TECHNOLOGY PLANNING FOR NASA's FUTURE PLANETARY SCIENCE MISSIONS Patricia M. Beauchamp[1], James A.Cutts[1], Leonard A. Dudzinski[2] and Carolyn Mercer[2], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109, USA (pbeaucha@jpl.nasa.gov), [2]NASA Planetary Science Division, 300 E Street SW, Washington D.C. 20546-0001

Introduction: As we look far into the future and imagine what we might be doing in planetary science in 2050 and beyond, we must also understand how to plan for the technologies that will be required to fulfill our future scientific goals. The technology planning processes must be an iterative, dynamic one that can be updated, particularly when the knowledge base changes. At the request of the NASA Planetary Science Division we developed such a technology planning process that delineates the technological capabilities needed for near, mid-term and future missions as defined by the science and missions recommended by the Decadal Survey in *Visions and Voyages*[1] and updated by the planetary science community through the assessment groups as science knowledge has evolved. This allows the PSD to keep up with the changing face of planetary science and enables a nimble response to developing key technologies.

Goals: The primary goal of the technology planning process was to provide upcoming planetary science missions, as prioritized in *Visions and Voyages*, with the technologies required to successfully implement them (preferably, at lower cost and higher efficiency). It was also essential to identify the longer-term mission needs and the technology priorities to satisfy them.

Approach: It became clear that in order to achieve these goals the PSD had to diversify their technology development program and ready all technologies for upcoming future missions. Important in achieving this was to determine the status of the current portfolio and how PSD could improve portfolio diversification by determining what technologies are missing from the portfolio. Folded into that were considerations of how to maintain current capabilities and facilities for advancing and testing technologies. Finally, it was necessary to identify partners for PSD to augment the funding required to develop needed technologies.

Figure 1 illustrates the overall scheme employed in the technology planning process. Scientific goals are the major driver for developing technologies. Additional requirements come from technology needs identified during specific mission studies. Incorporated into the plan are existing 'push' technologies from the community planning and assessments documents prepared by technologists and the actual technology development work that is being conducted in a range of different programs internal and external to the PSD.

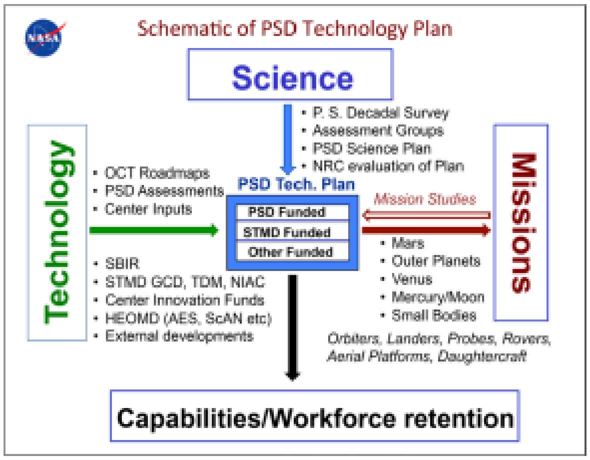

Figure 1: *PSD Technology Planning Elements*

To round out the information incorporated into our thinking, we conducted an assessment of disruptive technologies. These are technologies that would not necessarily show up in earlier documents or in a needs assessment and might not be a major part of existing technology programs but could radically change the way in which we conduct planetary exploration and potentially create totally new ways of exploring planets. The main focus in the current plan was miniaturization and, in particular, the impact of CubeSat technologies and applications to planetary exploration and the future needs of SmallSats (100–200 kg capable of planetary exploration, either as daughter-ships or launched with planetary missions as stand-alone spacecraft or landed elements).

Output: The primary output of this technology planning process is a technology gap analysis for all the mission types that are under consideration, which enables the PSD to develop a strategy for filling these gaps. Capability gaps are derived from analyzing the individual mission types and then looking for common capabilities needed across the missions and determining what was missing. An example of this is given in Table 1, where the color-coding indicates the maturity level given the current technology programs.

The technology gaps represent a menu of possibilities for PSD to examine as it formulates its technology program and advocates funding by other directorates. There are far more programs than there are resources to support them. Once the technologies have been identified, the PSD sets priorities for funding and/or co-funding and develops technology roadmaps delineating goals and objectives. In addition to the factors discussed earlier, answering the following questions aids in prioritizing:

1) Is this enabling or enhancing for a PSDS mission?
2) Is it applicable to multiple missions?
3) Will this technology save PSD resources in the short- or long-term?
4) What are the resource requirements?
5) What is the probability of success?
6) Can it be completed in time for the mission?

The ultimate goal is to infuse new technologies into scientific missions with minimal risk, so the critical final steps in any technology planning process involve managing the development of these prioritized technologies, assessing the readiness levels of the technology at all stages to monitor progress, and, importantly, planning for infusion into missions. All of these steps must be taken to ensure that the technology planning and development process is robust and that future missions reap the benefits of technological advances.

Conclusion: Significant and <u>sustained</u> technology investments throughout the next few decades are necessary to accomplish the existing planetary scientific objectives. This can only be achieved if a well-conceived, agreed-upon technology planning process exists and is practiced. The NASA PSD has embarked upon a technology planning process that will enable the development of novel scientific missions, whether they are competive or assigned missions. The process is flexible enough to accommodate improved scientific knowledge and the changes in direction that might result from those insights, as well as changes in direction that could arise from political shifts or technological breakthroughs. The process has now moved to a phase where detailed plans are being developed for those capabilities deemed to be of highest priority.

References:

[1] Planetary Science Decadal Survey—Vision and Voyages, National Research Council 2011

	Technology Information	Near-Term Missions						Mid-Term Missions						Far Term-Missions				
	Capability/Functionality	Small Bodies	Outer Planets	Venus	Mars	Moon	Common-ality	Small Bodies	Outer Planets	Venus	Mars	Moon	Common-ality	Small Bodies	Outer Planets	Venus	Mars	Common-ality
System Technologies	In Space Propulsion						MOD						MOD					MOD
	Aerocapture/Aeroassist	NA		Aerobrake			LOW	NA					TBD	NA				MOD
	Entry including at Earth					Earth	HIGH						HIGH					MOD
	Descent and Deployment			Plains			MOD			Tessera			MOD					MOD
	Landing at target object						LOW						MOD					MOD
	Aerial Platforms			Balloon	Rotorcraft		LOW		Balloon	Balloon			MOD			Balloon		LOW
	Landers - Short Duration						NA											LOW
	Landers - Long Duration						NA											LOW
	Mobile platform- surface near surface						NA											
	Ascent Vehicle						NA						LOW					LOW
	Sample Return						NA						LOW					LOW
	Planetary Protection						HIGH						MOD					MOD
Subsystem Technologies	Energy Storage- Batteries						HIGH						MOD					LOW
	Energy Generation - Solar																	MOD
	Energy Generation - Radioisotope Power											?	LOW					MOD
	Thermal Control - Passive						LOW						LOW					LOW
	Thermal Control - Active																	
	Rad Hard Electronics						LOW						LOW					
	Extreme temperature mechanisms						LOW						LOW					LOW
	Extreme temperature electronics						LOW						LOW					LOW
	Communications						HIGH	Optical	Optical	Optical	Optical		HIGH	Optical	Optical	RF-HT		HIGH
	Autonomous Operations						HIGH						HIGH					
	Guidance, Navigation and Control						HIGH						HIGH					HIGH
Insutrument	Remote Sensing - Active						MOD						LOW					HIGH
	Remote Sensing - Passive						HIGH						HIGH					HIGH
	Probe - Aerial Platform						LOW						MOD					LOW
	In Situ - Space Physics																	
	In Situ Surface - Geophysical												LOW					LOW
	Sampling						LOW						LOW					HIGH
	In Situ Surface - Long Duration - Mobile						LOW						LOW					LOW

TRL Maturity Legend	
	Very High. Ready for flight. Same as TRL 6
	High. Funding is in place to advance to Very High in one to four years
	High. Limited development and testing still needed
	Moderate. Major R&D effort needed.
	Low. Major R&D effort needed with notable technical challenges

Table 1: *Maturity of technology capabilities for implementing planetary science missions (as of 2015). Typically, for Near-Term missions the maturity is high or very high and in many cases funding is in place to achieve the maturity needed for flight. For Mid-Term and Far-Term mission there are increasing umber of instances where the technology maturity is moderate or even low. The columm marked Commonality indicates the degree of similarity in the capabilities needed across the five categories of target object.*