Lunar Commercial Logistics Transportation

Walter P. Kistler[1] and Bob Citron.[2]
Lunar Transportation Systems, Inc. Bellevue, Washington 98004 USA

Tom Taylor[3]
Lunar Transportation Systems, Inc. Las Cruces, New Mexico 88011 USA

This paper offers a commercial perspective to new lunar transportation and proposes a logistics architecture that is designed to have sustainable growth over 50 years, financed by private sector partners and capable of cargo transportation in both directions in support of lunar resource recovery. The paper's perspective is from an author's experience at remote resource recovery sites on Earth and some of the problems experienced in logistics that didn't always work. The planning and control of the flow of goods and materials to and from the moon's surface may be the most complicated logistics challenge yet to be attempted. The price paid, if a single system does not work well is significant. On the Alaskan North Slope, we had four different logistics transportation systems and none work successfully all the time. The lessons learned will be discussed and solutions proposed. The industrial sector has, in the past, invested large sums of risk money, $20 billion for example, in resource recovery ventures like the North Slope of Alaska, when the incentive to do so was sufficient to provide a return on the risk investment. Stimulating an even larger private investment is needed for the moon's resource development. The development of the moon can build on mankind's successes in remote logistics bases on Earth and learn from the $20 billion in private sector funds used to recover oil assets above the Arctic Circle. The moon is estimated to be 50 times more remote than Prudhoe Bay, Alaska, the early transportation to the moon is 100 to 1,000 times more expensive than to the Arctic and the lunar environment is more severe than the Arctic, but some of the logistics lessons learned in the Arctic can potentially work again on the moon. The proposed commercial lunar transportation architecture uses new innovations for modularity and flexibility leading to reduced development and logistics costs, faster development schedule, and better evolvability. This new lunar trade route of mankind utilizes existing Expendable Launch Vehicles (ELVs) available and a commercially financed small fleet of new trans lunar and lunar Lander vehicles. This architecture is based on refueling a fleet of fully reusable spacecraft at several locations in cislunar space, which creates a two-way highway between the Earth and the Moon. This architecture offers NASA and other exploring nations more than one way to meet their near term strategic objectives with commercial space transportation, including sending small payloads to the lunar surface in a few short years, sending larger payloads to the lunar surface in succeeding years, and sending crews to the Moon and back to the Earth by the middle of the next decade. Commercially, this new lunar logistics route permits capability and technology growth as the market grows, offers affordable transportation for the commercial sector and the later recovery of lunar resources. After NASA moves on to other destinations in our solar system, commercial markets and this "in place" commercial logistics system can service, stimulate and sustain a lunar commercial market environment.

[1] President, 227 Bellevue Way, N.E. #259, Bellevue, Washington 98004
[2] CEO, 227 Bellevue Way, N.E. #259, Bellevue, Washington 98004
[3] Vice-President, 3705 Canyon Ridge Arc, Las Cruces, NM 88011, Email taylort@mac.com
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I. Mankind's Driver – Trade Route Expansion for Commercial Resources

Trade Route Transportation - Most of mankind's expansion on this planet over 40,000 years has produced benefits in the form of new lands, trade route commerce, new resource development and knowledge.[1] Trade routes are driven by commerce and exploration, which produce benefits for mankind in the form of new lands, trade route commerce expansion, increased resources and knowledge. Genuine innovation is needed to achieve the goals of affordability and sustainability called for by the President.

Lunar Transportation Systems, Inc. (LTS) proposes a commercial transportation system for the new lunar trade route with different innovation and architecture hardware that would be built with private capital and government cooperation. The goal is a basic and modest early commercial lunar transportation system with hardware that could be abandoned on the surface with 800 kg of useful cargo[2, 3] and later evolve to 10 to 20 tons landed by a reusable vehicle with full transportation node support services.[4] This architecture is characterized by modularity, expandability, commercial sustainability and extreme flexibility leading to reduced development cost and better evolvability.[5, 6] Specific innovation includes the transfer of cryogenic propellant tanks instead of cryogenic propellant from one tank to another tank in microgravity. Further innovation includes payload transfer, nodes of transportation services, and eventually the return of resources to Earth. A hard look at this architecture will show that it enables NASA to meet its strategic objectives, including sending small payloads to the lunar surface in a few short years, sending larger payloads to the lunar surface in succeeding years, unmanned cargo transport in both directions and eventually with increased reliability, sending crews to the Moon and back to the Earth by the middle of the next decade.[7] The hardware shown in Figure 1, is commercial and takes advantage of the commercial first leg vehicles available from commercial sources. LTS uses commercially available launch vehicles for the Earth to LEO leg with payloads transported on a different vehicle. The strategy is refueling a fleet of fully reusable spacecraft at several locations in cislunar space, which create the equivalent of a two-way highway similar to the Transcontinental railroad between the Earth and the Moon. The LTS Concept is still evolving, but the early conceptual architecture[2, 3] proposed can be seen in video on
Website:

http://www.lunartransportationsystems.com

http://www.youtube.com/watch?v=26Y5w0vqtIU

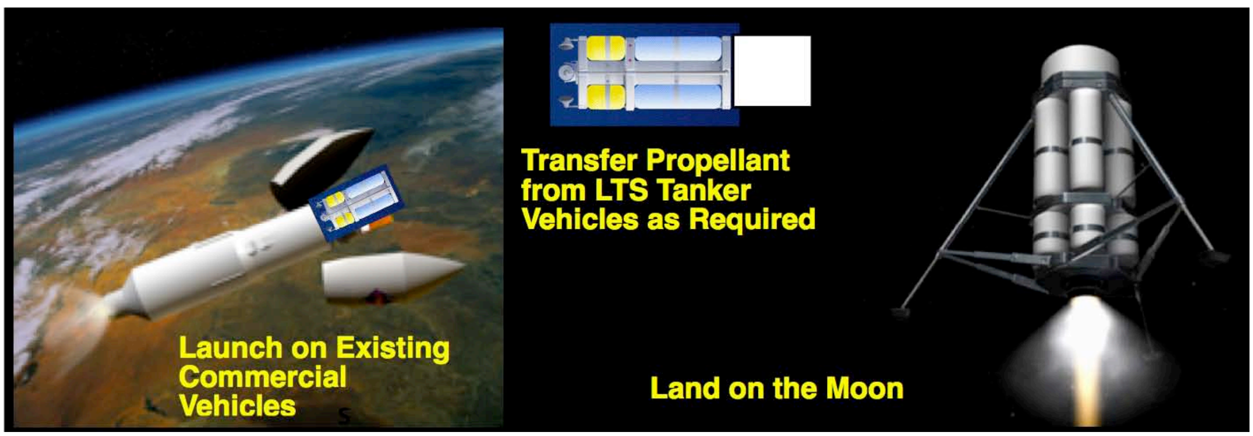

Figure 1. Lunar Transportation Systems Concept for Commercial Logistics

Go to the above youtube.com website for an LTS 7 Minute Video on the Lunar Transportation Systems Concept.[2]

Logistics is more than transportation. Lunar logistics is movement management or the planning, accomplishment and control of the flow of goods and materials to and from the moon.[8] Figure 2 depicts a large payload Lunar Transportation Systems would like to transport. Lunar logistics flow over a fifty-year period evolves into reusable systems and includes more than just transportation vehicles and hardware. This later logistics system becomes a system of supply that includes transportation both on the surface of two celestial bodies and in the space between them. In a remote resource recovery base on Earth it means the flow of mass away from a base in the form of useful resources must at some future time exceed the flow of mass into the base or there is little economic reason to setup the remote base commercially. At Prudhoe Bay Alaska, that mass break even point happened approximately 90 days after oil flow down the pipeline. In our lunar planning and development we seem to be focused hardware that people want to build rather than our reasons for going to the moon, which probably should focused on the commerce, which the taxpayers can actually understand and support long term. This means commerce and the recovery of resources that are significant to build the support within our taxpayer stakeholders, our industrial partners and our partners overseas. Commercial logistics means privately financed firms are providing the transportation services, including transportation vehicles and depots. In Alaska we tried many transportation methods and trade route concepts, but only four really worked most of

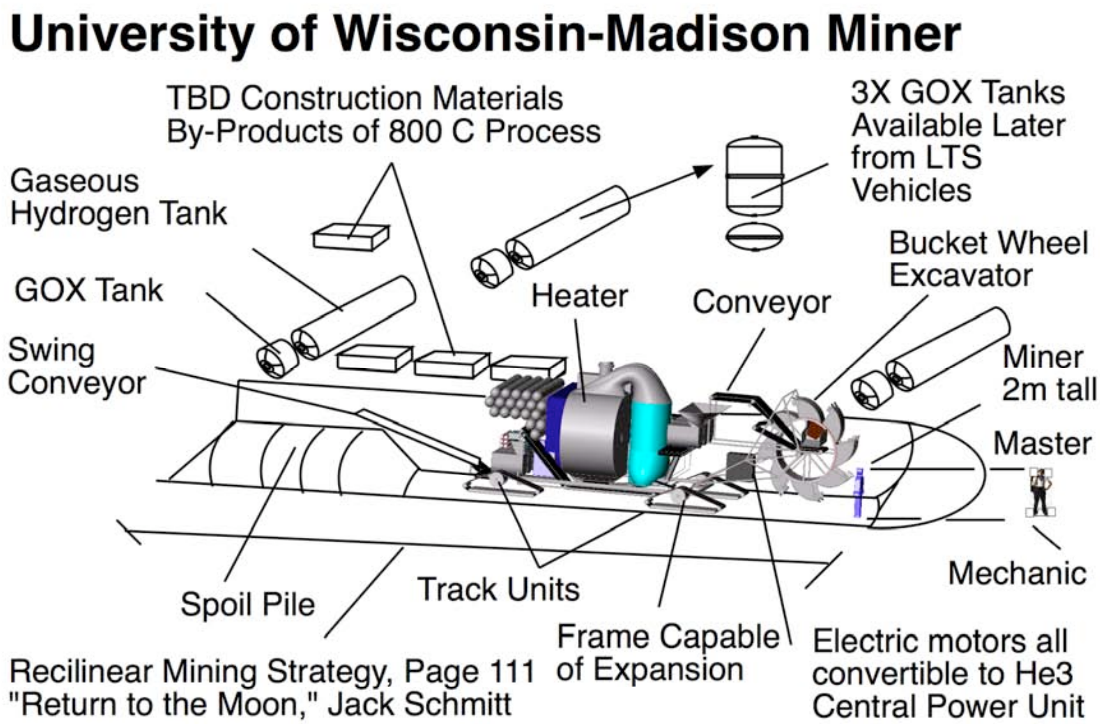

Figure 2. The University of Wisconsin-Madison Lunar Miner Mark III by Matthew Gadja. [9]

the time with some short winter periods where none worked. If the base is remote (Prudhoe Bay was ~ 6,000 miles from the lower 48 states and most supplies.) and the logistics tail is long, then transportation becomes more important and a larger, more expensive part of the logistics operation. The moon is ~20 to 40 times further than any logistics support of a remote base on Earth. The lunar temperature extremes are significantly different than Earth and much of what we take for granted on Earth, must be brought to the moon by logistics, until we learn to “live off the land.” A commercial logistic operation deals with the procurement, distribution, maintenance, and replacement of materiel and personnel with transportation just understood to be a part of it.

Arctic exploration on Earth may provide some incite and lessons learned for future lunar development. The company towns created, private investment required, benefits generate thru the resources recovered and other parameters of the Arctic Exploration fit reasonably well into a lunar scenario. Before we dream about the tourist’s phase, we need to understand the early commercial humans on the lunar surface maybe the people that build the facilities for the resource workers or miners. Before them come the resource locators in the form of geologists, resource extraction specialists, equipment designers and the dreamers capable of imagining the operations before they are created.

Figure 2 is a University of Wisconsin-Madison Miner by Matthew Gadja with some suggested innovation by LTS.[8] The miner processes the lunar regolith in place and extracts a multitude of near term and far term resources need by lunar company towns, production facilities and the mankind on Earth. The miner can be explored further at the University of Wisconsin-Madison.[10] Lunar Transportation Systems is proud to have contributed some funding for the miner evolving at the University of Wisconsin-Madison.[11] The bucket wheel excavator recovery technique also seemed to be validated at the recent NASA Excavator Challenge in Santa Maria, CA, where a bucket wheel excavator operate well in a NASA JSC1A stimulant box test. The bucket wheel was damaged in transport to the event and repaired, but failed after 11 minutes of a 30-minute run. It was excavating at a rate approximately one half of the rate required to meet the minimum required 150 kgs. The University of Wisconsin-Madison miner excavates the lunar surface regolith, conveys it into the vehicle, heats the materials, drives off the volatiles for recovery and disposes the regolith in waste form and as a variety of building materials yet to be determined. The miner also starts the process that is sometimes called "living off the land." In "living off the land" means developing an excavator that recovers gaseous oxygen and hydrogen that later is use to produce the cryogenic propellant for the LTS vehicle operation. This gaseous oxygen and hydrogen recovery is used to cryogenic propellant production in a plant requiring power and storage. This leads

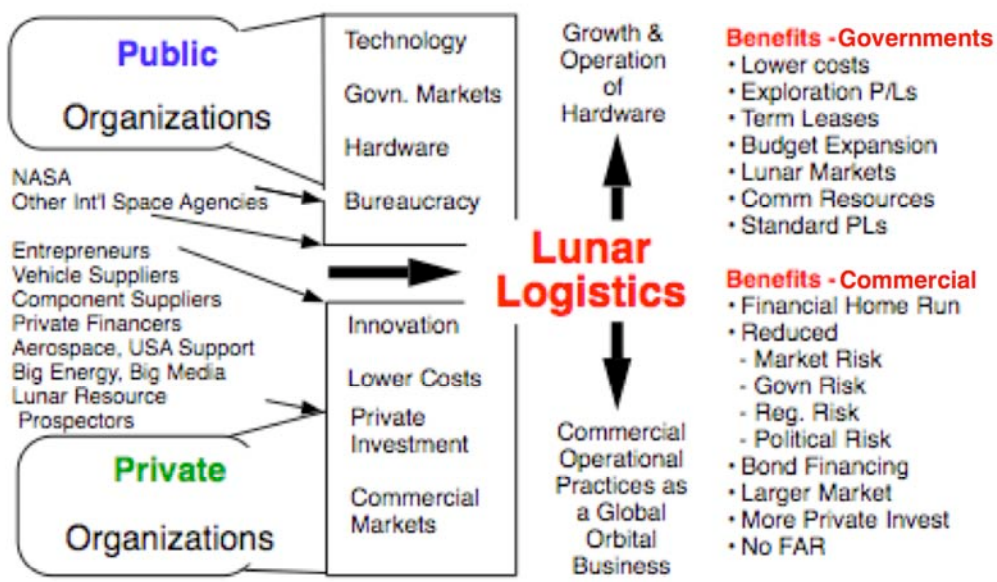

Figure 3. The Public Private Partnership is a Method of Cooperation between Government and Industry Allowing each to Bring Skin in the Game and Derive Benefits.

to a reduction in the cost of propellant for the company use compared to propellant transported from Earth and propellant for sale in new commerce to others. These LTS cryogenic tanks are reused as gaseous oxygen and hydrogen tanks using a special valve capable of both liquid and gaseous oxygen and hydrogen use. On the moon, the regolith appears to be managed by micro waving it to build road surfaces, capable of use as a concrete like material and capable of heating to recovery resources. The temperature required to accomplish different things and ranges from 800 degrees C for some materials of commercial value to ~ 2500 degrees C, if the process gets serious about more complete oxygen recovery in gaseous form.

Remote Base Lessons Learned can help. The lessons learned in Alaska and possibly help lunar explorers create a logistics system capable of a sustainable logistics support and growth with the lunar market.[12] The important lesson is how to get private industry to invest the kind of money they invested in Alaskan oil. Figure 3 is a partnership that may help. The biggest lesson is probably money, specifically, private money by big oil to find, drill develop and bring oil to the surface for $6.95/bbl, commonly called the wellhead price. The $20B in private risk capital was stimulated by a large return anticipated by the private oil company investors, but it took both majors and smaller companies pooling their risk capital to buy into the deal, which the author viewed as a 50-year deal starting with the state owned oil leases. The value of the pool of oil at Prudhoe Bay was calculated by the author and given the ~price of oil appeared to exceed one trillion.[13] Oil flowed down the pipeline in 1977. This majority of this investment was made when these same companies could buy oil from the Arabs at $0.50/bbl. The company town created in Alaska provided living quarters called ATCO Buildings reflecting the name of the manufacturing company and sheltered up to 12,000 construction workers at one time probably continues today two decades after the initial work started in 1975. All vehicles burned benzene cracked from the oil field and Mother Nature forced much of the work planned for the summer months into the dark winter months. Applying the same "Living off the Land" thinking could mean using an isotope of Helium, or He_3 as a power source for power grids, propellant recovery/processing and eventually vehicles on the moon. Such an effort could change the He_3 effort on Earth from DOE, which has little incentive to turn away from their focus on other fusion research and provides NASA or some other interested government agency with an incentive and the budget for the development of this potential power grid solution using the moon's vacuum and eventually the He_3 effort could evolve into solutions for the Earth power grid. Other industries include Lunar Tourists who spent their own money to come the moon and create added commercial markets. Living of the Land" also includes reuse of equipment and packing creates and more.[14]

The stimulation of commerce is one of NASA's mandates. Our company hopes to use existing Expendable Launch Vehicles (ELVs), EELVs, RLVs or government vehicles. Our commercial lunar architecture utilizes current commercial ELVs and/or EELVs to bring a new fleet of reusable spacecraft, lunar payloads, propellants, and eventually crews from the Earth to Low Earth Orbit (LEO). Expendable launch vehicles and other types of launch vehicles are already commercial for this first leg of our lunar journey. The LTS reusable spacecraft could do the rest of the job and take payloads from LEO to the lunar surface and later bring payloads back to Earth from the Moon. This commercial strategic roadmap permits a "pay as you go" and a "technology development pathway" that allows NASA to achieve a series of its strategic objectives as funding and technology developments permit. Our approach reduces recurring mission costs by advancing in-space transportation technology, and later, resource utilization, because this is less costly for us than investing in new ETO transportation.

NASA cooperation in the development of commerce can be an important goal for our government and may result in lower costs and increased sustainability of lunar development permitting NASA to depart for Mars and beyond earlier. The possibility of an innovative Public Private Partnership with NASA and other international governments could add a commercial market to the NASA vehicle use and provide potentially a 10m or 33' payload diameter, which would be very attractive to commercial organizations. Public Private Partnerships (PPP) can be productive are use through out the world to bring governments and private organizations together for their mutual benefit. Figure 3 provides a basic framework of cooperation and combined with a list of agreed milestones permits private sector financing and potentially lower costs for NASA.[15] Government can bring a government market and the start of a commercial market without narrowing the field to several winners. Private organizations can bring innovation and potentially lower costs. Each can bring much more, if the PPP is truly creative and broad in its scope and cooperation. One result maybe the conversion of a government program that needs tax dollars with one that is commercial and pays taxes. New Zealand is one of many examples of the PPP process and the dynamic effects it can produce for government.[16]

The Lunar Transportation startup team has in the past-created commercial companies that have achieved an order of magnitude in cost reduction. A commercial microgravity service in the form of a Mid-Deck Locker service for $2m/locker at SPACEHAB and a similar potential magnitude at Kistler Aerospace in launch costs.[17,18] The same startup team has created Lunar Transportation Systems, Inc. [19]

Public Private Partnership Model. The Public Private Partnership has been used within NASA with success. [20] The Public Private Partnership has been explored[21] and now is ready for discussions with interested space agencies. [21]

Enabling Technologies. This In-Space transportation architecture, as described briefly in this paper, does not depend on the development of any new launch vehicles. It does depend on the development of five emerging technologies: 1) an autonomous rendezvous and docking system, 2) a new autonomous payload transfer system, 3) a new spacecraft to spacecraft cryogenic propellant tank transfer system, 4) an autonomous propellant tank tapping system, and 5) an autonomous lunar payload offload system. Developing these technologies is less risky and less costly than investments in ETO transportation or cryogenic propellant transfer technologies. These emerging technologies, except AR&D, are developable by ground test and our program plan includes flight demonstration on early robotic missions to the Moon.

Lunar Payload Capabilities. The initial fleets of reusable spacecraft[4] are designed to fit the payload

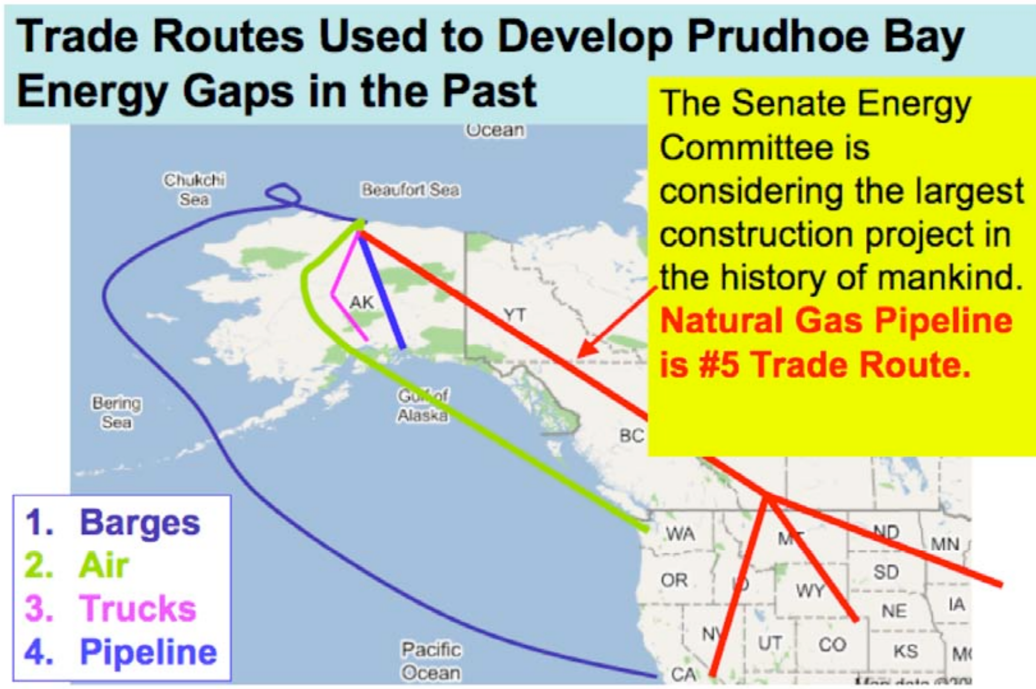

Figure. 4 The Logistics Routes used on the Development and Recovery of Resources at Prudhoe Bay, AK in the 1970-80 Timeframe. Trade route emerges, because of a logistics market driven by resource recovery by Mankind. Route 5 is emerging now after 40 years, because it is a market logistics driven link sensitive to the economics between the resources and the users.

capabilities of Delta II Heavy class launch vehicles, commercial RLVs or other vehicles, but the Earth to Orbit vehicle payload bay defines the size of the LTS vehicle system. Basically, the larger the diameter of the initial payload, the more capable and efficient the LTS highway scales up to become. Lunar Lander spacecraft can deliver payloads of up to 8 metric tons from LEO to the lunar surface; depending on where and how frequently they are refueled on their way to the Moon. This architecture is capable of delivering 800 kg to the lunar surface directly from LEO without the need to refuel in space. It is capable of delivering payloads of 3.2 metric tons to the lunar surface with refueling at L1 only. Comparable payloads can be returned from the lunar surface to the Earth with refueling at one or more of those locations.

Existing Trade Routes created by Prudhoe Bay Oil are depicted graphically in Figure 4 showing the different methods used for the commercial logistics route to and from the arctic. Figure 4 details the four logistics routes. The first trade route shown in blue and the greatest tonnage at pennies per pound was transported on leased 300' long barges towed by ocean tugs from ports on the west coast of the United States to a point off shore of Point Barrow, AK. These barge fleets sometimes as large a 40 barges would circle a month or more waiting for Arctic Ocean ice to recede from the shoreline, so these barges could race 300 miles to Prudhoe Bay to unload at the North Slope Oil Fields at Prudhoe Bay. In the 1975-9 ice receded two out of four summers and unloading was accomplished, but in two summers the ice failed to provide the unloading opportunity and large Soviet icebreakers and other means were used. The second logistics route shown in green was by commercial air for humans and critical cargo at approximately $5 per pound. The third logistics route shown in violet was overland truck with oversized fuel tanks, because Prudhoe had no Diesel fuel and the truck logistics price varied greatly around a dollar per pound. The fourth system shown in dark blue was the pipeline itself, which took 8 days to transport oil 800 miles and cost pennies per pound to operate even when including the initial $8 billion of private money used to construct it. The oil field development is also important as an indication of the amount of private money capable of being raised, if the return is significant. While this LTS initial logistics system is not meant to transport crews to and from the Moon, it is meant as a technology development testbed to prove the reliability thru repeated non-critical cargo mission of a later crewed Earth – Moon transportation system capable of sustaining the commercial development of the moon and allowing NASA to move to destinations beyond Earth.

Scalability. This new Lunar Transportation System is scalable. A follow-on fleet of larger spacecraft, designed to fit the payload capabilities of Delta IV Heavy class launch vehicles, can transport payloads of up to 30 metric tons from LEO to the lunar surface, depending on where and how frequently they are refueled on their way to the Moon.[5] These larger and later LTS spacecraft are capable of transporting crews to the lunar surface and returning them to the Earth. They also have the capability to provide heavy cargo transportation to support a permanent lunar base.

Cost Reduction. The non recurring costs to develop this Earth – Moon transportation system are much lower than the cost of developing systems that use more traditional architectures because there are fewer unique developments and it relies on existing launch systems. A significant reduction in lunar mission costs comes from the reusability of the major elements of this system.[5, 6] The largest cost in operating this system is the delivery of the spacecraft, the propellants, and the lunar payloads from the Earth to LEO, which could be a government cost and an increase in NASA budgets. Our commercial company plans to bring the Earth – Moon transportation infrastructure from the Earth to LEO on existing expendable launch vehicles, but it could easily provide NASA with a second commercial customer for their new larger diameter (10m) payload Ares vehicles. Big vehicles, like the space shuttle and the new exploration vehicles require many launches per year to spread the overhead. Perhaps as much as 70% of the cost of each lunar mission will be to transport the LTS infrastructure from Earth to LEO. While these NASA vehicles are expensive to operate, the development cost of a significant new launch capability represents at least 100 launches of existing EELVs and many years of lunar transportation operations. Our commercial company is prepared to start now using existing hardware. When propellants can be manufactured on the Moon, Earth – Moon mission costs may be reduced by 60% or more. If and when reusable Earth to LEO launch vehicles become available, lunar mission costs may be reduced by a further 60% or more.

Schedule. Because this system relies on existing technologies and existing ELVs and only requires the maturation of several enabling technologies, it can deliver payloads to the lunar surface relatively quickly and well within NASA's schedule for robotic and human lunar exploration, if a start can be immediate.[15]

The Bottom Line. This lunar architecture is based on concepts that reduce lunar mission life cycle costs and technical risks, improve reliability and crew safety, accelerate lunar mission schedules, and allow for the routine delivery of lunar payloads on a two-way highway between the Earth and the Moon.

II. Innovation on the Moon Reusing LTS Hardware

Lessons Learned Summary.

Prepositioned Logistics. Before major resource recovery work is started on the moon, these mining companies need incentives to spend the risk money to recover resources from the moon. The Alaskan incentive was mining leases. The incentives used in the Transcontinental Railroad were mineral rights to land under the track as the track was laid. The 80' soft coal seam mined 600 feet under these original Transcontinental Railroad mineral rights still have value as incentives.

Lunar incentive is or can be mining leases on the moon. The North Slope of Alaska drew $20m in private funds from the largest oil companies in the world by using drilling leases in similar manner. These same companies and/or other companies of similar risk takers, asked various industries for studies on how to get the oil off the North Slope after it was found and developed. They also set up the design and materials to build the facilities and pipelines into the field and how to get the oil out. They asked submarine, pipeline, railroad, aerospace industries and others for suggestions, proposals and studies. Each industry oddly enough suggested solutions using their industry. Submarine organizations suggested giant submarines, railroads suggested train tracks on the tundra, etc, only to be ruled out by a very shallow Arctic Ocean, difficult tundra foundation problems for rail lines, and other technical and cost barriers. The tundra for example, thaws the top 5' every year making gravel roads and runways repaired by grading, but tundra can be more difficult, and railroads are impossible. Some industries suggested aircraft as an alternative, but the movement of mass cargo should be as economical as practically possible and it is not realistic to move mass cargo on the same hardware as people given the economics involved. Most people can understand the choice for the oil flow out as the pipeline, but little was said about the four transportation systems used in construction for the flow of crew and materials into the oil field development and out. Each of these four logistics systems had a different cost, speed, safety, surge storage, weather sensitivity and mass transport capability. Depending on any one transportation of these logistics systems for all cargo and human passenger transport would have caused many cost problems, plus no single system could operate all the time. All of the logistics routes were commercial and most were available with competitive pricing.

Logistics Transportation Systems and Storage. A brief Figure 4 depiction of the logistics transportation and storage methods used includes: **First,** aircraft, 737 passenger and cargo jets, 3 flight per day, hauled up to 12,000 workers and high value cargo pallets of materials forgotten or critical to operations like welding rod, sockets, tools, etc. at about $5 per pound. Surge storage of critical cargo and materials plus staff located in Fairbanks, Anchorage and the lower 48. Winter travel was delayed for weeks at a time due to weather and the gravel strip didn't always remain serviceable in the summer thaw. **Second,** heavy highway trucks with 1500 gallon tanks north of Fairbanks required for the round trip, because Prudhoe didn't have gas or diesel, but burned benzene in all vehicles, which was cracked from the oil in a small refinery. Winter travel was too severe at times for trucks. Trucks cost about $1.00 per pound of cargo. **Third,** ocean going 300' long barges towed by ocean tugs with entire buildings on board, probably cost pennies per pound to transport, but only work well when Mother Nature blew the ice from 300 miles of Arctic shoreline for ~30 days in ~August. Figure 4 shows the Beaufort Sea 300-mile shoreline east of Point Barrow, which failed to open fully 2 out of 4 summers. Barges were used only one direction and storage was in fabrication yards in Seattle and San Francisco. Half the time the ice and shallow Arctic Ocean were major problems forcing summer work into construction winter work. Finally the **fourth** logistics route, the pipeline only works in one direction, takes eight days, 2.1 million barrels a day, but construction costs were increased by the permafrost foundation problems and difficult terrain. Some pump stations used natural gas, some oil for power. Large storage at south end and transportation estimated cost, pennies per barrel transported. A fifth trade route may emerge as the very expensive natural gas pipeline discussed in Congress.

Logistics Lessons Learned.[12]

1. Arctic engineering and construction are different than regular construction – Recognize lunar engineering and construction techniques will be ~ 10 times more severe and more different than the difference between normal engineering design and construction in the lower 48 compared to Arctic engineering and construction; impacting everything from packaging requirements to mass of large structures and equipment. Recommend lunar Engineering be a course at interested universities. The lunar environment is more difficult.

2. No single transportation or logistics system worked all the time – Weather and ocean ice precluded each logistic transportation route at different times, so more than one was required and probably would be required for significant surface operations on the moon. Recommend at least four different lunar logistics routes using different vehicles with different hardware to be considered, so the launch failure of one vehicle will not impact the safety of the lunar crew and that pre-positioning of logistics be considered as part of any logistics plan. Suggest more than one system.

3. No single transportation or logistics system offered the affordability for all materials – Recommend multiple government agencies attempt to encourage multiple logistics transportation routes to and from the moon. Smaller affordable systems can be commercial and more frequent in delivery.

4. Sometimes you need something so quickly that transportation cost is overshadowed by need – Recommend a last minute emergency cargo system be considered similar to throwing a part on a jet flight at the last minute and paying the increased cost. It happened every day on the slope with hundreds of companies filling about half of all passenger flights with cargo pallets and paying the cost. More frequent helps.

5. Once a logistics system is created, commerce flourishes – Recommend commercial alternatives be considered early. Non-workers or tourists would pay $1,000 to fly to Prudhoe Bay in the summer just to look at the tundra flowers and look at what $12 billion could build. The tundra flowers were smaller than a fingernail and under whelming. Hotels were non-existent and food was difficult. Plan for lunar tourists early.

6. Some packing crates were used for a second purpose, because they were available[14] – Recommend the use of Henry Ford's method of specifying crate materials and using them later as Henry did as oak running boards for Model As.

7. Even equipment used in transportation needs to have a second use at the destination – Recommend reuse of tankage, and everything be considered for reuse in some form.

8. Tooling and fasteners can be standardized and provide second use opportunities – Recommend agreeing on fewer, but standard fasteners and the ability to take items apart and repair or reuse.

9. The labor intensive work is done in the lower labor cost area and transported assembled to the high labor cost area when possible – Recommend equipment, structures and other items be assembled by the future lunar worker at least once on Earth and "repairable thinking" be a part of all lunar thinking.

10. In the use of piece parts to be assembled on the slope, we suffered from single parts in structural steel, for example, not making it to the assembly site due to **logistics handling, mis-marking and storage** requiring a new fabrication on the slope of the part or adaptation of a mis-fabricated part. Recommend parts, boxes and all items be marked with bar codes plus "Plug and Play" information accessible from a space suit.

III. LTS Earth – Moon Transportation System Reuse

The lunar Transportation System proposed is for non-critical cargo initially and may become reliable enough for crew transportation to and fro m the lunar surface at some later date, when reliable unmanned flights are repeatable with sustained success and safety comfort. The nearer term market include a variety of missions to test and refine our in-space flight architecture and architecture support bases (propellant depots in LEO and Low Lunar Orbit (LLO), LEO missions as an unmanned tug, missions in and beyond LEO to the L-1 point in support of facilities in that part of space and missions to the lunar orbit. The size of the LTS vehicles may offer more trips to and from the lunar surface than the larger vehicles and provide some benefit in the frequency of flights. This proposed system builds a two-way transportation highway between Low Earth Orbit and the lunar surface, either from LEO directly to the lunar surface for smaller payloads, or from LEO by refueling in cislunar space for heavier payloads and for payloads returning from the Moon. The system uses a small fleet of reusable spacecraft, supported by a small fleet of expendable spacecraft, to transfer payloads in LEO, to transfer propellant tanks at specific locations in cislunar space, and to transport payloads to and from the lunar surface. The system uses existing ELVs to transport its entire infrastructure from the Earth to Low Earth orbit and could consider using government vehicles in some cost sharing manner suggested later.

Entrepreneurial Opportunity

The same team that brought researchers the mid-deck locker in microgravity offers a special small surface delivery package for your creativity, inventions and special equipment for the purpose "prospecting" the lunar surface. Figure 5 is one idea. On Earth we use FedEx, with package pickup at your door and no return delivery, to the moon you can use the LTS vehicles and on the moon's surface you are on your own, after we gently set you down. The mid-deck locker became an industry standard for researchers in the microgravity environment created by the SPACEHAB Module in low Earth orbit. The mid-deck locker was and still is a 2 cubic foot locker that cost $2m and used an average of 125 watts of power and averaged 42 lbs flying on the space shuttle. SPACEHAB still offers this smaller module version of an existing NASA Module called Spacelab started by an entrepreneurial startup company and manufactured in Italy by an early portion of the current Alenia Spazio Aerospace conglomerate. The space shuttle has launched the module and/or their evolving components 22 times with the launch scheduled in the fall of 2007. Launched in this special commercial SPACEHAB Module is 60 or 80 individual lockers prepared and controlled by independent researchers with astronauts providing on orbit hands on services as required. This cooperation between NASA and a small entrepreneurial company allows NASA to utilize the back half of the space shuttle payload compartment for other payloads. An estimated 2,000 such experiments have launch since the company started in 1983 and many of those 2 cubic foot experiment setup are ready to launch again, but the space shuttle has reached the end of its useful life and these experiments must transfer to Space Station and the Express Rack pricing and with a different launch vehicle and orbital accommodations.

If such an exploration package could be delivered to the lunar surface and landed effectively for use via the Internet, then what actions are required for its care and accommodation in this new environment besides transportation? First, it needs a name but it is not a mid-deck locker, but the same approximate size. It is not as cheap as an order of magnitude or two less than the traditional lander packages in cost. It does not just sit there on the surface, but goes out and prospects at the command and control of its “Prospector” on Earth. It does not sense the lunar environment with sensors, but travels out into the lunar environment and actually accomplishes things like prospecting and many other things at the direction of the owner. This platform needs locomotion, but rover technology should be able to provide a small platform with wheels and a solar array with some additional expense. In fact a whole list of equipment, sensors, solar cells and camera can be carried on the traveler rover for the prospecting of the lunar surface. Does positioning one’s rover over a part of the moon become a claim, because it is occupied? Well, that may not be entirely clear at this early stage.

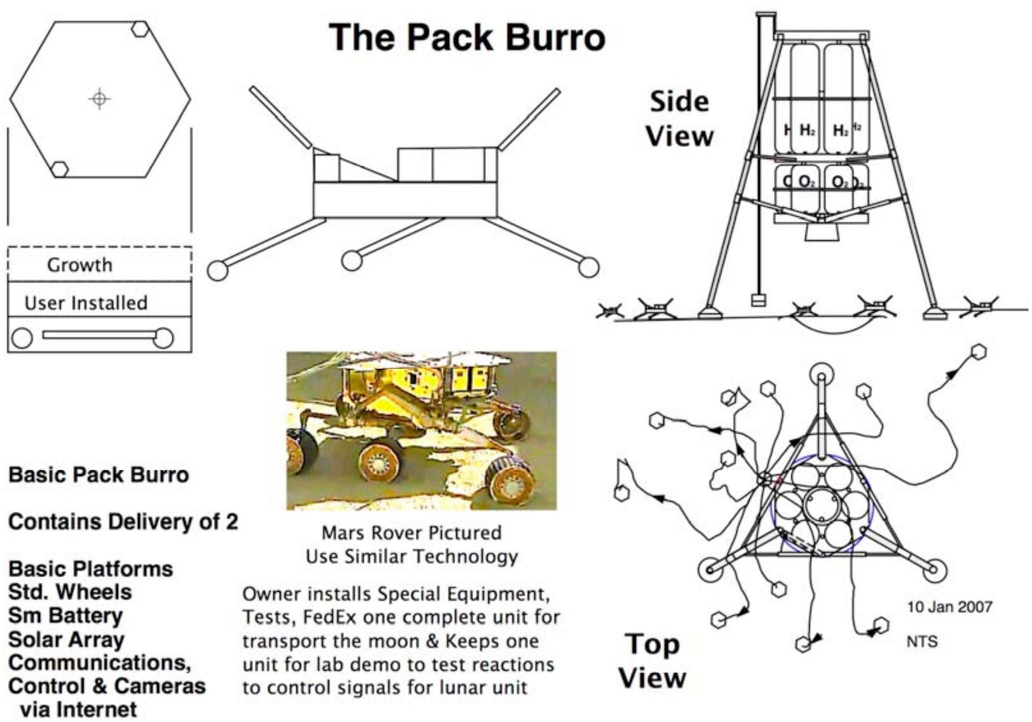

Figure 5. The Prospector’s Pack Burro on the Moon’s surface. Controlled remotely via the Internet, Free to roam around and perform experiments.

Well, let’s get back to a name. Maybe this is a little package is a bit like a miner’s “burro.” It carries equipment for the miner; it is packed by the miner with what is anticipated and becomes an active assistant to the miner’s activities. Could the “burro” come back to the LTS vehicle for food and water and reconfiguration, well maybe? Is there a limit to how far such a wireless “burro” could go, probably? If the burro came back to the “barn” could it be repaired, fed with new software and repacked? If the standard chassis were combined with standard bolt on components, it is realistic to think such a feeding could take place at the "barn." Could Universities all over the world have duplicates in their labs to try the software on, before it is feed to the Burro, well maybe? Could students learn by doing and be inspired by the exercise, very likely. Could the "burro' ever come home to Earth, probably not for a while. It must work until worn out and wait to be picked up as a museum article in the University's museum. What would such a "burro" look like? Not all burros look alike. They have four feet and consume basic food and water, but each has a personality of its own. The Lunar "Burro" is likely to evolve to fit the lunar environment, much the way the Mars rovers evolved and became very adept at traveling across the Mars surface, but a "burro" is the Miner's friend and the Miner has a mission, a life long mission of finding something of value that the miner can recover his or her investment in time, energy, creativity and money. The miner of the American West was a dreamer and explorer driven to find resources of value and to recover those resources for reward for the many years of effort.

Lunar Transportation Systems, Inc. proposes the "Burros" for sale program. Figure 5 depicts the basic "Pack Burro" Concept and outlines the basic platform and the anticipated hardware to be supplied for a price, which includes the one-way transportation to the lunar surface. The "Pack Burro" package includes a platform frame, some wheels and basic wireless communications, solar power and small batteries and a lifting eye. LTS expects to transport the "Burros" to the lunar surface and place them on the regolith. Their "Standby " ticket price on our vehicle is expected to reflect their contribution to filling up our vehicle beyond the normal customers. We don't know much about "Burros," but other entrepreneurs do and we will help you sell your equipment in this out of this world miner's community. A platform with some wheels with communication gear with cameras might be a good start on a "Burro." It has been suggested that small exploring and innovative unmanned devices operated by inventive creative people could establish a beachhead for resource miners on the moon and use the same technique to explore the universe. Maybe LTS as an entrepreneurial company on the frontier of a new celestial body can be the "General Store" by helping to sell "gold pan like support equipment" and transporting "Burros" to the region. Maybe LTS could get interested in setting up a corral, restoring the "Burros" feet like a Burro might get horseshoes and some "hay" and new batteries, when they are hungry. This is not just our idea. We are not smart enough to think of all this by ourselves, but like the resource miner of the American West and countries all over the world, we see opportunity for great wealth in finding lunar equivalent to "gold " and the "Burro" can help.

Reusability. A key feature of this Earth – Moon transportation system is that the two principal spacecraft, the lunar Lander and the Propellant Transporter are fully reusable. The lunar Lander transports payloads from LEO to the lunar surface and back. The Propellant Transporter transports cryogenic propellant tanks from LEO to any place in cislunar space where the lunar Landers need to be refueled. When approximately $100k per pound is spent transporting a vehicle to the lunar surface, then is value on the surface should be explored in all ways.

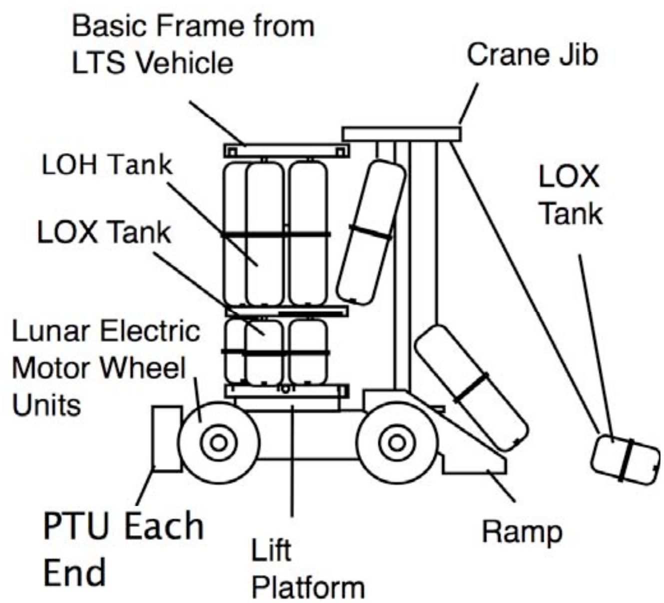

Figure 6. LTS Uses Utility Vehicle for Surface Tasks.

Shared Vehicles Figure 6 is the LTS vehicle being serviced by a lunar service or utility vehicle. This surface utility vehicle is transported to the moon on an LTS vehicle, assembled with a crew, uses various methods to make use of local materials and provides services and materials to other organizations as well as provides LTS with services. The Basic Frame of the surface vehicle comes without the mass required to provide the stability and non-tipping capabilities in the $1/6^{th}$ gravity of the moon by using the mass of the regolith and/or melted regolith to add the weight to compensate for the massive counterweights, and other normal one gravity stability problems. The $1/6^{th}$ gravity is different than one gravity in that it appears an increase in the tendency to tip as a vehicle goes around a curve, because the mass holding it down on the road is greatly reduced. Crane counter weights need to be local materials, hopefully reduced in volume by melting. This counter weight mass can be local materials, but a revolution is required for the designers of the equipment. Local mass can be to fill volumes of voids within the vehicle. The utility and function of the "Live Off The Land" vehicle uses Power Take Off Units (PTO) for each end, which slave power from the basic vehicle, but add versatility and increased functions for the vehicle. The first vehicle will have to dig, plow, grade, microwave in place the regolith, carry large items like payloads, tanks, vehicles and building materials including lifting into place plus some unknown functions yet to be determined. The components of larger mining machines going to the moon's surface must be small enough for LTS P/L bay, delivered in pieces & assemble on the lunar surface. The only real size constraint is the diameter of the originating vehicle delivering from Earth to the transfer to an LTS vehicle in orbit. LTS expects this diameter to quickly expand to 10 meters or more in diameter with the advent of commercial resource recovery operations beyond Earth. Manned operation of the lunar surface utility vehicle is one of several methods of operation and would include a pressurized cabin with provisions for removal of exterior space suits and recharging of suit consumables plus a safe haven using the mass of the vehicle counterweight and frame as a radiation shield. The remote control operation from Earth or anywhere in between is thought to be a part of a surface vehicle hardware and capable of a graduated preplanned upgrade path of many segments, because spending the transportation money to place something on the moon needs to be a 30 to 50 year design life sort of thing given the transportation cost of imported mass beyond Earth.

The full reuse of hardware can be carried one step further to the component level. The Electric Wheel Units, for example, can be interchangeable and capable of repair on the moon. Limiting the piece count and component count may seem to be limiting commerce and discouraging differences between commercial products from different companies, but reuse must, in the early development stages, take center stage for cost reasons. A master mechanic, the usual innovator on remote construction projects shown in Figure 2, must be given a reasonable chance at keeping hardware operational and the more remote the base is the more difficult and expensive the "problem" even on Earth. Fasteners, wiring, tires, EVA suit items, batteries, solar arrays, containers, beds, reusable water bottles and a myriad of other well labeled logistics items fit into a general reuse policy of cost reduction using "Smart Logistics" techniques.

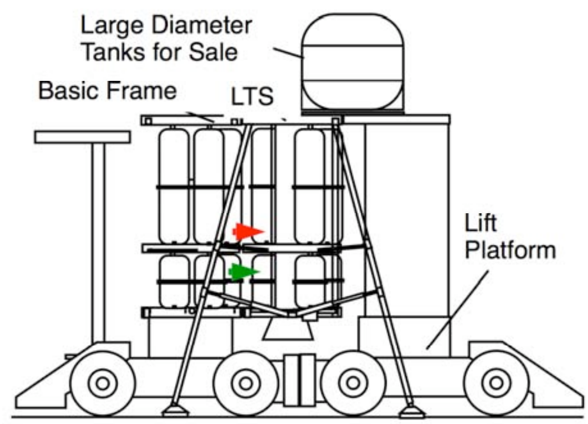

Figure 7. Surface Utility Vehicle Loads Payloads and Propellant.

That's why lunar surface vehicles, like Earth vehicles, have hook locations, outriggers, tires of different types, weight shifting to increase traction and a multitude of new challenges imposed by the lack of air, increased temperature extremes, long night operations, both manned and remote operations and many more with all to be in the public glare. Special functions for the possible LTS operations include a Platform Lift capable of reloading the LTS vehicles with propellant and payloads as shown in Figure 7. Also needed on the surface and capable of reusing the LTS tanks to collect and recover the gaseous oxygen form the lunar miner?

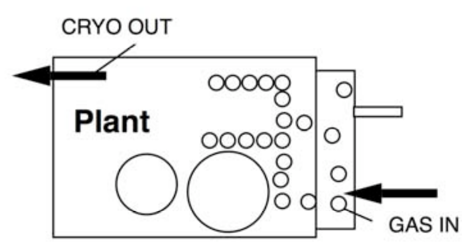

Figure 8. Surface Propellant Plant Converts Gaseous Recovered Resources to Cryogenic Propellants.

Increased Payload Capabilities The size of the payloads delivered to and from the Moon depends on where and how many times lunar Landers are refueled on their way to and from the lunar surface. This system is capable of delivering 800 kg to the lunar surface directly from LEO without the need to refuel in space. It is capable of delivering 3.2 metric tons to the lunar surface with refueling at L1 only. And it is capable of delivering up to 10 metric tons to the lunar surface with refueling at MEO, at L1, and in lunar orbit. Comparable payloads can be returned from the lunar surface to LEO or to the Earth with refueling at one or more of those locations.

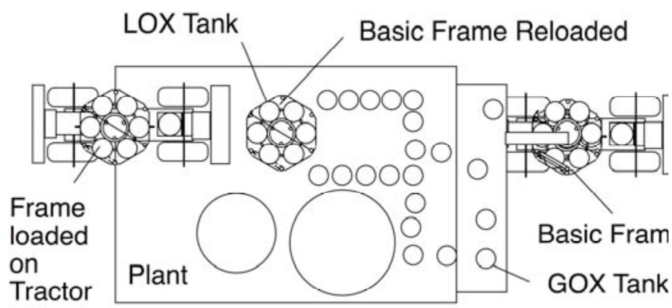

Figure 9. Surface Utility Vehicle Transports Recovered Resources and Production Propellants to and from the Plant.

Cooperative Plants Figure 8 is an early processing plant and again early operations are crude and minimized until a market actually buys the product and services available, then the commercial financing flows quickly to spend the money required to meet the existing market, but upgradeable to more capability and production, so as to lead or stimulate the early market and follow the market with easier to raise private capital as the market grows or disappears. This means the NASA government funding of all up front budget expenditures are changed in the commercial world to the way most of the commercial world builds in a high cost remote environment. The plant basically converts gaseous oxygen stored and transported in reusable tanks into lox in as efficient way as possible given the cost and schedule. The processing is thought to be easier, if ice is present in significant quantities on the moon and the plant can be planned and even conceptualized including transportation planning prior to the first trip to the moon. This advanced thinking allows commercial space entrepreneurs the ability to raise the private capital and organize the transportation in parallel to early NASA efforts rather than in series and after traditional government space development. The plant will require a lot of power, needs radiation protection and staff plus significant automation. This maybe an opportunity for commercial sources to fall in love with a future market, develop the hardware, test the processes, determine the power source and provide the service plus related surface facilities and transportation with NASA encouragement in a Public Private Partnership.

The plan could include the developmental pull of He_3 into the venture rather than fighting for DOE budgets in an Earth environment where DOE has no real incentive to consider He_3 research. On the moon the "Living off the Land" using He_3 becomes easier to sell and incentivize research to move in a different way. Incentivize in this meaning or case means to provide a motivation for moving in a new direction in a manner similar to the oil companies on the North Slope, who agreed to burn benzene in most equipment and power plants instead of a more expensive alternative gasoline and/or diesel. It was an accepted practice and the use in the Prudhoe Bay Oil Field of a small refinery to crack the oil on site and use benzene as a power source for almost everything. The cost was modifying the carburetors on the equipment and the saving was a small "cracking plant" refinery instead of a full refinery producing several blends of fuel. The decision for these commercial "big oil" companies was an easy one to make and had probably been made on every new remote oil field for the last few decades. Benzene is a colorless and flammable liquid with a sweet smell and a relatively high melting point. Benzene is also carcinogenic and when spilled tended to melt the threads of the Arctic Parkas before damaging the cloth itself. He_3 is positive for health reasons and may be helped by the hard vacuum of the moon plus both He_3 and nuclear require some research for use on the moon and He_3 seems to provide more advantages for the future for both celestial bodies involved. Research is a major economic driver to eventually use He_3 to power all lunar activities for the same reasons as benzene was used on the North Slope, availability and "living off the land.

Surface Transport Enhanced Use Leasing Figure 9 depicts a Lunar Transportation Systems utility vehicle being a transportation service on the surface of the moon using the surface utility vehicles and transporting empty, gaseous tanks and the full tanks (same tank, different mass and contents) of cryogenic propellant for a launch using resources recovered and processed into propellants on the moon. Commerce continues into other commercial services financed by private money, because NASA and other space agencies see the value of saving their budget dollars and applying the techniques of Public Private Partnership agreements. Other commercial services could include propellants for LTS use, "live off the land" services for company town, like oxygen, water, local transport services, camp construction and management including logistics, propellant for sale to others, incoming payload handling, return payload handling and other commerce.

Container Reuse In Figure 10 depicts containerized cargo. It took mankind 40,000 of trade route development in Earth commerce to evolve into containers, why start at zero again? Traditional aerospace design includes an integration process between the payload and the vehicle, but no integration tie to vehicle can save money and permit the most effective and affordable vehicles to be use on each different leg. LTS does not anticipate a complex integration process between the cargo container and the LTS vehicles except structural.

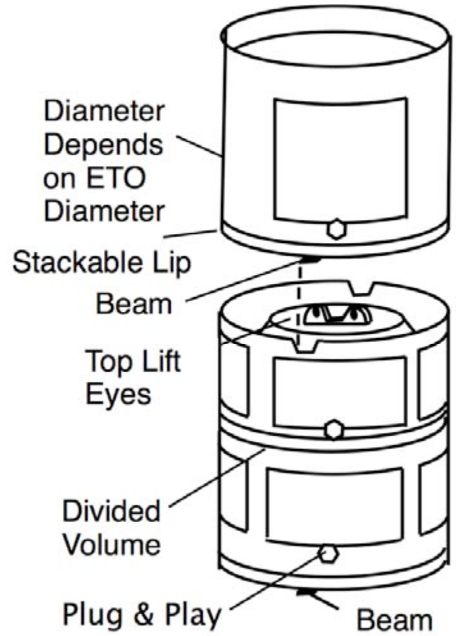

Figure 10. LTS Container Freight with Reuse on Several Levels on the lunar Surface.

Container Reuse Our structural tie allows the quick transfer payload from one vehicle system to another much like the container transfer process in Figure 11, where a shoreline and drastically different vehicles requirements from land to ocean travel naturally force a node in the transportation cycle. This changing of vehicle requirements also occurs at LEO where the ascent up from the Earth and thru the gravity well requires a different vehicle than the coast to the low lunar orbit. The no integration and standard container size is OK for 90% of the unmanned cargo and oversize equipment can be accommodated on a relatively affordable non-manned vehicle. In Alaska, for example, the human passenger and emergency cargo for them, probably made up less than 1 % of the total mass transported to the remote base and to pay the expense to fly everything would have been wasteful.

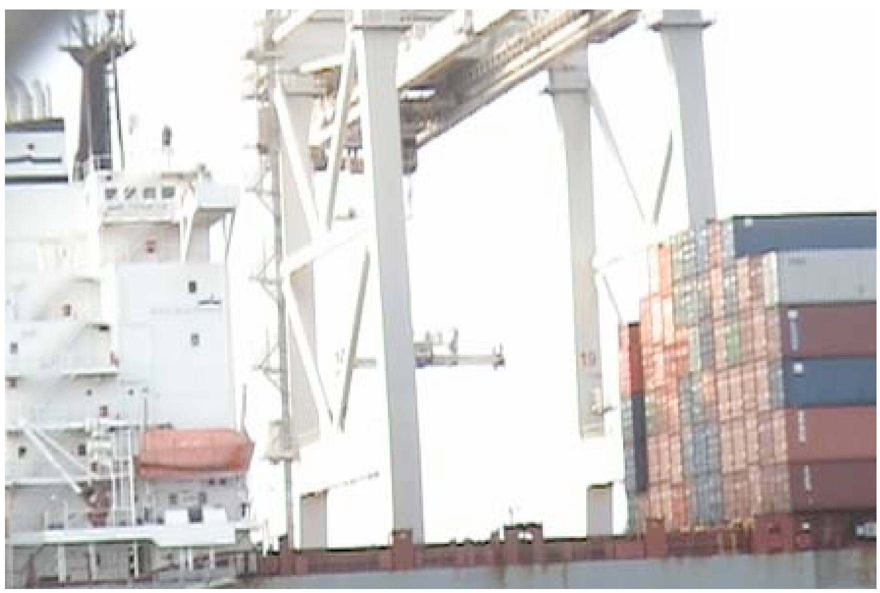

Figure 11. Low Earth Orbit is like a Shoreline, because Major Vehicle Requirements change at LEO and a Transportation Node Emerges Like a Modern Harbor Emerges at Vehicle Change locations on the Trade Routes of Earth.

The container design could include some Special Features to assist crews on the moon including solar cells with batteries to provide a small amount of power for a plug & play content of the container output interface. Containers are customer sensitive and configured in many forms including liquid, dry, pressure, with hatches, cryogenic with mini coolers, and many others.

Special Mining Customers Special customers are accommodated in a variety of ways including Figure 12, where the LTS basic vehicle is modified and is reused, because the LTS basic stack is used to land special drilling equipment. This service encourages innovation, permits a design to accommodate Drilling Operations and telescopes to cut the cost and increase functionality. Figure 13 depicts the drill operation using the LTS hardware as the initial structure and a mining system that uses a dragline to move regolith to a central processing plant. While this maybe more expensive than processing regolith in place, it does provide a shaft operation, which is another option used by the mining industry on Earth. Figure 13 shows the Shaft Sinking/Drilling mining operation possible.

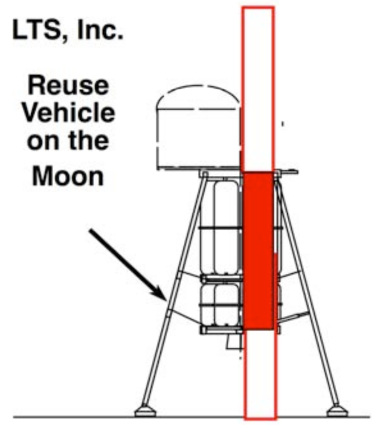

Figure 12. Special Drilling Accommodation on the LTS Vehicle.

All LTS hardware needs commercial launch vehicles to launch each of the four types of LTS hardware from Earth to LEO. This first vehicle sets the diameter of the LTS hardware and can be on government vehicles, EELVs, ELVs commercial vehicles and on vehicles yet to be created. The remaining passive minimum payload dispenser and the final stage are available for discard or reuse as mass for a propellant platform of other uses, because each pound of mass has $5k to $10k of valuable invested transportation energy in it in LEO. To use this discarded item to replace something that must be launched at $10k per pound leads to cost reduction on a potentially significant scale. This discard mass with potential value could be view as the modern day equivalent of the land and mineral rights given to the Transcontinental Railroad builders as they built track. The track laying companies got every section of land they touch and in turn sold it for operating capital. Their customers were railroad customers, towns, cattle men and mining companies.

In the past the government has stimulated private investment with incentives. The Transcontinental

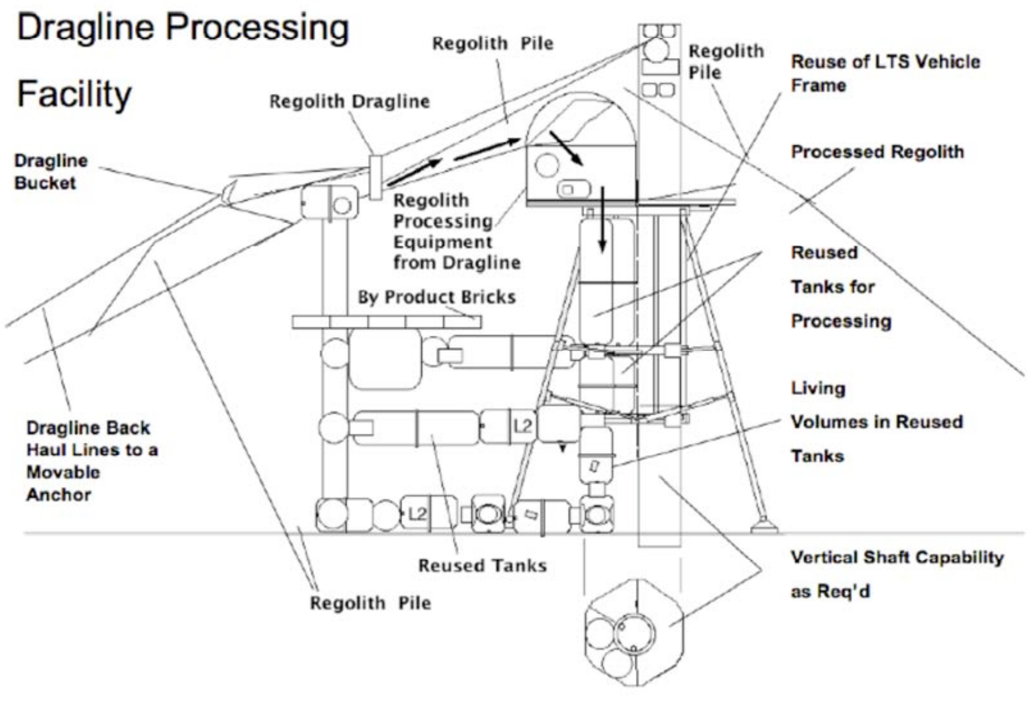

Figure 13. Reuse of the LTS Vehicle Structure Telescopes into a Shaft Sinking/Drilling Mining Operation.

Railroad, for example, gave two organizations land deeds and mineral rights for each mile of track laid. The issue was how to finance the railroad. The incentive worked so well that opposing track-laying crews went 200 miles past the other in Utah without connecting. In the 1840's western America was a remote wasteland between the Mississippi River and the West Coast. A gold rush in California help make the railroad reality. The railroad sold the land and the mineral rights to get the private investment to lay the track, buy the hardware and create future customers.

Conclusion

Commercial operations on the moon's surface can happen and will happen sooner or later.[22] Lunar commerce can emerge in parallel with the President's Space Exploration vision, if government is prepare to join with commercial organizations to explore and implement realistic cooperative ventures benefiting both sides.

The Public Private Partnership may be the method of cooperation between government and commercial organizations, because both sides can benefit. Before private money flows into exploration activities, investors need to see an open ended "Financial Home Run" much the way big oil developed Prudhoe Bay Oil field. Figure 2 depicts one method of mining and recovering lunar resources leading to the recovery of resources from the moon. Figure 2 depicts a University of Wisconsin-Madison research concept[11] for recovering the lunar regolith by heating it to drive off the volatiles and recovering those volatiles for further processing and use in propellant sales and for use on the surface of the moon. The recovered products can be near term consumables for the lunar outpost and later the propellants NASA requires to go to Mars and beyond. The regolith is excavated, continuously conveyed into the machine and heated to drive off the volatiles for recovery with the processed regolith returned to the surface and/or made into products for use on the moon.

Figure 3 suggests a Public Private Partnership to stimulate private money flow into the recovery of resources. It is too early to predict the cost savings resulting from the use of lunar propellant, but for our company such production, once in place, could provide a 60% reduction in our operations cost, because propellant is a large part of the operations cost. Lunar Transportation Systems, Inc. is prepared to work with resource development organizations, willing to be the first customer for lunar produced propellant and abandon our vehicles on the surface to stimulate their reuse in surface facility cost reductions. Sharing the transportation from Earth to LEO with government may be the first step in cooperating on a large scale within a Public Private Partnership providing the underpinning of sustainable commerce supported by private investment.

Remote resource recovery bases on Earth have been on the leading edge of mankind's quest for resources on our planet and as we as humans move beyond our planet; resource development is still a major driving force providing the economic and political sustainability for continued exploration.

The development of the moon is like the North Pole. Early explores want to plant the flag and gain prestige. When commercial developers came to the Arctic some 50 years later, they were interested in profits thru resource development and recovery. They also brought $20B in private risk capital in the 1970s and after finding 18 other oil fields they have invested several hundred addition billions, because that later money comes out of profits.

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