How is the Artemis Base Camp Sustainable?

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Earlier this year, NASA released its Plan for Sustained Lunar Exploration and Development (https://www.nasa.gov/sites/default/files/atoms/files/a_sustained_lunar_presence_nspc_report4220final.pdf), which represents a good start, but lacks the details to show the path forward to achieve any sustained lunar exploration and development. Furthermore, there is no definition of "sustained" or "sustainable". However, what is in the document represents a way to establish "sustained lunar exploration and development". There are a number of significant quotes that show sustainability is already in the document – but it has been hidden.

> Page 9: *We will develop new technologies that advance our national industries and discover new resources that will help grow our economy*.
> Page 12a: *ISRU will enable the production of fuel, water, and/or oxygen from local materials, enabling sustainable surface operations with decreasing supply needs from Earth*.
> Page 12b: *Artemis Base Camp might also include a hopper that could deliver science and technology payloads all over the Moon and which could be operated by crew at Artemis Base Camp and refueled using locally sourced propellant*.

The Page 9 quote shows that "sustainability" requires involvement of industry and economic growth – a return on the taxpayer investment through the NASA budget. How, then, is the Artemis Base Camp sustainable? Because it is planned that life support consumables and rocket fuel will be sourced from the Moon (eventually: Page 12a quote). Such local resources could also be used to maintain a Moon transportation system (Page 12b quote), as well as refueling the ascent stage of the human lunar lander.

One of the biggest issues in using lunar resources to support human exploration is the simple fact that we do not know is the known resources are actually reserves. The VIPER mission is an initial start to exploring lunar polar volatile resources, but more than one deposit/area will need to be visited in order to truly show the viability of any as a reserve deposit. This is where the Artemis Base Camp can stimulate lunar resource exploration (i.e., prospecting) through a public-private partnership. However, in order for commercial entities to get involved, there must be a reason for them so to do (Lunar ISRU Workshop Report 2019: https://www.hou.usra.edu/meetings/lunarisru2019/workshop-report.pdf). NASA can provide this reason by defining specific quantities of the life support consumables it would be willing to purchase and at what price.

The amounts of life support consumables (oxygen and water) needed on an annual basis can be estimated using the details in Harper et al. (2016, New Space 4, 40-49). Calculation of water and oxygen per astronaut per Earth day are shown in Figure 1.

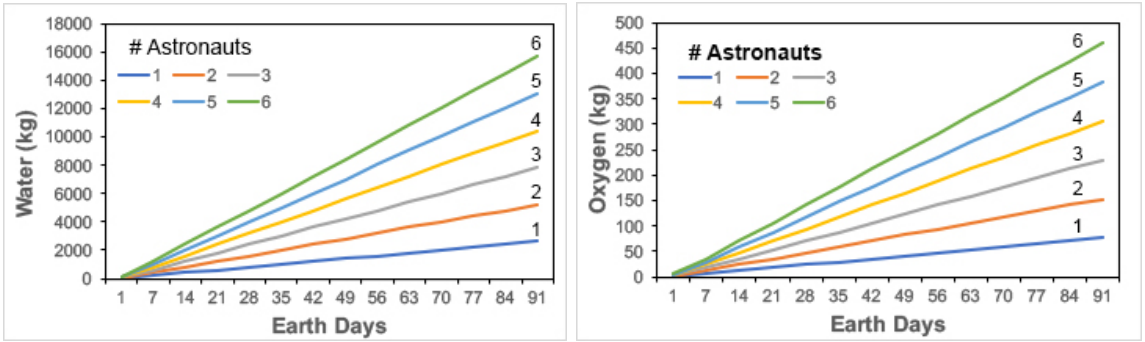

Figure 1: Estimates of oxygen and water per astronaut per Earth day up to 3 months (91 days) using data from Harper et al. (2016).

If astronauts are to be on the lunar surface for extended periods, the graphs above can be used to estimate the amount of water and oxygen required. If fuel is also required for a hopper and for refueling the human lunar lander (and assuming both will have liquid H – liquid O_2), the amount of water required will increase dramatically. In looking at hopper architectures, the amount of fuel could range from <1 tonne, for robotic hoppers, to several tonnes for human rated hoppers and the lunar lander.

Therefore, 150-300 kg of oxygen and 6-10 metric tonnes of water will be required for life support consumables at the Artemis Base Camp. If fuel for a hopper and the lunar lander are also needed, several more metric tonnes of water will be required, along with the ability to split water and store the constituent elements for later use.

If NASA can create a public-private partnership (PPP) with industry for development of lunar resources for the Artemis Base Camp, this could leverage from the VIPER mission development and further resource locations could be explored to understand the reserve potential. The incentive for the commercial companies to be involved in the prospecting stage would be for NASA to state how much they are willing to pay for the development of lunar resources to support the Artemis Base Camp. This approach would enable a robust prospecting campaign to be developed along with incentives for the emplacement of ISRU pilot plants leading to full production, thus enabling development of new technologies that will advance our national industries and discover new resources that will help grow our economy.