SAMPLING THE SOLAR SYSTEM. A CRITICAL EXPLORATION COMPONENT FOR FUTURE PLANETARY DISCOVERY. C. K. Shearer, Institute of Meteoritics, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, New Mexico 87131. (cshearer@unm.edu).

Introduction: Sample return from a wide range of planetary bodies provides valuable insights into the origin and evolution of the Solar System and identifies potential hazards and resources for future human activities on planetary surfaces. Sample return is a valuable exploration tool as it increases the value of both orbital and surface observations. In 2007, the Curation and Analysis Planning Team for Extraterrestrial Materials was requested by the Director of the NASA Planetary Science Division (PSD) to conduct an analysis of potential linkages between simple and complex sample return missions and to identify those critical investments that would best reduce risk and cost for increasingly complex sample return missions over the next 20 years. Results of this analysis are available at http://www.lpi.usra.edu/captem/sampleReturnWorkGroup.pdf. Here, we expand this analysis to 2050 in light of the most recent PSD decadal survey, observations from previous and ongoing planetary missions, new planetary discoveries, and current NASA goals for human exploration.

Sample Return Mission Styles: There are a variety of mission styles for implementing sample acquisition. *Flyby style missions* acquire samples of material from a planetary body without touching its surface. Most recent missions of this type include Stardust (comet) and Genesis (Sun). These missions used passive collecting approaches, whereas future missions could potentially use more interactive systems. With increasing complexity and durability, this type of mission style could be used to collect materials (e.g., dust) from upper planetary atmospheres (e.g., Mars, Venus) and explosive eruptive and outgassing events on several outer Solar System bodies (e.g., Io, Enceladus). In the *touch-and-go mission style*, samples are acquired by the spacecraft by briefly touching the surface of the body, quickly collecting the sample, and moving to another sample collection site (or body) or returning to Earth. This type of mission is ideal for sampling the surface of small bodies where the gravitational force is negligible, obviating the need for elaborate and expensive descent and ascent systems. Previous and on-going missions such as Hayabusa, Hayabusa 2, and OSIRIS-REx demonstrate this style of sample return. Taken to more complex levels, these styles of missions could incorporate components to better preserve collected samples (e.g. volatiles), subsurface samples, higher sample mass, deploy more sophisticated instruments on the surface, and tour multiple and more distant bodies (e.g., asteroid belt). *Landed surface sampling style missions* require safe landing on a surface, and spending sufficient time on that surface. These missions have the capability of collecting higher sample mass, collecting over a range of sites, landing on a variety of planetary bodies (e.g., comets, asteroids, Moon, Mars, Venus, Mercury, Phobos, Deimos), and deploying surface instrument packages. This style of mission has the capability of returning regolith, rocks, ices, organics, and atmosphere. Collecting many of these materials will require advance collection, contamination prevention, preservation, and curation technologies. Previous sample return missions of this style include the Luna missions carried out by the Soviet Union and the Apollo missions in the 1970s. The Luna missions were the only successful robotic sample return missions of this style.

Within and between each style of mission there are different levels of complexity. There are common technological linkages among mission styles and among planetary destinations. Technological overlap also exists between robotic and human exploration.

Examples of the increasing complexity of mission styles: NASA has a recent heritage of *flyby sample return missions*. The success of these missions provides a foundation for increasing complexity and destinations between 2017 and 2050. For example, a mission of intermediate complexity may involve sampling in the inner

Solar System using a projectile fired from the spacecraft and collected from the resulting plume. An intermediate mission could provide the capability to preserve volatile elements. A flyby mission of much higher complexity may involve sampling the atmosphere of Venus or Mars, plumes from the moons in the outer Solar System, or rings of the giant planets.

NASA does not have a heritage of *landed surface sampling style missions.* However, landed missions on Mars, developing technologies for the Mars ascent vehicle, rovers, sample manipulation capabilities (e.g., scoop, sieve, corer, rake), and orbital rendezvous, feed forward to other sample return missions. Simple missions may involve sampling outside gravity well from a static lander with direct return to Earth (small bodies). Missions of intermediate complexity may involve sampling of the surface of moderately hostile environments/planetary bodies (Moon, Mercury, Mars) with a static lander, simple sample selection and manipulation, and either direct to Earth or rendezvous return. More complex missions may involve higher sample mass, roving capabilities, a variety of sample manipulation and selection tools, more sophisticated sample preservation capabilities, and operation in highly hostile environments (e.g., Venus, planetary cold traps).

Commonality among missions: To efficiently reduce risk and cost of increasingly more complex sample return missions in the next decades, it is critical to advance technologies that have overlap among missions. There are several types of technology/capability linkages that are either appropriate for several missions with minor modifications, or feed forward to more complex missions. There are linkages between sample return and non-sample return missions such as precision landing and hazard avoidance. There are linkages among different styles of missions (flyby, touch-and-go, surface landing) such as reentry and hard-landing on Earth, reducing contamination, and preserving environmentally sensitive samples. There are linkages with a single style of mission to a variety of planetary bodies such as sample collection, manipulation, and storage on a planetary surface or sample collection and verification of success during a touch-and-go mission. Finally, there are linkages between sample return and human exploration such as rendezvous around a distant planetary body and return to Earth.

There are technologies that are specific to a single planetary body (i.e. Mars Ascent Vehicle, Mars rendezvous). Investment in these technologies will substantially reduce risk to a single sample return mission and perhaps will feed forward to more complex missions to sample this body (e.g., human missions) and reduce both cost and risk.

Initial conclusions for the future of sample return: Sample return is a vital component to any future planetary science exploration program. A variety of mission styles have application to most Solar System bodies. Higher risk and cost is commonly associated with sample return missions relative to other types of Solar System exploration missions. This is a result of sample return missions commonly being more complex and the necessity for the spacecraft to return to its point of origin. However, sample return has many important attributes. First, it is the closest approximation to a human exploration mission. Second, samples provide a unique perspective of a planetary body that cannot be obtained by any other mission approach. The mitigation of cost and risk of the mission and its development puts an even higher priority on early technology development than for more conventional mission types. Technology linkages among different types of planetary missions feed forward to increasingly complex sample return missions. Investing in developing and flying these technologies will increase the rate of success of future sample return missions and lower the overall cost in the decades to come.