Strategic Knowledge Gap	Narrative	Enabling or Enhancing	Status	Exploration Science or Technology	Measurements and Missions Needed to Retire SKG	Notes from 2016 Assessment
Theme 1-A Solar illumination mapping	Combined elevation-illumination models to map solar energy incidence over time. Data is in hand but R&A resources are required to reduce and leverage the data. LRO extended mission enables detailed multi-temporal mapping of lunar poles.**Detailed mapping enables polar exploration mission site selection and misison technology design (heaters, batteries, etc.)**	Enabling	RETIRED	Exploration Science	Measurements obtained by LRO during 1st and 2nd Extended Missions and associated illumination models created using LRO data.	Illumination model SKG closed; additional LRO NAC observations could facilitate RP or similar polar missions. Might need an HRSC-type instrument on another orbiter for global 10 m/pixel topography.
Theme 1-B Regolith 1:Quality/quantity/distribution/form of H species and other volatiles and organics in mare and highlands regolith as measured in Apollo samples	Measure volatiles and organics returned in "pristine" Apollo samples (core vacuum sample containers 69001, 73001). Measure the extent of disruption of volatiles during handling and processing.**Enables prospecting for lunar resources and ISRU. Feeds forward to robotic and human analysis and sampling of lunar regolith and NEA-Mars. Relevant to Planetary Science Decadal survey.**	Enhancing	OPEN	Exploration Science	Need permission to proceed, and a well-defined technical strategy for opening the samples, and funding to do so. Measurement at precision and accuracy of current state of the art for cosmochemical analysis.	
Theme 1-C Regolith 2: Quality/ quantity/distribution/form of H species and other volatiles in nonpolar mare and highlands regolith (requires robotic precursor missions).	Robotic in situ measurements of volatiles and organics on the lunar surface and eventual sample return of "pristine" samples.**Enables prospecting for lunar resources and ISRU. Feeds forward to NEA-Mars. Relevant to Planetary Science Decadal survey.**	Enabling	OPEN	Both	Need landed surface mission. Multiple measurements of undisturbed soil at depth at meter and decameter scales (laterally) and 0-2m depth. Need to measure abundance of solar wind gases or H species at the 10 ppm level. Need capability for multiple analyses at different locales and subsurface depths. Notional instruments include neutron spectrometer and a mass spectrometer, heat source for samples, and GCMS (concentrations and species).	Required for stay times > 28 days. Enables thriving industry and enduring commercial opportunities in cislunar space. Dramatically reduces costs and increases capabilities of missions to other destinations beyond cislunar economic activity zone.

Strategic Knowledge Gap	Narrative	Enabling or Enhancing	Status	Exploration Science or Technology	Measurements and Missions Needed to Retire SKG	Notes from 2016 Assessment
Theme 1-C Regolith 3: Preservation of volatile and organic components during robotic and human sampling, handling, storage, and curation.	The volatile record that is preserved in lunar regolith is very fragile and could be easily disturbed during sampling-analysis by robotic and human exploration of volatile polar and non-polar deposits. Methodologies and technologies must be developed to sample, handle, contain, and curate these valuable samples to minimize volatile loss and contamination.	Enabling for short-duration (≤ 28 days) lunar missions and long-term, sustained human operations on the Moon.	OPEN	Both	Ground-based applied science research and technology development. Requires creation and analysis of appropriate simulant materials and studies. Comparison of in-situ and returned samples would definitively address this SKG - sample return from a mare surface, for example.	New SKG for 2016.
Theme 1-D-Polar Resources 1: Extent of Cold Traps.	DIVINER maps show temperature distributions, model stability and evolution of spin axis, mapping of old topographic lows.	Enabling	RETIRED	Exploration Science	LRO Observations have satisfied objective	Continued Diviner observations in 3rd extended mission will improve spatial coverage of polar regions by increasing SNR
Theme 1-D-Polar Resources 2:Correlation of cold traps and permanent darkness (PSR)	Use LRO data to understand thermal environments of partly illuminated areas near poles	Enabling	RETIRED	Exploration Science	LRO Observations have created measurement baselines.	

Strategic Knowledge Gap	Narrative	Enabling or Enhancing	Status	Exploration Science or Technology	Measurements and Missions Needed to Retire SKG	Notes from 2016 Assessment
I-D Polar Resources 3: Geotechnical characteristics of cold traps	Landed missions are required to understand regolith densities with depth, cohesiveness, grain sizes, slopes, blockiness, association and effects of entrained volatiles.	Enhancing	OPEN	Both	Can be addressed partially through remote sensing, additional observations, and data analysis. Requires ground truth at the 10 meter scale (laterally) over 1-5 km baselines. Must determine trafficability, compressibility, rolling resistance, bulk density variations, and grain sizes. These properties need to be verified through in-situ observations. Minimal information will be provided by rover tracks. A scoop with a variety of end effectors could be an interesting assessment tool. In-situ GPR measurements would also have value to characterize subsurface properties. LRO has provided relevant data at the 10-20m scale, particularly LOLA observations for South Pole during Extended Science Missions. Data at the meter scale requires landed rover mission. Some information on surface roughness could be obtained at the 1m scale with an imaging radar.	Geotechnical properties of cold traps remain an open SKG due to a lack of landed mission, although further observations and associated data analysis by LRO can provide valuable new data.
I-D Polar Resources 4: Physiography and accessibility of cold traps (robotic and human).	Needs landed missions to understand slopes, elevations, block fields, cohesiveness of soils, trafficability.	Enhancing for short-duration (≤ 28 days) lunar missions. May be enabling if trafficability is an issue. Enabling for long-term, sustained human operations on the Moon.	OPEN	Exploration Science	Landed surface exploration missions. Can be addressed partially through remote sensing, additional observations, and data analysis.	

Strategic Knowledge Gap	Narrative	Enabling or Enhancing	Status	Exploration Science or Technology	Measurements and Missions Needed to Retire SKG	Notes from 2016 Assessment
I-D Polar Resources 5: Charging and plasma environment within and near PSR.	Landed missions to understand the charge reservoirs (plasma or ground) in the low conductivity environment. Limited plasma flow into PSRs may create poor electrical dissipation for tribocharging objects like drills, rovers, etc. The electrical 'ground' or reference point is not identified. Examine ion entry into PSRs as sputtering loss process.	Enhancing	OPEN	Exploration Science	The electrical "ground" or reference point is not identified. Examine ion entry into PSRs as sputtering loss process. Moving a rover in and out of shadowed region provides ground-truth. Use wire in shadowed and sunlit region to check whether current gets induced. Implications for astronaut safety and long-term maintenance.	
I-D Polar Resources 6: Composition, Form, and Distribution of Polar Volatiles	Water and possibly other exotic volatile species are present in lunar polar regions; must determine the form, concentration (including mineralogical, elemental, molecular, isotopic make-up of volatiles), and distribution of these species and how they vary from depths 0-3 m over distances of 10-100m scales. Required "ground truth" in-situ measurement within permanently shadowed lunar craters or other sites identified using LRO data. Technology development required for operating in extreme environments. Enables prospecting of lunar resources and ISRU. Relevant to Planetary Science Decadal survey.	Enhancing for short-duration (≤ 28 days) lunar missions. Enabling for long-term, sustained human operations on the Moon.	OPEN	Both	Requires ground truth at the 10 meter scale (laterally) over 1-5 km baselines. Landed surface mission. Surface mobility is absolutely essential to be able to provide ground truth to orbital sensor datasets and characterize the regolith concentrations laterally at the 10s of meter scale over baselines of at 1-5 km. Two desirable instruments: (1) Gas Analyzer/ICPMS: Heat the soil, measure and determine the different species for H+ and OH contained within; similar conceptually to Viking GCMS experiments. (2) Neutron Spectrometer: bulk H/OH measurements to the 1-5 ppm level, including the subsurface to at least 2 meters depth. (3) UV/VIS/NIR spectrometer to assess presence of OH- (4) Multi-frequency GPR to assess subsurface distribution.	Previous set of SKGs has been simplified to enhance focus on strategies for closing the SKG. Notional mesurement baselines, guided by LRO results, have now been established and inform desirable classes of measurements.

Strategic Knowledge Gap	Narrative	Enabling or Enhancing	Status	Exploration Science or Technology	Measurements and Missions Needed to Retire SKG	Notes from 2016 Assessment
I-D Polar Resources 7: Temporal Variability and Movement Dynamics of Surface-Correlated OH and H2O deposits towards PSR retention.	Survey surface-correlated OH at >65 degrees through orbital mapping; correlate with exospheric measurements, and use results to determine the temporal and spatial distribution of water and other volatile species in lunar surface-bound exosphere.	Enhancing	OPEN	Exploration Science	More orbital measurements (resolved imaging spectrometer capable of detecting OH and H2O over long temporal baselines) and long-lived ALSEP-style instrument packages required to close this gap.	LADEE measurements were a good first step. CHASE measurements indicate some exospheric H2O might be present. Futurher LRO observations (LAMP, LOLA) might help. Ultimately, long-lived imaging spectrometer with multi-temporal coverage and ALSEP-style surface stations required.
I-D-Polar Resources 8: Subsection f: Earth visibility timing and extent	Understand if Earth is sometimes visible from portions of PSR.	Enabling	RETIRED	Exploration Science	LRO Observations have created measurement baselines.	Can now be deduced using LRO data.
I-E Composition/Volume/Distribution/form of pyroclastic/dark antle deposits and characteristics of associated volatiles	Need to understand the volatile contents of RDMDs, as well as their depth and distribution in order to fully assay resource potential and develop useful processing technologies. Understanding the amount and form of solar-wind implanted volatile species in pyroclastics may inform other SKGs.	Enhancing	OPEN	Exploration Science	Either sample return from RDMD (e.g., Aristarchus) or in-situ measurements. GPR could provide information on depth of mantling deposits.	Need to determine how representative Apollo 17 samples are of other RDMDs (Sulpicius Gallus, Aristarchus Plateau).
I-F. Lunar ISRU production efficiency 1	Determine the likely efficiency of ISRU processes using lunar simulants in relevant environments. Must understand the yields of volatiles versus strongly-bound species. **This is enhancing long duration activity on the Moon and potentially beyond LEO.**	Enabling	OPEN	Technology	TRL 6 flight unit testing with appropriate simulants (basalt, highlands, and pyroclastics) to test various (See Taylor et al., 1991) processes and flight hardware. Results of efficiency testing will play a role in ISRU utilization strategies.	

Strategic Knowledge Gap	Narrative	Enabling or Enhancing	Status	Exploration Science or Technology	Measurements and Missions Needed to Retire SKG	Notes from 2016 Assessment
I-G. Lunar ISRU production efficiency 2	Measure the actual efficiency of ISRU processes in the lunar environment. Highly dependent on location & and nature of the input material This could be tested in the following ways: (1) Produce and store small quantities of hydrogen and oxygen from lunar regolith by melting ice. (2) Demonstrate disposal of heated regolith after processing.(3) Process at high temperature to test techniques for extracting metals (e.g., Fe, Al) from regolith. This is enhancing long duration activity on the Moon and potentially beyond LEO.	Enabling	OPEN	Technology	Landed surface mission. Different techniques and different approaches with different feedstocks are all viable. They must be tested in-situ on the Moon.	Still wide open. Demonstration planned for notional RP mission. Missions similar to the proposed Resource Prospector mission could validate ISRU procedures in lunar environment to feed forward to future lunar activity.