APPLYING THE USGS RESOURCE ASSESSMENT METHODOLOGY TO THE MOON: THREE VERY DIFFERENT CASES. L. Keszthelyi[1], C.F. Williams[2], D.A. Howard[3], T.C. Crafford[4], L.D. Meinert[5], J. Hagerty[1], W.I. Ridley[6], [1]USGS Astrogeology Science Center, Flagstaff, AZ 86001, [2]USGS Geology Minerals Energy and Geophysics Science Center, Menlo Park, CA 94025, [3]Office of Land Remote Sensing, Reston, VA 20192, [4]USGS Mineral Resources Program, Reston, VA, 20192, [5]Economic Geology, Washington, DC 20003, [6]USGS Geology, Geophysics, and Geochemistry Science Center, Denver, CO, 80225.

Introduction and Rationale: Before ISRU can be prudently incorporated into the exploration architecture, the resources need to be assessed in a transparent, unbiased, and quantitative manner. Creating such assessments is the responsibility of the US Geological Survey.

Although some aspects of the USGS quantitative resource assessment methodologies differ between water, energy, and minerals assessments, the basic approach is the same. In the assessment context, a resource is defined as a concentration of material or energy in such form and amount that economic extraction of a commodity is currently or potentially feasible. USGS resource assessments report (1) boundaries delineating the spatial extent of resource occurrence, (2) the statistical distributions of resource size and quality, and (3) estimates of the total number of occurrences for spatially discrete resources such as mineral deposits or portions of the study area or volume within which the resource exceeds a defined minimum quality for spatially continuous resources. The results of these three steps are combined to yield a quantitative estimate, with uncertainties, of the total identified and undiscovered resource.

The applicability of the 3-part USGS quantitative mineral resource assessment methodology to asteroids was demonstrated in 2017. A similar study has been initiated for the Moon, with an initial focus on solar energy, bulk regolith, and ice.

Assessing Lunar Solar Energy: Our understanding of the nature of solar energy and the technology to extract it are mature. The quantity of extractable solar energy is tied to our knowledge of (a) the ephemerides of the Moon and Sun; (b) lunar topography; and (c) technologies for converting solar energy to electricity. The relative motions of the Moon and Sun are known to exquisite precision and accuracy. The interaction with lunar topography is directly observed via insolation maps. The technology to extract energy from sunlight is at TRL10 with well-known costs.

Assessing Lunar Regolith: We have a firm understanding of the impact gardening process that creates regolith. We have excellent in-situ data from the Apollo missions and useful additional data from robotic landers. This allows us to use a variety of global remote sensing data sets to map out key properties of the regolith, such as thickness, petrology, and boulder abundance. This state of knowledge is well-suited to the USGS resource assessment methodology. There are many potential uses for the lunar regolith, including being a source of oxygen or the main ingredient in concrete. To limit the scope of the initial study, we plan to focus on the use case of simply bulldozing regolith over a habitat for micrometeorite shielding.

Assessing Lunar Ice: Water, especially in the form of ice in polar cold traps, is the most desirable lunar resource. However, a quantitative assessment of lunar ice is currently impractical because critical information is missing. Still, the USGS mineral resource assessment methodology can be used to lay out a methodical campaign that would allow future data-driven decisions related to ISRU of lunar ice.

Before the USGS mineral assessment methodology can be applied, it is necessary to develop “descriptive” models of the key characteristics and physical/geological process(es) that created the deposits. Therefore, the first step toward an assessment would be a mission that directly interacts with the ice in at least one location and obtains fundamental observations such as a vertical profile of the ice concentration and the detailed composition of the ice and its contaminants. With development of deposit models, the next part of the resource assessment is to identify “tracts” where the deposits could plausibly exist. For example, DIVINER temperature maps can already be used to map, to first order, locations where shallow subsurface ice can be stable for a billion years. Next we need a probabilistic estimate of the number of deposits within the tracts. This may be possible to accomplish this with orbital remote sensing, especially if the ice deposits are created by processes that act over very broad geographic regions. The third part of the assessment is to measure the sizes and qualities of a statistically relevant number of deposits. If the deposits are relatively homogenous, this could require simple in situ measurements at only about a dozen sites. However, if the nature of the ice proves to be more complex, missions with mobility and/or drilling will be required. In either case, the end product would be mathematical expressions describing the probability distribution functions of the size and quality of the deposits. These are combined with the number densities developed in the second part to estimate the total ice resource.

Framing the entire assessment process is the evaluation of ISRU technologies to create an economic model that identifies the cost of extracting water from the lunar regolith. With this suite of information in hand, commercial and governmental decisionmakers can make informed decisions on how to pursue industrial-scale ISRU of lunar polar ice.