Progress with the International Lunar Resource Prospecting Campaign (ILRPC). C.R. Neal[1], A. Abbud-Madrid[2], J.D. Carpenter[3], C. Espejel[4], K. Hadler[5], C.A. Hibbitts[6], K.J. Kim[7], A. Salmeri[8], G. Sanders[5].
[1]University of Notre Dame, IN 46556, USA (cneal@nd.edu); [2]Colorado School of Mines, Golden CO 80401, USA (aabbudma@mines.edu); [3]European Space Agency, European Space Research and Technology Centre, Noordwijk, Netherlands (James.Carpenter@esa.int; [4]Space RS Luxembourg (carlos.espejel@space-rs.com); [5]Director of ESRIC, 41 Rue du Brill, Luxembourg (kathryn.hadler@list.lu; sandersisru@gmail.com); [6]Johns Hopkins University–Applied Physics Laboratory, Laurel, MD 20723, USA (karl.hibbitts@jhuapl.edu); [7]KIGAM, Daejeon, Korea (kjkim@kigam.re.kr); [8]Lunar Policy Platform, 22 Calle De Valdesangil, Spain (antonino@lunarpolicyplatform.org).

"***If God intended Humans to be a space-faring species He would have given them a Moon***" [1]

Introduction: The paraphrased quote above illustrates the utility if our Moon for executing the U.S. Space Policy [2,3]. It is enabling asset because of its proximity, contained resources, and the science secrets it contains regarding the Moon, the Earth-Moon system, and the history of the inner Solar System. The Moon is 3 days away and is ~585 times closer than Mars so it provides incredible utility in reducing risk for sending humans further out into the Solar System. An essential lesson to be learned is living off the land by utilizing the available local resources. This begins with the Moon.

The U.S. has pledged to place the initial infrastructure for a permanent Moon Base on the surface by 2028 [3], as well as potentially placing a 100 kWe fission power reactor at the south pole of the Moon by 2030 [4] (although this appears now be ~20 kWe to start with [5]). These infrastructure elements need to be placed near abundant and accessible resources that can support and sustain humans on the Moon, just as will be needed as more distant destinations are visited. However, the current orbital data sets cannot unequivocally provide the requisite information needed to place the infrastructure and power elements at an appropriate location to take advantage of local resources.

Table 1: Lunar resources identified to date and their potential use in situ, for export, or both.

TYPE	RESOURCE	LOCATION	USE	
			In-Situ	Export
POLAR VOLATILES	Water	PSRs	X	X
	Helium-3			X
REGOLITH	Building Materials	GLOBAL	X	
	Metals		X	
	Oxygen		X	X
	Solar Wind Implanted:			
	Hydrogen		X	X
	Helium-3			X
	Carbon		X	
	Nitrogen		X	
	Platinum Group Metals			X
	Rare Earth Metals			X
	Th, U		X	
PYROCLASTICS	Metals	MARE	X	
	Oxygen		X	X
	Water		X	X
STRUCTURES	Lava Tubes	Mostly MARE	X	
	Impact Craters	GLOBAL	X	

Lunar Resources: The data already returned from the Moon have been used to identify multiple resources for use in situ, for export, or both (**Table 1**). By export, we mean to use off the lunar surface (to Earth and cislunar space). In order for this to happen a coordinated resource prospecting campaign has to happen – and happen now. Given the scale of what needs to be done, we have developed the concept of the International Lunar Resource Prospecting Campaign (ILRPC) [6].

ILRPC in 2025: Two workshops were held in 2025 to define how to initiate the ILRPC Phase 1:

- 1A – Data mining, analysis, and integration
- 1B – Identification of hot prospects
- 1C – Prospecting campaign development and coordination

These workshops also identified that hot prospects are enhanced by orbital and ground-truth surface data. Orbital data can broadly define probability of occurrence and accessibility. Surface data are required to understand the distribution, ore grade and form, nature and concentration of impurities, and extractability [7].

Table 2: List of orbital data sets that could be used for prospectivity mapping of lunar resources.

MISSION	INSTRUMENT	Pixel Size (m)
Lunar Prospector	Neutron Spectrometer – LPNS	15,000 – 45,000
Lunar Reconnaissance Orbiter (LRO)	Lyman Alpha Mapping Project – LAMP	240
	LRO Camera Narrow Angle Camera – LROC-NAC	PSR imaging = 10-40
	Lunar Exploration Neutron Detector – LEND	10,000
	Miniature Radio Frequency - Mini-RF Synthetic Aperture Radar	150 and 30
	Diviner - thermal infrared radiometer	240
	Lunar Orbiter Laser Altimeter – LOLA	500
Chandrayaan-1	Moon Mineralogy Mapper (M3)	280
	Hyperspectral Imager	80
	Mini-SAR Radar	150
SELENE/Kaguya	X-ray Spectrometer	20,000
	Spectral Profiler	500
	Multi-band Imager	20
	Terrain Camera	10
	Laser Altimeter	800
Chandrayaan-2 Orbiter	DF Synthetic Aperture Radar – DF-SAR (L & S band)	2-75
	Imaging Infra-Red Spectrometer – IIRS	80
	Terrain Mapping Camera - TMC 2	5
	Orbiter High Resolution Camera – OHRC	0.32
Korean Pathfinder Lunar Orbiter - Danuri	ShadowCam	1.7
	Wide-Angle Polarimetric Camera – PolCam	80
	Lunar Terrain Imager – LUTI	2.5
	KPLO Gamma Ray Spectrometer – KGRS	TBD
Lunar Crater Observation & Sensing Satellite (LCROSS)	Geochemical data (5.6±3.3 wt.% H_2O)	~25
	Cratering data (~25 m diameter)	
GRAIL	Ka band Lunar Gravity Ranging System (LGRS)	3-6 km/pixel depending on model and data used

We have begun the data mining of 1A and have identified orbital data sets that are applicable for integration to identify hot prospects for polar water ice (**Table 2**). But defining "reserves" of these resources requires mobile surface assets to be sent to hot prospects (1B) identified from the integration of the existing orbital data (**Table 2**). However, the task is daunting because the top 10 permanently shaded regions (PSRs) ranked for water-ice potential cover an area of almost 6,000 km^2 [7]. Hence, a coordinated prospecting campaign has to be international in nature, which represents an opportunity for collaboration and cooperation between states and their respective industrial bases.

While efforts are underway to obtain better spatial resolution orbital data over the poles (e.g., neutrons) via the DARPA LASSO initiative [8] and Oasis-1 from Blue Origin [9], we anticipate that integration of the current orbital datasets may be able to broadly define hot prospects, at least for water ice at the poles, such that mobile surface missions could explore them. In previous Roundtables, we have highlighted the difference between "resource" and "reserve" (e.g., [10]), but the immaturity of the lunar economy requires definitions to be adjusted compared to their use on Earth. In the case of lunar ice deposits, they are currently too poorly characterized to be considered a reserves.

This ILRPC effort will determine the ***reserve potential***. By using the current cost per kg to the lunar surface as a bench mark, the quantity of the water ice in a hot prospect can be given a maximum value. Through this approach, a rubric for evaluating "**reserve potential**" can be derived.

Table 3: Data needed for ground-truthing lunar polar volatile deposits.

Dataset	Specific Data	Use	Measurement Sensitivity
Accessibility	Safe traverse paths	Ease of accessibility has an impact on cost of robotic miners	DEM <5 m
Composition	Concentration of the resource; Concentration/composition of impurities	Evaluate potential investment needed for refining the product	> 100 µg/g; TBD
Form	Cement in pore space; Layers; Irregular blocks; Loose ice grains with regolith	Develop efficient extraction techniques	Hi-Res Images - surface & subsurface
Distribution	Horizontal; Vertical	Variability must be documented to understand resource volume	≤10 m ≤10 cm
Geotechnical	Torque and power required for any machinery to penetrate the deposit; Energy required to move loose regolith; Hardness of the deposit	Understand the effort required to mine the deposit & investment needed in developing extraction capabilities	Any data will be useful!
Near-surface Regolith Stratigraphy	Buried and surface rock populations; Ice block/layer distribution	Will impact the extractability of the regolith resource	≤50 cm

Ground-Truth Data. The types of data needed for mobile ground-truthing missions [6] are given in **Table 3** with the estimated fidelity needed to estimate the reserve potential of any resource hot spot (note that the detection limits for potential contaminants are not defined here, but will be when definitive data on these are obtained). Landing site and PSR accessibility requires extensive processing of multiple overlapping Chandrayaan-2 OHRC, LROC-NAC and/or KPLO-ShadowCam images [11,12].

But how can one rover get the needed data? Understanding the lateral and vertical distribution of the along with the compositional variations requires mobility, examination of the surface and subsurface, and high-resolution imagery. VIPER is a good example of a pathfinder rover for ground-truthing lunar polar volatile reserve potential because of it's broad instrument suite [13]. Extractability from geotechnical properties can be estimated by examination of rover wheel tracks (surface) and from the drilling process (subsurface). More VIPER-like vehicles, that can survive longer in PSRs, are needed with the ability to get higher fidelity subsurface stratigraphy than a neutron spectrometer can give. Multiple builds of the same design give cost savings per unity produced, but requires considerable investment. LUPEX is another capable rover that will be sent to the south polar region, as will Rashid-3 from the UAE. Coordinating these scheduled rovers such that they have a higher chance of finding water ice is what the initial phase of the ILRPC will do.

Relevance to NASA and It's Partners: The latest Artemis Architecture Definition Document [14] has called out a number of data gaps (**Table 4**) that could be addressed by Phase 1 of the ILRPC (DN-006-L) and coordination of mobile surface missions (DN-007 L; DN-008 L; DN-010 L). Therefore, the ILRPC can help address data gaps and demonstrate that lunar resources should be in the critical path for enabling a permanent human presence on the Moon, thus forming a blueprint for making humans to Mars sustainable.

Table 4: NASA ADD Data Gaps [14].

ID	TITLE	PARAMETERS
DN-006 L	Orbital observations of water ice deposits in the south polar region	Water spatial resolution of <10 km (<5 km preferred) to 1 m depth; Coverage <15° from poles; Sensitivity ≥ 1 wt%.
DN-007 L	In situ measurements of the horizontal and vertical distribution, abundance, and physical makeup of shallow bulk water ice	Water ice abundance: vertical res. <20 cm intervals to 1 m depth; ≤ 50 m horizontal resolution; 1 wt.% water ice DL
DN-008 L	Geotechnical properties of highland regolith at the lunar south pole	Particle size distribution (<10µm), particle morphology & density. Also porosity, permeability, bulk density, bearing capacity, cohesion, etc.. Finest fraction (< ~50 microns) variation with depth up to ~3 m.
DN-009 L	Electrostatic properties of highland regolith at the lunar south pole	Measure several electrostatic properties of regolith (e.g., chargeability, volume & surface resistivity, charge decay)
DN-010 L	South polar lunar regolith elemental and mineral composition	Elemental & mineral composition of bulk rocks and minerals; relative abundances of constituent components (to 0.1 wt%) over various locations and with depth.
DN-011 L	In situ lunar surface plasma environment characterization	Measure plasma electron and ion density and energy (0-30keV), secondary populations (secondary electron emission & photoemission), and spacecraft and lunar surface electric potential.

References: [1] Ehricke K. (1985) Lunar Bases Wksp, 827-855; [2] Trump D.J. (2020) National Space Policy of the U.S.A. [3] Trump D.J. (2025) Ensuring American Space Superiority. [4] Rannard G. (2025) NASA to put nuclear reactor on the Moon by 2030 - US media. [5] NASA (2026) Ignition: NASA Unveils Initiatives to Achieve America's National Space Policy https://www.nasa.gov/ignition/ [6] Neal C.R. et al. (2024) *Acta Astronautica 214,* 737-747. [7] Brown H. et al. (2022) *Icarus 377*, 114874. [8] DARPA (2025) LASSO: Lunar Assay via Small Satellite Orbiter. [9] Tarnas J. et al. (2026) LPSC 57 abstract #1321. [10] Neal C.R. (2024) The International Lunar Resource Prospecting Campaign, SRR 24. [11] Keszthelyi L. (2026) LPSC 57, abstract #1560. [12] Beyer R. et al. (2025) *Planetary Science Journal* 6:236. [13] Fernando B. et al. (2025) Planetary Science Journal 6:289. [14] NASA (2025) Moon to Mars Architecture Rev. C.

Formatted: Default Paragraph Font