National Space Society

Position Paper:

U.S. Development and Settlement of the Moon and Near Earth Asteroids

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The National Space Society (NSS) believes that the development and settlement of the Moon, cis-lunar[1] space and near Earth asteroids should be conducted in a logical and practical manner. NSS has previously proposed a set of milestones to space settlement in the form of a roadmap which can be found at www.nss.org/settlement/roadmap. However, the time has come to move beyond a high-level set of stepping stones and begin to discuss the policies needed to make the roadmap a reality. Toward that end, we offer the following principles to guide the next steps in asteroidal and lunar development and settlement. As these conversations mature, we intend to supplement these recommendations with additional guidelines as appropriate.

1. NSS supports space development and settlement in multiple locations – free space,[2] the Moon, among the asteroids, on Mars, and elsewhere in our Solar System.

2. There is a logical ordering of space development projects, with locations closer to Earth (in terms of time and/or energy) being more convenient to reach, and thus would logically be developed earlier. A step-by-step approach to development and settlement enables technology and infrastructure to emerge and evolve that can make later steps easier and less costly: accomplishments should not be abandoned but built upon. The development of near-Earth space, the Moon and near-Earth asteroids will further enable development and settlement beyond cis-lunar space, including Mars. NSS believes that the development of cis-lunar and Near-Earth Object (NEO) resources will actually speed our path to a sustained exploration of Mars while significantly reducing the cost of going there.

3. Although the ordering of space development projects, starting with those nearest to Earth in terms of time and energy, should generally be followed, it may be desirable for technical or economic reasons to proceed in some other order to achieve a particular objective. For example, only Low Earth Orbit (LEO) refueling might be used for some projects, while for others only Lagrange-point[3] and lunar surface fuel

depots might be used. In all cases, the target should be a reusable infrastructure that enables downstream goals rather than single-mission cost minimization.

4. LEO infrastructure[4] should be a foundation on which space development proceeds by facilitating activities beyond LEO (i.e., higher Earth orbits, Earth-Moon Lagrange points, the Moon, etc.) as sustainable rather than one-shot missions. For example, LEO facilities could serve as transportation hubs, similar to seaports on Earth, but where vehicles optimized for Earth-to-LEO operations transfer cargo and passengers to vehicles optimized for in-space transportation, analogous to how ocean vessels interface with rail and highway transportation systems. Like on Earth where settlements develop around transportation hubs, providing ever-increasing levels of service to visiting vehicles and crews, more capable LEO facilities could also evolve around such LEO infrastructure.

5. Recent studies suggest that particular low-radiation orbits in LEO might be the best location for an initial space settlement.[5] Development of LEO infrastructure at some level and scale, especially after reusable in-space transportation becomes available, may rely on lunar products such as water and oxygen for life support, metal for structure, silicon-oxide for windows, propellants for reboost and station-keeping, and other uses. Some of these materials might also be sourced from NEO asteroids.

6. Mining of near-Earth asteroids logically should be co-developed along with lunar resource processing, leveraging knowledge gained in LEO facilities as well as from lunar surface processing. Potentially useful materials returned from asteroids, and possibly certain raw materials from the lunar surface, may best be processed in microgravity at orbital facilities in cis-lunar space. Development of infrastructure in cis-lunar space could become another major market for lunar and/or asteroid materials. Such materials for radiation shielding may be a key enabler for space settlements beyond the limited capacity low-radiation low-inclination orbits close to the Earth.

7. The U.S. Government should approach the development and utilization of lunar resources and the resources from near-Earth asteroids in an equitable fashion.[6] Any activity that, for example, fills a propellant depot with oxygen obtained from lunar resources (such as oxygen from a private company) should be organized in such a fashion that other space resource utilization entities (for example, asteroid mining companies) can also participate.

8. The FAA and other government agencies involved in licensing and regulating cis-lunar activity (including lunar surface activity) should support resource development by providing appropriate and timely licensing and regulation in the context of compliance with the Outer Space Treaty. In no case shall the so-called "Moon Treaty," which the U.S. has not signed, nor the Law of the Sea Treaty be used as a guideline for the regulation of the activities of U.S. companies on the Moon.

9. Although some may be interested in returning to the Moon as a candidate for settlement, future lunar exploration and development is mainly justified in the short to medium term by potential access to lunar resources (including but not limited to minerals, ices, etc.), the potential for ambitious science from the Moon (e.g., far side radio astronomy), and also to support understanding whether one-sixth gravity is sufficient for humans to thrive in the long term. The development of lunar resources and infrastructure will enable large-scale lunar science efforts such as far-side radio astronomy and eventual lunar settlement. NSS support for an eventual return of humans to the Moon in the context of resource extraction is not an endorsement of the Moon as a preferred target for settlement over other locations, including LEO, free space, the asteroids, or Mars.

10. The characterization and development of lunar resources should be the major focus of future U.S. government lunar efforts, including oxygen and potentially hydrogen for rocket propellant[7] and life support, construction materials for stations, hotels, and settlements throughout cis-lunar space and on the lunar surface, as well as radiation shielding for free-space settlements beyond low-radiation equatorial LEO orbits. Future human and robotic activities on the Moon will also open new vistas of science. U.S. efforts to "return to the Moon" should not be focused on human-centered milestones like "boots on the Moon" but instead on technology, infrastructure or commercial milestones like "first use of lunar oxygen in a re-usable lander."

11. International involvement by interested governments should be solicited with the expectation that NASA might engage in certain lunar activities within the context of a broad, multi-lateral agreement, such as the international framework for the ISS program.

12. NASA's programs should internally balance exploration, development, settlement and science, lunar and near-Earth asteroid activities, and activities in Earth orbit and beyond. Advocating a balanced approach should be understood as implying a rough equivalence that shifts over time, not exact annual budget balancing. NASA budget planning shows all human LEO activity (ISS, Commercial Crew) ending when the ISS is de-orbited, currently planned for 2020 with a requested extension to 2024. Abrupt and complete termination of major and successful programs is the opposite of the balanced approach NSS suggests for the NASA budget. In a recent position paper, NSS advocates that NASA transition from the current International Space Station (ISS) to being an anchor tenant in multiple future commercial space stations in Earth orbit,[8] and to continue support for Commercial Resupply Services/Commercial Crew to support NASA research on these commercial space stations.

13. In the context of increasing lunar activity, a balanced NASA program should also include sufficient funds not only for automated/human-tended mining/ISRU, but also for robotic prospecting missions and related activities. For example, it is

reasonable to expect that as part of a lunar development strategy, some part of the annual robotic exploration budget should be used to fund lunar polar missions to evaluate the potential for use of available water ice. Another important area of investigation is lunar lava tubes, which may provide radiation shelters for future lunar settlers. Such missions, although possibly not essential for a lunar development program, are highly desirable and, if successful, would make all lunar activities more affordable. A full survey of lunar resources at the lunar poles and other locations will inevitably produce additional valuable insights.

14. Future lunar and cis-lunar activities should be based on the creation of cost-effective, sustained, reusable Earth-Moon transportation and lunar surface infrastructure that will support resource development, exploration and settlement as well as exploration and settlement of Mars, asteroids, free space, and any other suitable locations. Moreover, such activities should make substantial use of existing and new commercial space transportation capabilities.

    For example, desirable elements of a lunar infrastructure might include:

    - Reusable lunar landers
    - Lagrange-point fuel depot,[9] operations control sites, and transportation nexus
    - Lunar communications satellite network
    - Lunar GPS network
    - Power for lunar operations, possibly from a Lagrange-point, orbital or surface lunar space solar power (SSP) systems
    - A standardized interoperable set of lunar mining robots and processing tools based on extensible and publically available standards
    - A diversity of interoperable Moon suits, habitats, rovers, and other elements
    - 3-D manufacturing facilities
    - Reusable systems for Earth-Moon transportation of crew and cargo
    - Closed loop life support systems and radiation shielding for habitats, rovers, and work areas
    - Lunar rover vehicles for surface mobility with extended autonomous capability
    - Systems for transporting and stabilizing the Lunar regolith for landing pads, berms, roads and habitats
    - Lunar surface robotic systems for diverse purposes (including exploration, operations, etc.)
    - In the longer run, a maglev launcher and/or a lunar elevator[10]

15. NASA should not compete with any on-going commercial effort on the Moon or in cis-lunar space. For example, if a COTS/CRS program to bring cargo to an Earth-Moon Lagrange-point way station is established, NASA should avoid running operations that compete with the on-going commercial effort. This principle does not prevent U.S. government ownership and operation of appropriate parts of the cis-lunar infrastructure. However, NASA should consider obtaining services and

resources on a COTS-like basis wherever possible so as to avoid having to become the owner of systems that would otherwise have commercial applications. One potential balancing of public and private ownership would be NASA ownership of a Lagrange-point station and a Mars-focused fuel depot combined with private ownership of lunar surface mining operations and transportation infrastructure including a Moon-focused fuel depot. An eventual staffed scientific base on the lunar surface might also be a NASA or an international project supported by privately owned transportation and habitation services.

16. Future NASA and other U.S. Government agency lunar initiatives should be accomplished in the context of other U.S., international and commercial activities, in order to balance exploration, development, settlement and scientific goals. The U.S. government should take into account both international and commercial efforts in its planning to maximize the value of public investment and avoid, if possible, duplicative efforts. In attempting to avoid duplication of effort, U.S. Government planning should seek to encourage competition and avoid single points of failure, especially in transportation systems. An excellent example of this is ISS cargo resupply, which relies on Progress (Russia), the HTV (Japan), Cygnus and Dragon (U.S.), and historically the ATV (Europe).

17. Finally, NASA and other U.S. government agencies should make substantial usage of Space Act Agreements, both funded and unfunded, Other Transaction Authority (OTA), and public/private partnerships to increase the impact of available funding as deemed appropriate by each organization.

Footnotes and References

1 "Cis-lunar" space as used in this paper refers to all areas in the vicinity of the Earth-Moon system excluding the Earth's surface.

2 Here "settlements in free space" refers to artificial habitats orbiting celestial bodies. Often such habitats are envisioned as rotating to replicate gravity.

3 An Earth-Moon "Lagrange Point" is one of five points of dynamic stability in the Earth-Moon system. L1 (in a halo orbit between the Earth and the Moon) and L2 (in a halo orbit on the opposite side of the Moon from the Earth) are often cited as possible locations of a refueling station and transfer point. Note that there are also five points of dynamic stability in the Earth-Sun system.

4 "LEO infrastructure" should be understood to include the ISS and follow-on commercial space stations, as well as future fuel depots, solar power stations, and tourist hotels. There is no endorsement here of a particular architecture for LEO fuel depots, which may turn out to be "on the fly" where a tanker refuels another ship.

5 See "Orbital Space Settlement Radiation Shielding," Al Globus and Joe Strout http://space.alglobus.net/papers/RadiationPaper.pdf.

6 NSS will address the topic of property rights in space, which is a complex issue, in a separate position paper. Generally, NSS believes the companies mining resources in space are legally entitled to own space resources once they have been extracted.

7 See Appendix E "Proposed processes for lunar oxygen extraction" in THE MOON: RESOURCES, FUTURE DEVELOPMENT, AND SETTLEMENT by Schrunk, Sharpe, Cooper, and Thangavelu, 2nd edition 2008, and especially section E.2 "Trade Studies" and especially two by Woodcock. It should be noted that in these trade studies the usage of lunar oxygen at a wide variety of locations ranging from LEO to EML1 to the lunar surface are considered. For a more recent review see "Resource Production on the Moon" by Geoffrey A. Landis (2014) at http://www.isruinfo.com/docs/srr15_ptmss/7-Resource%20Production%20on%20the%20Moon-Landis.zip.

8 See NSS position paper "Next Generation Space Stations" at http://www.nss.org/legislative/positions/NSS_Position_Paper_Next_Generation_Space_Stations_2015.pdf.

9 Such depots are often envisioned as being in Earth-Moon Lagrange points EM1 or EM2. However, they might also be in particular lunar orbits, or in Earth-Sun Lagrange points for optimal Mars mission support.

10 https://en.wikipedia.org/wiki/Lunar_space_elevator accessed 6/16/15.