MINING TECHNOLOGIES TO ADVANCE LUNAR ISRU OBJECTIVES. D. M. Morrison, Centre for Excellence in Mining Innovation, (CEMI), 105 Elm Street, Sudbury Ontario, Canada P3C 1T3. dmorrison@cemi.ca.

Introduction: As recently as 2022, the lunar ISRU topics that are most actively investigated within the framework of the ISRU Functional Roadmap [1], tend to concentrate on the utilization of the resources on the moon such as regolith and water-ice. To date, there has been an expectation that the mining industry will provide the solutions needed to develop the capability to shape and modify the surface of the moon to help develop the physical infrastructure required to house these kinds of processes. The Mining Industry has demonstrated very little interest in working on these issues because of the misalignment of scale between the extremely small tonnages of prospective lunar activities the relatively huge tonnages produced by even very small mines. The CEMI organization is focused on accelerating innovation in the mining sector by working with the small to medium enterprises (SMEs) in the Canadian mining service and supply (MSS) sector. We believe these companies are the best source of practical innovations for mining and we also believe they are the companies most likely to deliver solutions to the problem of built infrastructure on the moon.

Current Context: Over the last thirty-five years, the equipment systems used in surface and underground mines have converged and they rely on economies of scale for productivity gains. Before this, the constraints on underground shaft-access mines required much smaller, but highly effective mining systems but in the 1980s the urgent need for greater productivity was fulfilled by mechanization and the introduction of much larger and more powerful equipment (Fig.1).

Figure 1. Modern Mining LHD Underground.

Consequently, the bulk mining of base-metal commodities has been able to continue to depths below 2.5km below surface where heat management begins replace geotechnical stability as the primary technical challenge. Overcoming the original constraints on underground mining with size and power was a temporary respite, but thus approach can no longer be used to increase mine productivity and another technology platform has to be implemented. Greater mine productive capacity at lower cost is essential if the mining industry is to be able to supply the coming demand for metals and minerals that are vital to the Energy Transition to a lower carbon economy.

Conventional mining equipment tends to be heavy, slow, and energy-intensive and despite its current hegemony, many of these systems do not make good use of energy or time. A typical load-haul-dump (LHD) machine weight 3 times the mass it carries and returns empty, so that less than 20% of the total energy used moved the product and LHD consumes the rest.
For a truck the equivalent measure is about 25%. Also, after a brief loading period a typical LHD or truck cycle leaves the source material untouched while the carrier travels to and from the delivery point - roughly 90% of the time. The required production targets are met by multiple units that collectively require huge energy resources. The performance characteristics of these technologies may be tolerable in an energy-rich environment but they should clearly not be transferred to the resource-constrained environment on the moon.

The previous generation of mining equipment was manually operated, pneumatically powered and presented serious safety hazards - but it was also small, light and highly effective.

Figure 2. Historic Mining: Loader-carrier.

Figure 2 shows an example of a pneumatic loader-carrier that was the model for the unit built by the student team that won the regolith simulant transport Challenge in 2011, using electric power and remote control. This result prompted CEMI to examine the potential of other obsolete or historic equipment that could be augmented by modern power and digital control systems and so out-perform the conventional mining systems used today. A second example is the application of an Archimedes Screw (265 BC) that was used to win the 'Over the Dusty Moon' Challenge in 2022.

Design Approach: Over the last five years, CEMI has used this approach to re-design several new, highly effective equipment units, that can overcome the constraints in ultra-deep, hot, hardrock mining environment. The ambient rock temperature of at least 60 degrees requires autonomous systems to avoid the unsustainable cost of maintaining a human-tolerable working environment. Autonomous systems dramatically reduces the two highest mine operating costs of labour and ventilation. We believe this kind of design approach offers several solutions that will also enable lunar infrastructure development without human operators. In addition to operating autonomously, these all-electric systems can be sustained by lunar resources alone.

A key design component of autonomous systems is that the individual tasks are accomplished by a suite of modular units using a common core platform. In the case of the modular units designed for autonomous hardrock production, the conceptual designs are complete, and are moving to prototype design. The designs for lunar ISRU systems are at various conceptual and prototype levels but the most advanced address rock drilling to any length and orientation, regolith harvesting and packaging, over-land transportation, surface rock grooming and surface rock excavation.

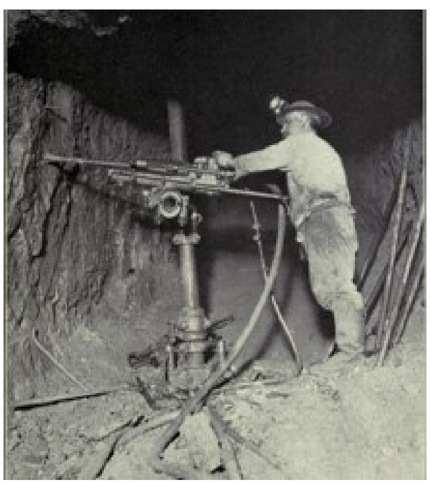

Figure 3. Historic Mining: Drill.

The drill capability was drawn from historic examples in mining, as in the bar and arm drill in figure 3, but the others were drawn from several historical examples in other industries. The designs for power and heat production during the lunar daylight cycle are simply extensions of conventional solar power devices, but the storage and recovery of heat and power throughout the 14-night lunar darkness cycle are still conceptual. However, since all of these systems have already operated historically, adjusting them to slightly different operating constraints will determine the final design of a workable prototype for lunar conditions.

Metal ore production from over 3km below the Earth's surface, and infrastructure development for lunar ISRU operations are subject to similar cotraints. Transportation to and from operations is difficult and expensive and once on site, production has to be accomplished by small, light, low-energy systems. From the end of the Stone Age, mining on Earth overcame its constraints using ingenious techniques to access the resources that enabled the development of ever greater scale and power. But the lunar environment is resource-constrained, and many current resource-intensive Earth-models will be difficult to sustain without repeated consumable deliveries. Lunar ISRU developments that are free of such deliveries are more likely to be achieved by implementing modernized versions of historical technologies that used minimal resources to achieve monumental outcomes such as aqueducts and pyramids. Much smaller feats of engineering can be achieved on the moon using these historical techniques operated autonomously and powered by the sunlight readily available on the moon.

Operational Roadmap: The SME companies involved in innovation in the mining sector can be attracted to advancing lunar ISRU objectives, but they have to be able to see the intersection of working on system developments in both sectors. CEMI is working on an Operational Roadmap that will set out a possible sequence and timeline of the kinds of practical techniques required to establish a continuous human presence on the moon. Simply working on projects that might have some lunar application at some ill-defined time in the future is insufficient to attract SME company interest or investment. There will be no significant near-term return on investment for projects that are executed on the moon, so there has to be the prospect of a significant return on investment for parallel systems deployed in the mining sector or other sectors, on Earth. In Canada, significant Government investment in Lunar ISRU projects will likely depend on describing a Commercial Model that will show how investments in lunar surface developments can be transferred to the broader economy, primarily to the mining sector. The first step in achieving this is to design an executable Operating Roadmap that shows how systems that could be deployed on the moon can first be proven to operate autonomously here on Earth.

References:

[1] Sanders, G, and Author A. B. and Kleinheitz, J., In Situ Resource Utilization (ISRU) Envisioned Future Priorities, Space Resources Roundtable (SRR) Golden, CO June 7, 2022.