INITIATING A LUNAR POWER UTILITY

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Statement of Purpose

The non-profit Sacramento L5 Society herein proposes that Aggressively Collimated Technology (ACT) be developed to aid in the creation of a publicly-owned Lunar Power Utility (LPU). In Appendix II, "Settling Space", it is conjectured that an ongoing collision between population growth and a burgeoning demand for resources is presently afflicting the Earth's environment, and that developing space resources can help mitigate the impact of this collision.

The main goal of the LPU will be the establishment of reasonable rates for lunar power. These reasonable rates would in turn foster the development of Lunar Surface Resource Utilization (LSRU). LSRU will, in its turn, help establish a foundation for massive lunar settlement and eventually full-scale settlement of space.

The LPU will commence with the construction of solar-powered ACT laser platforms orbiting in the vicinity of the Earth/Moon Lagrange point 1 (EML1). The platforms' laser beams will economically and continually broadcast power to any point on the lunar surface, where it can be purchased at a reasonable price by public or private entities in need of power. Over time, the utility will also include power grids extending outward from the lunar poles.

A key element of this proposal involves adding prime lunar power generation real estate to the publicly-owned LPU, thus allowing the LPU to keep rates at a level sufficient to encourage timely development of LSRU and simultaneously generate revenue to grow the LPU. For example, the mountains on the rim of Shackleton Crater, located almost precisely at the Moon's south pole, can be considered prime lunar power generation real estate.

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Appendix

Appendix I: Video - "Initiating a Lunar Power Utility" (Work in progress)
Appendix II: "Settling Space"
Appendix III: Video - "Powering a Moon Base Through the Lunar Night"

Acronyms	Meaning
ACT	Aggressive Collimating thin-film Technology
ACDS	Aggressively Collimated Deflecting System
EML1	Earth/Moon Lagrange point 1
EML2	Earth/Moon Lagrange point 2
ISRU	In Situ Resource Utilization
kg	kilogram
km	kilometer
LPMS	Lunar Polar Multi-array System
LPN	Lunar Power Node
LPR	Lunar Power Rover
LPR1	Lunar Power Rover 1
LPU	Lunar Power Utility
LSRU	Lunar Surface Resource Utilization
NASA	National Aeronautics and Space Administration
OLO	Oscillating Lagrange point Orbit
PVRP	Photovoltaic Receiver Pane

Establishing the Lunar Power Utility (LPU)

What is the LPU?

The LPU would be a single body which coordinates the development of lunar power as a utility or basic service. The LPU's primary importance rests in it's ability to foster the establishment of Lunar Surface Resource Utilization (LSRU).

Why is LSRU important?

• Given time, LSRU can help reduce Earth's resource and environmental pressures. Earth's need for continued growth in resources to keep up with it's growing population is resulting in increased environmental impact and reduced quality of life. LSRU will make new resources available to Earth's growing population. Also, since LSRU development takes place on the lunar surface, the Earth's environment will benefit from the resulting displacement of Earth-based resource development.

•LSRU can jump start full space settlement, and vice versa. The only realistic way to fully settle space is to shield against cosmic radiation, which arrives from all directions. The only presently practical system for shielding against cosmic radiation outside the Earth's magnetic field is by developing LSRU. Consequently, developing LSRU is essential to the eventual achievement of full space settlement.

Why is the Moon important?

Radiation shielding and resources. Due to the unavoidable issue of cosmic radiation, the two most affordable candidates for space settlement are Low Earth Orbit, and the surface of the Moon. The Moon's advantage is that it also offers substantial physical resources, both for radiation shielding and for LSRU in general.

Why is the proposed LPU important?

The LPU can keep lunar energy affordable. Since the Moon typically has two full weeks in a row when there is no sunlight available to create energy, one of the keys to developing the Moon's resources in a timely fashion will be making affordable energy continuously available during the formative stage of lunar resource development. A publicly-owned LPU coordinating lunar power as a utility ensures that essential property for the development of lunar energy won't be controlled by a single individual, corporation, or country.

Jump-starting an LPU can jump start LSRU. The use of Aggressive Collimating thin-film Technology (ACT) as described in Appendix II will immediately create the potential for continuously available energy over the entire lunar surface and jump-start the LPU, which will in turn jump-start LSRU. Jump-starting LSRU is seen as a critical step towards reducing the pressure on Earth's environment and resources in a timely fashion.

The proposed LPU can be exceedingly competitive. An ACT-based system doesn't rely on surface energy storage to get through the two week lunar night. As a result, it has major advantages over energy storage systems. The only system capable of similar or better overall delivered energy per launch mass than an ACT-based system is an atomic fission power plant, which requires the launching of radioactive material from the Earth's surface.

The proposed LPU can start small. A complete system would require two components; an orbiting laser, and a receiver on the lunar surface. However, the initial LPU won't need to develop lunar surface components, since there are many entities planning to launch solar-powered instruments to the lunar surface over the next several years.[1] Any one of these can become a "target" for the orbiting laser. In fact, these entities can possibly both verify the usefulness of an ACT-based system and become the LPU's first customers.

The proposed LPU can quickly upscale. A 400 kg orbiting laser component would massively overproduce at first. A single lunar rover similar to the Mars Spirit rover would utilize less than a tenth of one percent of the total laser beam energy impacting the lunar surface. Over time, the laser beam could be redirected to a central location, where the full energy of the laser beam would be redistributed to where it is needed with cables, microwaves, or a laser deflector system.

Over time, an LPU can pay it's own way. Once established, the orbiting component of the LPU is expected to quickly become self-sufficient, generating net income. The expected income for the LPU would accrue from the price charged for energy delivered to projects on the lunar surface, creating a revenue stream that both secures funds for further LPU expansion and, eventually, pays back early investors.

What is the LPU development schedule?

The LPU starts with robots. As suggested above, long before there exists a large settlement of humans on the Moon, there will be robots and uninhabited outposts. They will need power to do their jobs, and many of them will need to be able to relocate easily from place to place. The LPU will be the consortium that will power those robots, and the human settlements that follow them, with abundant, inexpensive, constantly available energy.

Costs. An EML1-based laser-powered manned lunar rover was studied in depth in National Aeronautics and Space Administration (NASA) Technical Memorandum 4496.[2] The memorandum was developed in 1993. Assuming a similar project were initiated, costs would need to be revisited in light of present technological advancements. As an example, replacement of the reflecting collimating device in this memorandum with the proposed ACT-based system would drastically reduce the cost of constructing the EML1-based laser system proposed therein.

The present proposal is primarily directed at proving the principal of deploying an ACT-based system. Since there are major benefits if such a system can be deployed at EML1, a secondary target is to determine the likelihood of low power orbits other than halo orbits in the vicinity of EML1. Both of these goals will be achievable within the funding limits of the MacArthur 100&change grant. "Stretch" goals that follow on are also defined should funding be available.

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Timeline/Milestones

> The Timeline/Milestones section is being expanded to include Phases 1A, 1B, and 1C in addition to Phase 1D. Phase 1A will be a ground-based pilot program. Phase 1B will be a balloon-lofted pilot program. Phase 1C will be a LEO pilot program.

LPU Phase 1D

LPU Phase 1D will see the design, construction, launch, and deployment of satellite with a 1 meter thin-film aggressively collimating lens powered by an approximately 4 kW output laser in orbit in the vicinity of EML1 (located approximately 60,000 km from the Moon). This satellite will ensure continuous delivery of electrical energy to a Mars Spirit-sized robotic lunar rover throughout the lunar night.

- Phase 1D Stage 1:
    - Timeline: Begin March, 20~~17~~20.
    - Begin R&D on constructing and orbiting 1~~0~~ meter thin-film collimating lenses. Subcontractor: Beam Engineering for Advanced Measurements Co., 1300 Lee Road, Orlando, Florida 32810 (www.beamco.com). Duration: 2 years.
    - Determine efficacy of low power orbits in the vicinity of EML1: Determine trajectory from Earth to LEO: Determine laser target guidance parameters. Subcontractor: Innovative Orbital Design (www.spaceroutes.com). Duration: 1~~-6~~ year~~s~~.
    - Begin in-depth cost analysis of high budget and low budget alternatives. SL5S Technical Team. Duration: 1 year.
- Phase 1D Stage 2a:
    - Timeline: Begin March, 20~~18~~21.
    - Finalize satellite design and finalize contractors. SL5S Technical Team. Duration: 1 year.
- Phase 1D Stage 2b (alternative):
    - Timeline: Begin March, 20~~18~~21.
    - Finalize LEO design and finalize contractors. Duration: 1 year.
- Phase 1D Stage 3a:
    - Timeline: Begin September, 20~~18~~21.
    - Begin EML1 satellite buss construction. Duration: 2 years.
    - Begin rocket contract. Duration: 2 years.
- Phase 1D Stage 3b (alternative):
    - Timeline: Timeline: Begin March, 20~~18~~21.
    - Begin LEO satellite buss construction. Duration: 2 years
    - Begin rocket contract. Duration: 2 years.
- Phase 1D Stage 4a:
    - Timeline: Begin March, 20~~19~~22.
    - Continue satellite buss construction. Duration: 1 year.
    - Continue rocket contract. Duration: 1 year.
- Phase 1D Stage 4b:
    - Timeline: Begin March, 20~~19~~22.
    - Continue LEO satellite buss construction. Duration: 1 year.
    - Continue rocket contract. Duration: 1 year.
- Phase 1D Stage 5a:
    - Timeline: Begin March 202~~0~~3.

- Launch to LEO & begin electric propulsion to EML1. Duration 1-2 years.

- Phase 1D Stage5b:
    - Timeline: Begin March 202~~0~~3.
    - Launch to LEO & begin testing. Duration 1 year.
- Phase 1D Stage 6:
    - Timeline: Begin March 202~~1~~4-January 202~~2~~5.
    - Orbit EML1 & begin testing. Duration 3-9 months+, based in income.

If successful, LPU Phase 1D will prove:

- The potential of supplying energy to the lunar surface throughout the two week long lunar night via a solar-powered laser located at EML1.
- The potential of an OLO or other low-power orbit in the vicinity of EML1.

LPU Phase 2

The LPU will begin with the successful landing and permanent deployment on the Moon of a Lunar Power Node (LPN). An LPN may be a single non-mobile station. However, an LPN may alternatively consist of a Lunar Power Rover (LPR), either robotic or manned.

Phase 2 will also see a test of the solar sail/gravity winch station-keeping process at EML1, assuming the successful conclusion of the Phase 1 Stage 2 study of low power orbits in the vicinity of EML1.

The first LPU LPR, or LPR1, will preferably be landed in the vicinity of the Earth-side rim of Shackleton Crater on the lunar South Pole. If the only relatively stable orbit in the vicinity of EML1 is found to be a halo orbit, LPR1 would need to be powered by three lasers spaced approximately 120 degrees apart around the halo orbit. Note that these orbiting lasers have the potential to continuously power two other LPN's; one located at the opposite pole and one located in a location that can simultaneously be seen by all three orbiting lasers. Doing so would be considered one of the "stretch" goals for LPU Phase 2.

Upon first landing on the Moon, LPR1 will deploy a Photovoltaic Receiver Panel (PVRP) oriented generally towards EML1. The PVRP will be tuned to the same wavelength as the beam of a solar-powered laser situated near EML1. The laser receiver will convert, at very high efficiency, the laser beam into both continuous electric power for LPR1 and a continuous waste heat supply. The waste heat will either be rejected or used, depending on the solar insolent radiation at the time and the requirement for either heating or cooling LPR1. The laser beam will thus constitute a continual supply of electrical and thermal energy for the LPR1, including throughout the 2 week long lunar night. For moments when the LPR1 PVRP is blocked from sunlight, as when it traverses behind a boulder or other physical obstruction, The LPR1 will either carry sufficient energy storage to traverse an obstruction that blocks laser access or will tilt the laser receiver at the sun.

If successful, LPR1 will prove, in order of primacy:

- The efficacy of economically supplying energy to the lunar surface throughout the two week long lunar night via a solar-powered laser system located at EML1.
- the efficacy of supplying laser energy from EML1 to power a lunar robot rover on the lunar surface;

• the efficacy of exploring the rim area of Shackleton Crater via a lunar robot rover.

• The efficacy of solar sails and/or the gravity winch as means for station-keeping in the vicinity of Lagrange points.

In addition to these three primary goals, the LPR1 will have several stretch goals:

• Scouting at least part of a pathway up one of the higher elevation points along the Shackleton Crater rim. Once achieved, this higher elevation, with it's ability to approach continual reception of solar insolation throughout the year, would provide a lunar surface solar energy power source for the LPU for at the two weeks of the lunar day. It would also establish the initial link in a Lunar Polar Multi-array System (LPMS) (see Appendix II).

• Reaching one of the higher elevation points along the Shackleton Crater rim. The achievement of this point will allow the LPR1 to plant a flag and "claim" the immediate physical territory for the purpose of creating an LPMS "node".

• Continue traveling and exploring routes to other points of higher elevation around Shackleton Crater.

• Planting claim flags on as many of these higher elevation points as possible.

• Exploring and planting flags at other areas in the vicinity of Shackleton Crater which may afford higher elevation points useful in the establishment of the LPU.

<u>LPU Phase 3</u>

Following the successful operation of the LPR1, other LPR's will be sent to accomplish the various "stretch" goals defined above. To power the additional LPR's and to fulfill customer's requests for power, the laser platform at EML1 will be upgraded to supply both customers and LPR's with power.

<u>LPU Phase 4</u>

<u>Construction of an LPMS power grid on the lunar surface will begin</u>. Following the route to the higher elevation points established by the LPR's, the LPMS grid will be comprised of electric cables, laser deflecting nodes, and heat transfer conduits connecting the various lunar power nodes. Note that the surface solar energy nodes of the grid will extend as a minimum in two directions 180 degrees apart. In this way, the grid will be "balanced", receiving solar-generated power from one side of the grid while the other side of the grid is in lunar night, and will thus generate continuous power.

<u>LPU Phase 5</u>

<u>An Aggressively Collimated Deflector Systems (ACDS) laser will enable remote laser prospecting.</u> Consider the advantage of being able to precisely target a laser beam into the sides and bottom of a super-cold crater. Should lunar material with a significant amount of water ice be struck, the laser will effectively turn the lased area into mud, then into steam, releasing volatiles which can be analyzed. "Laser drilling" would be an extremely cost-effective way to prospect for volatiles. Once a deposit is located, industrial-level laser drilling

can then take place, with the resulting steam and other volatiles being captured, quickly chilled back to liquid or solid, and stored for transport.

Over time, other ACDS lasers will enable laser prospecting of other potential sources of volatiles in the vicinity. In the case of Shackleton Crater, an ACDS on the near side of the crater can deflect a laser beam, either directly or via a second ACDS on the far side of Shackleton crater, to any point on or in Shackleton, permitting prospecting of the entire crater literally from the rim-tops.

LPU Phase 6

The north and south pole LPMS's will continue to be enlarged, laying down the foundation for true lunar settlement. The growing LPMS's and the lasers at EML1 and EML2 will provide power as a service to most if not all lunar projects, creating a revenue stream that both pays back early investors and secures funds for further expansion.

LPU Phase 7

Design, construct, launch, erect, and inhabit permanent Moon settlements. Having established LSRU and ISRU on the lunar surface, settlement of the Moon will become much more practical. However, until a low cost method is developed for transferring people and material in and out of the lunar gravity well, these settlements will be minimal.

LPU Phase 8

Build a lunar elevator at EML1/EML2. As LSRU, ISRU, and permanent settlements on the lunar surface are established, ways to reduce the cost of transport to and from the Moon's gravity well need to be given consideration. As mentioned earlier, various technological approaches exist for accomplishing this, including mass drivers/landers, and cislunar tethers.

One intriguing solution is to build a space elevator.[3] Since a fairly large orbital system will inevitably congregate in the vicinities of EML1/EML2, it makes sense to link those orbiting systems permanently to the lunar surface with cables climbed by highly efficient lunar elevators.

From EML1, building a lunar elevator will involve extending a cable about 60,000 km to the Moon's surface. During construction, the cable will be counterbalanced by the mass of a second cable extending towards the Earth. Once the cable is firmly attached to the lunar surface, a slight counterbalance towards the Earth will ensure that the Moon can permanently "latch on" to the cable as the Earth side of the cable will get heavier from perigee until apogee. Once the cable is permanently attached to the lunar surface, it will no longer be necessary to use station keeping of any sort at EML1/EML2. And with the advent of a low cost method for transferring people and material in and out of the lunar gravity well, the growth of lunar settlements can begin in earnest.

LPU Phase 9

Establish O'Neill settlements at EML1 and EML2. Having established permanent settlements on the lunar surface and a lunar elevator for economically transporting people and material to and from the lunar surface to EML1 and/or EML2r, continued LSRU will yield more than enough low-cost material to construct sufficient shielding at EML1 and EML2 to protect life from cosmic radiation and solar storms. At that point, the first true O'Neill settlements can be constructed at those two islands in space.

LPU Phase 10 Ad Astra!

Endnotes:

[1] http://moonexpress.com

[2] http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19940015629.pdf

[3] lunarelevator.com/wp-content/uploads/2014/07/NASA-Lunar-CATALYST-Final.pdf