express

Moon Express Inc., a U.S. company, is one of the Google competitors and is planning a launch to the Moon in December 2017. In July 2016, the FAA completed a Payload Review for the Moon Express MX-1E spacecraft and made a favorable determination. The MX-1E is a "spacecraft/lander capable of transfer from Earth orbit to the Moon, making a soft landing on the lunar surface, and performing post-landing relocations through propulsive "hops.""[14]

The favorable determination gives Moon Express confidence to proceed with their business plans and raise additional funding. The company has raised $30 million of the $55 million it requires.[15] Moon Express believes that the Payload Review set a precedent for industry in showing how regulatory approval could be obtained for missions to deep space.[16]

If a launch operator applies to the FAA for a license to launch a vehicle carrying the MX-1E payload, the favorable payload determination will be incorporated into the FAA's review of the license application. The FAA "determined that the launch of the payload does not jeopardize public health and safety, safety of property, U.S. national security or foreign policy interests, or international obligations of the United States."[17]

Future missions are planned by Moon Express to assess, extract and exploit lunar resources.

Astrobotic

Astrobotic Technology Inc. is developing the Peregrine Lander to deliver payloads to the Moon like a package shipping company. The company has also won three Google milestone prizes: the Landing Prize ($1 million), Mobility Prize ($500,000), and Imaging Prize ($250,000). The first landing site on the Moon selected by Astrobotic is believed to be near a lunar cave or what is called a skylight. "The discovery of lunar caves would be a boon to future lunar exploration, protecting equipment, infrastructure, and human astronauts from solar radiation, micrometeorite strikes, and extreme surface temperatures."[18]

Astrobotic is also partnered with NASA in the Lunar Cargo Transportation and Landing by Soft Touchdown (Lunar CATALYST) program. The company was spun out of Carnegie Mellon University's Robotics Institute in 2007.

Bigelow Aerospace

Bigelow Aerospace is looking at soft landing habitable modules on the Moon's surface. In December 2015, the FAA completed a Payload Review of Bigelow Aerospace's plans for a future Moon habitat, using the U.S. Government's interagency review process. Note that a request for a Payload Review may be submitted separately from a launch license application. In this case, it was intended to allow Bigelow to proceed with plans for its Moon habitat, including investment, with increased certainty regarding the future regulatory framework.[19]

The company deployed the Bigelow Expandable Activity Module (BEAM) on the International Space Station in April 2016 (launched by SpaceX) under contract to NASA. The module will be tested for two years and offers increased volume, better onboard acoustics, improved protection from micrometeoroid debris, and increased thermal protection. The module is part of Bigelow's plans for a privately operated low Earth orbit habitat (using a larger, B330 model), and eventually for a habitat on the Moon.

Use of an expandable module, "which are lower-mass and lower-volume systems than metal habitats,

can increase the efficiency of cargo shipments, possibly reducing the number of launches needed and overall mission costs."[20] Such a module can also provide a "varying degree of protection from solar and cosmic radiation, space debris, atomic oxygen, ultraviolet radiation and other elements of the space environment."[21]

Under a NextSTEP contract, Bigelow Aerospace will demonstrate to NASA how B330 habitats can be used to support safe, affordable, and robust human spaceflight missions to the Moon, Mars, and beyond.[22]

Shackleton Energy Company

Shackleton Energy Company is developing plans to extract water ice from the poles of the Moon to create rocket fuel. The company would first test systems in low Earth orbit by operating propellant depots. Then it would test and operate lunar surface mining equipment and establish a space transportation supply chain by bringing water from the Moon back to stations in low Earth orbit (LEO). The on-orbit stations would convert water ice and sell the resulting rocket fuel to customers in low Earth orbit (or at other locations).

Lunar surface mining crews, starting with 6 to 8 people on 6-month rotations, would be required by Shackleton.[23] The company notes that, "it is about 20 times cheaper to deliver water to lower Earth orbit from the Moon's surface than it is to deliver it from the Earth's gravity well."[24] As an example, they observe that to get from LEO to Trans-lunar injection, 50% of a system mass is propellant. To get from LEO to the Moon's surface, 75% of a system mass is propellant. Because of the high percentage of propellant mass needed to get from LEO to other destinations, such as geosynchronous transfer orbit, the Moon's surface, or Trans-Mars injection, the "capability to refuel spacecraft in LEO underpins a paradigm shift that considerably increases the mass of useful spacecraft possible per launch because of the reduction of onboard propellant requirements."[25] Having a fuel supply station in place would be a key enabler for other missions and a variety of customers.

Shackleton has identified precursor research and development areas with commercial mining companies and government agencies. For example, the company has an agreement with the Center for the Advancement of Science in Space (CASIS) to develop a reentry vehicle. (CASIS has been selected by NASA to manage use of the International Space Station U.S. National Laboratory to inspire innovative research.) The reentry vehicle would bring small payloads from the ISS back to Earth, an enabling technology to test crew return vehicles and aerobraking that will be needed in Shackleton's transportation supply chain.[26]

9. The Moon and Future FAA Commercial Space Transportation Regulations

The way the U.S. approaches regulations in commercial space transportation today could be a model for a Moon Village era.

Under the Commercial Space Launch Act of 1984, as amended (51 U.S.C. Chapter 509),[27] the Department of Transportation (DOT), and by delegation, the FAA, is authorized to oversee, license, and regulate commercial launch and reentry activities and the operation of launch and reentry sites as carried out by United States citizens or within the United States.

The Commercial Space Launch Act directs the FAA to exercise this responsibility consistent with public health and safety, safety of property, and the national security and foreign policy interests of the United States. The FAA is also responsible for encouraging, facilitating, and promoting commercial space launches and reentries by the private sector.

The FAA does not regulate space transportation activities that the U.S. government carries out for the government (such as launches overseen by NASA that carry NASA payloads). The FAA also does not regulate commercial satellite activities overseen by the Department of Commerce's National Oceanic and Atmospheric Administration (for commercial remote sensing) or the Federal Communications Commission (for communications satellites).

Historically, DOT/FAA authority has been increased on an incremental basis. Oversight began with launch authority in the 1980s. Reentry authority was added in 1998 and human space flight in 2004. There is currently a moratorium on issuing regulations to protect occupant safety (either flight crew or space flight participants).

The FAA published Recommended Practices for Human Space Flight in 2014 after consulting with industry.[28] Ninety practices were included to assist industry development in commercial human space flight. Topics not included in the 2014 report but identified for future versions of FAA recommended practices included Extravehicular Activity (EVAs),

rendezvous and docking, integration of occupant and public safety, long duration space flight missions, and missions beyond low Earth orbit.[29]

Because of the incremental approach to regulating U.S. space industry, there is no clear authority in the United States for "non-traditional" space activities proposed by U.S companies such as on-orbit space transportation, planetary mining, commercial habitats in orbit or on other planets, or commercial activity beyond Earth orbit in general. As a result, there is a need to establish an authority to maintain U.S. obligations under the 1967 Outer Space Treaty.

The Outer Space Treaty states that: "The activities of non-governmental entities in outer space, including the Moon and other celestial bodies, shall require authorization and continuing supervision by the appropriate State Party to the Treaty."[30]

In 2015, the U.S. Congress passed the Commercial Space Launch Competitiveness Act (CSLCA; Public-Law 114-90). The Act required 12 reports to be prepared, including one by the White House Office of Science and Technology Policy (OSTP) to address current and future commercial space plans, such as conducting operations on the Moon and mining asteroids.

In their report in April 2016, OSTP proposed new legislation that would enable the FAA Office of Commercial Space Transportation to establish a "Mission Authorization" based on its existing Payload Review authority.[31]

Under a Payload Review, which may be requested by industry, the FAA consults with other agencies to determine whether the launch of a proposed payload or payload class would present any issues affecting public health and safety, safety of property, U.S. national security or foreign policy interests, or international obligations of the United States.

Instead of a comprehensive new regulatory framework, the report proposed "a process no more burdensome than is necessary to enable the United States Government to authorize these pioneering space activities in conformity with its treaty obligations, and to safeguard core public interests, such as national security. By providing a clear path for authorization and supervision of new space activities, the legislation would encourage investment in those activities and foster and promote a robust domestic commercial space industry."[32]

Under a Mission Authorization, "the FAA would coordinate an interagency process in which designated agencies would review a proposed mission in relation to specified government interests, with only such conditions as necessary for fulfillment of those government interests. For example, the Department of State would be responsible for reviewing proposed missions for consistency with the Outer Space Treaty, and would recommend authorization conditions only as necessary to ensure conformity with the provisions of this treaty. The legislative proposal is not intended to authorize any agency to prescribe substantive, generally applicable regulations. The regulations FAA would develop would simply outline the procedural aspects of getting a Mission Authorization, consistent with the case-by-case interagency process outlined above."[33]

A Mission Authorization would apply to any U.S. citizen/operator, regardless of whether they launched on a U.S. or non-U.S.-manufactured vehicle.

10. Conclusion

The idea of a Moon Village opens up many new possibilities including roles for private industry to partner with governments as contributors.

As the capabilities of commercial space companies increase, governments should consider commercial approaches to gain advantages in terms of cost and in opening new markets for industry.

Private industry contributions to a future Moon Village need not be limited to the operation of commercial space transportation vehicles. Plans under development by U.S. companies to carry out their own missions on the Moon are an indication that industry can be one of the many users of the Moon Village.

The United States FAA approach to regulating commercial space transportation today, with an emphasis on public safety while enabling industry growth, may be more broadly applicable as companies expand activity outside of low Earth orbit. Such approaches could be beneficial in helping private industry become Moon Village partners and contributors in the future.

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[29] Ibid.

[30] "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies," Article 6, (entered into force on October 10, l967). Available at: http://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/outerspacetreaty.html

[31] "Report on on-orbit authority, as required by the Commercial Space Launch Competitiveness Act (Public Law 114-90)," Office of Science and Technology Policy, [letter to Congress on Section 108], April 4, 2016. Available at: https://www.whitehouse.gov/administration/eop/ostp/library/docsreports

[32] Ibid., page 4.

[33] Ibid.