

# ARTEMIS PROGRAM IN-SITU RESOURCE UTILIZATION REALITIES AND A CRITICAL NEW ROLE FOR COMMERCIAL SURFACE CREW

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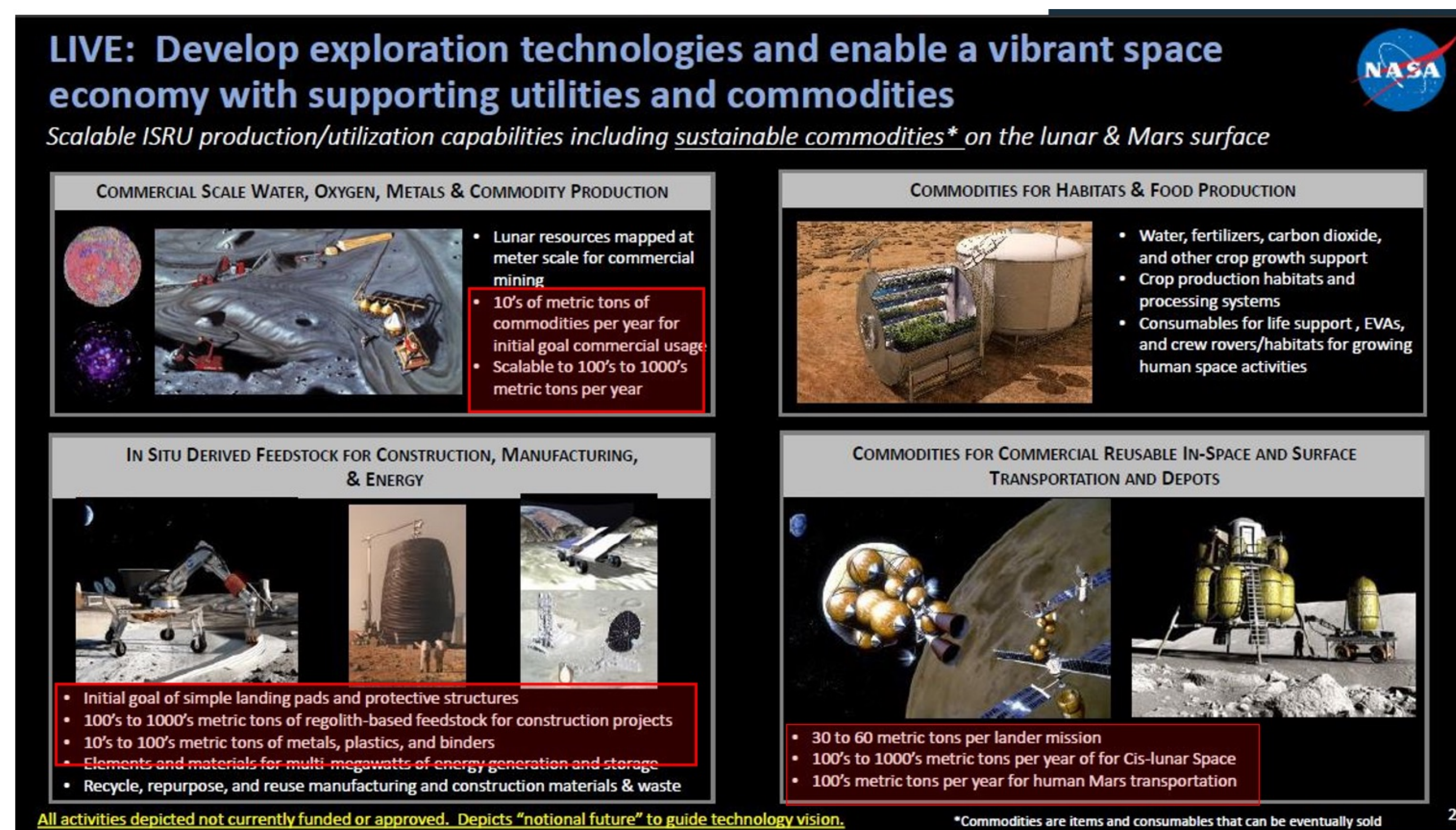
1: The lunar environment is at least an order of magnitude more challenging for industrial equipment than the harshest terrestrial coal mines.

2: Lunar industrial equipment, especially those types that interact most heavily with the lunar regolith, will suffer breakdown rates in excess of terrestrial counterparts.

3: Lunar resource providers must anticipate an indispensable need for human maintenance technicians to rescue and repair lunar industrial robotics.

## 1 If robotics are going to produce this:

“100’s to 1000’s of tons” of lunar-sourced products...



**LIVE: Develop exploration technologies and enable a vibrant space economy with supporting utilities and commodities**  
Scalable ISRU production/utilization capabilities including sustainable commodities\* on the lunar & Mars surface

**COMMERCIAL SCALE WATER, OXYGEN, METALS & COMMODITY PRODUCTION**

- Lunar resources mapped at meter scale for commercial mining
- 10's of metric tons of commodities per year for initial goal commercial usage
- Scalable to 100's to 1000's metric tons per year

**COMMODITIES FOR HABITATS & FOOD PRODUCTION**

- Water, fertilizers, carbon dioxide, and other crop growth support
- Crop production habitats and processing systems
- Consumables for life support, EVAs, and crew rovers/habitats for growing human space activities

**IN SITU DERIVED FEEDSTOCK FOR CONSTRUCTION, MANUFACTURING, & ENERGY**

- Initial goal of simple landing pads and protective structures
- 100's to 1000's metric tons of regolith-based feedstock for construction projects
- 10's to 100's metric tons of metals, plastics, and binders
- Elements and materials for multi-megawatts of energy generation and storage
- Recycle, repurpose, and reuse manufacturing and construction materials & waste

**COMMODITIES FOR COMMERCIAL REUSABLE IN-SPACE AND SURFACE TRANSPORTATION AND DEPOTS**

- 30 to 60 metric tons per lander mission
- 100's to 1000's metric tons per year of for Cis-lunar Space
- 100's metric tons per year for human Mars transportation

All activities depicted not currently funded or approved. Depicts "notional future" to guide technology vision. \*Commodities are items and consumables that can be eventually sold

NASA 2023. Space Technology Mission Directorate Strategic Framework. "Excavation, Construction, and Outfitting (ECO) Envisioned Future Priorities", viewed 19 July 2023, <<https://techport.nasa.gov/framework/>>.

## 2 In an environment.....

At least 1 OOM harsher than the most challenging terrestrial coal mines.....

Table 2: Mohs versus Absolute Hardness Scales: Coal Compared to Typical Lunar Minerals

Present in Regolith. (Mukherjee 2011)

Mineral	Mohs Mineral Hardness Scale	Absolute Hardness
Talc	1	1
Anthracite (hardest terrestrial coal)	2.88	12
Enstatite / Ilmenite (lunar regolith components)	5.5	60
Anorthite (lunar regolith component)	6.0	72
Labradorite / Olivine (lunar regolith components)	7.0	100
Spinel / Hercynite (lunar regolith components)	8.0	200
Diamond	10	1500

Chief mechanical breakdown vector in a mine:

Hardness / Abrasivity of Dust<sup>1</sup>

Harshest terrestrial coal mine

Lunar regolith

Resultant lunar context:

Dust: harder / more abrasive

Quantity: vastly more

Adapted from: Mukherjee, S. 2011. "Applied mineralogy : applications in industry and environment." Springer Science and Business Media. Dordrecht: Springer.

<sup>1</sup>Ho, M., and M. Hodkiewicz. 2013. "Factors That Influence Failure Behaviour and Remaining Useful Life of Mining Equipment Components." Advances in Mechanical Engineering, 5, p.913048..

## 3 Terrestrial mining breakdown state-of-the-art:

Despite Billions of \$ spent on Preventative maintenance...

82% of maintenance is unscheduled<sup>2</sup>

Coal mine breakdown rates<sup>3</sup>:

Excavator: 24.9%

Loader: 22.5%

Transporter: 10%

60% of onsite MX personnel perform their work:

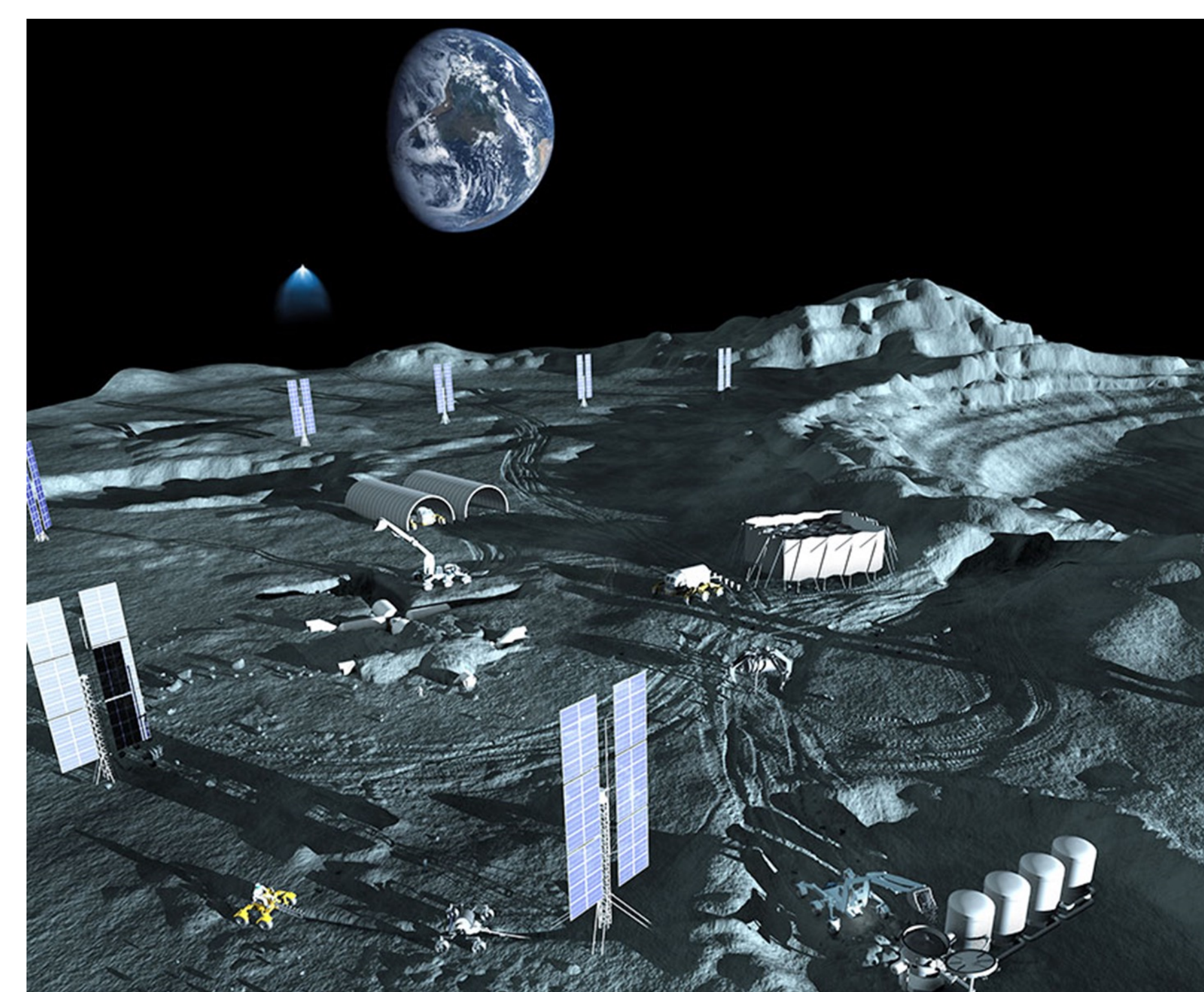
"In the field"<sup>4</sup>

<sup>2</sup>Stummer, R. 2018. "How new technology and AI can control rising maintenance costs." Australasian Mine Safety Journal, 16 November 2018, viewed 12 Dec 2021, <<https://www.amsj.com.au/mining-maintenance-costs-technology/>>.

<sup>3</sup>Samanta, B., Sarkar, B. and Mukherjee, S.K. 2001. "Reliability centred maintenance (RCM) for heavy earth-moving machinery in an open cast coal mine." The CIM Bulletin. 94. 104-108.

<sup>4</sup>Mining Global 2020. "Implementing Effective Maintenance Strategies for Long Term Production Goals." Mining Global, viewed 3 Jan. 2022, <<https://mininggloabl.com/supply-chain-and-operations/implementing-effective-maintenance-strategies-long-term-production-goals>>.

## 4 Thus, a commercial lunar industrial-scale resource provider should expect....



Lunar polar mining base with buried crew habitats, widely spaced solar power panels, propellant production plant and depot tank farm. Image: anna.j.nesterova@gmail.com.

Significant maintenance will be required

Especially for industrial robotics

Lunar industrial robotics will breakdown/embed at rates greater than their terrestrial counterparts

Just like on Earth, humans will be required to keep the machinery operating.

**Without persistent on-site human maintenance support, it is likely not possible to produce industrial quantities of lunar-derived products.**