Lunar Infrastructure Development. Douglas Morrison[1] and Dale Boucher,[2] [1]Centre for Excellence in Mining Innovation (105 Elm Streeet, Sudbury, Ontario, Canada, P3C 1T3, dmorrison@cemi.ca and [2]Interstellar Mining, One Yonge Steet, Suite 1506, Toronto, Ontario, Canada, M5E 1E5, dboucher.deltion@gmail.com.

Introduction. The most critical transition in advancing human activity in space is not physical activity but rather the change in mindset from an Expeditionary approach to an Explorational commitment. Expeditions are adventures with tenuous logistics sufficient to get there and back if everything goes well, and some kind of backup plan if they don't. An explorationary commitment requires the design of the overall architecture, developing reliable transportation systems, creating infrastructure that can be supported by reliable supply-chain systems for all the consumables and, finally, the processing capability necessary to sustainably dispose of, or re-use, waste material. Achieving a sustained human presence on the Moon is a major milestone in advancing the Lunar Development Enterprise (LDE) and is 'Step One' in the further human development of a Space Economy. It is not a series of expeditions.

Developments in Antarctica over the last century are instructive. The transition required in the Space Sector today is the difference between Captain Scott man-hauling sledges and Amundson eating his dog team on their way back from the Pole, versus the permanent logistics depot at McMurdo Station that supports the US research station at the South Pole. This difference evolved in the 30-year gap between Shackleton's last Antarctic expedition in 1922 and the establishment of McMurdo Station in 1955. The 40-year gap between Apollo 17 (1972) and the next human landing should reflect at least as much evolution in the collective approach to further developments in the Solar System.

Fundamentals of a Human Presence on the Moon. Not even Antarctica offers conditions as hostile to human survival as the Moon. Given the much longer and more tenuous supply-chain capability, delivering massive stockpiles of life-sustaining consumables must be stored securely before any facility can be considered operational. Even today, scheduled transportation of supplies to McMurdo Station cannot be guaranteed, but they are assured to happen sometime when all but the most severe weather abates. On the Moon, in addition to food, fuel and communications systems, lunar consumables must initially include supplies of air and water. These two essential resources can be recycled, but only in a secure facility where they can be recaptured and re-processed without fail. We are a long way from establishing such a secure facility, and as a result we are, collectively, a long way from establishing a sustained human presence on the Moon.

The lunar equivalent of the modern, systematic approach to establishing a sustained human presence on Antarctica cannot remain an afterthought, that will be resolved sometime in the future. This has to become the primary coordinated focus of all Space-related developments, by both commercial enterprises and national Space Agencies. This is not to discourage the scientific studies that are already underway - they will all be utilized at some time in the future - but they are driven by an singular interest in a new individual technique; they are not focused on a strategically integrated operational Roadmap.

This current approach has left the basic, mundane requirements that are the basis any self-sustaining community to languish. It may be appropriate, then, that the strategic inclusion of these mundane requirements in a coordinated Roadmap should be proposed by members of the mining community. Mining is the second fundamental enterprise after agriculture, responsible for the successful march of humanity out of the Stone Age. Metal mining was how humanity escaped the Stone Age and only refining our wasteful carbon-fuelled mineral production processes can save us from returning to it. It is clear that the current high-capital, mass-mining approach to mineral resource recovery is, alone, not capable of meeting the metal demand of the global energy transition in the next two decades. Developing small-scale mining systems with low-cost, hyper-effective, autonomous equipment for recovering smaller, more remote deposists is imperative. This is the convergence of the future of both the Terrestrial Mining Sector and the Lunar Development Enterprise and creates a common Roadmap for future advances.

The current focus on water-ice resource recovery is a good example. As of today, despite many attempts by several enormously well-funded organizations, there is no assured system for routinely landing safely on the lunar surface. Until such a routine delivery system is achieved there is simply no way to advance even the most basic human-sustaining outpost on the Moon, far less implementing processing facilities for lunar water resources or manufacturing. Both these processes, however, are easily achievable in a quasi-atmospheric facility, so developing the systems needed to create such a facility is a presquisiste for all future advances. So too, is development of a suite of modular autonomous construction units that can create this facility on the Moon. The building and rigorous testing these systems on Earth is, therefore, an urgent impertive. This is Step One in developing the infrastructure architecture for a sustained human presence on the Moon.

This phase of development is not a research project: it is a program of Lunar Infrastructure Development by Integrated Autonomous Engineering (LID-IAE), using long-established mining techniques. An engineering approach is essential at this stage since even today, after fifty years of advancing modern maritime systems routine scheduled delivery of essential consumable supplies to the Antarctica cannot be assured. Using the McMurdo Station in Antarctica as a model, the following developments for the creation of a sustained human presence on the Moon appear to be essential priorities:-

1 design Re-usable Landing Facility (RLF), located and prepared for receiving routine delivery of materiel,

2 design a safe, secure Bulk Storage Facility (BSF) located some safe distance from the\ RLF,

3 design a safe, secure Sustainable Human Habitat (SHH) with consumable storage and access to the BSF,

4 develop a suite of modular Utility Transport Vehicles (UTV) for transportation and unit recovery activities,

5 develop a lunar-resourced Heat and Power Station (HPS) for charge/re-charge/warming of UTV batteries,

6 develop Resource Production Modules (RPM) designed for Us to recover regolith and rock at scale,

7 design small-scale Route Support Stations (RSS) to support UTVs in case of delays, failures or recoveries.

This list is not necessarily a sequence of developments since there may be ways to deliver large volumes of consumables before re-usable lunar landing facility is completed. But consumables have to be moved to a secure warehouse-like facility in preparation for breaking down into manageable volumes suitable for the habitable Station – autonomously.

The Human Habitation Station has to be a permanently air-locked atmospheric unit with all the supplies needed to sustain the crew for at least a year. The safest location for such a facility, of course, is not on surface, exposed to radiation and micrometeorites. It could be established within the regolith but a more stable, secure and manageable environment would be excavation in the Mare Basalts. There are several simple, well-established rock excavation techniques ideally suited to autonomation with swarm-communication protocols, now in the detailed design phase.

Rover exploration will remain limited while there are only a few UTVs without Route Support Stations having been established. A single design for these modular stations, and the autonomous units that can ceate them will allow rover missions to be accelerated safely.

For the all-electric, autonomous systems on the lunar surface, heat and power are essential for ensuring continuous operation. Solar resources and traditional cold-climate building techniques are more than sufficient to provide continuously comfortanble human environments, without relying on any kind of nuclear devices. These are easily supported by lunar resources for both large, permanent central facilities and temporary Route Support Stations.

Finally, the long-term viability of a sustained human presence on the Moon will require technologies that for repair and replacement, depend far more on lunar resources than on Earth-sourced materials. Lunar equipment will have to rely on simple, robust systems to identify, extract and process lunar surface resources and will maximize the utilization of all lunar energy resources. These largely self-sustaining resource extraction and utilization systems are long-established and their modern versions are now in detailed design.

Conclusion.

There is a tendency to assume that since travel to the Moon requires the level of technology that is at the peak of human sciece and engineering ingenuity, the technology that will support a sustained human presence on the Moon will also be at the peak levels of technological systems. However, the extreme ambient conditions on the lunar surface - prolonged day- and night-time temperatures, aggressive fine regolith, radiation and micrometeorites - speak to the need for brutally simple and robust technologies to provide the necessary system resilience. With a level of hostility to human survival more inimitable than the worst Antarctica has to offer, makes establishing a sustained human presence on the Moon the most daunting task humanity has ever contemplated. Despite the awe-inspiring technologies developed to explore Space, the a permanent presence on Moon is no place for technological hubris.

The success of the Lunar Development Enterprise depends a systems approach much more complex than just identifying, recovering and processing lunar water resources at the South Pole. Achieving this will certainly be an important part of the process, but executing it as an expeditionalry activity it is a long way from Step One. Lunar Infrastructure Development by Integrated Autonomous Engineering is the first stage the future of the Lunar Development Enterprise.