Overview of Technology Needs for Planetary Science Missions

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Context

- The technologies discussed represent a summary of those presented to the Decadal Survey panels and committee in community white papers and presentations
  - different communities identified technologies required to achieve their scientific goals (with some overlap)
    - OPAG
    - MEPAG and Mars Program Office
    - VEXAG
    - SBAG
- Presentation styles differed
- Technologies are often based on ‘design reference missions’ commissioned by NASA and the community.

Outer Planet Technologies

Table 2. Summary of Technologies required for Outer Planet Missions

Technology Development	Missions								
	Titan Orbiter *In Situ* Sampler	Neptune Orbiter	Neptune Flyby to KBO Flyby	Uranus Orbiter	Saturn Probe	Jupiter Probe	Neptune Probe	Enceladus Sample Return	Europa Lander
Power									
RPS	E	E	E	E	e	e	*E	E	e
Low intensity, low temperature solar arrays				e	e	e			
Transportation									
Electric propulsion	e	E	e	e	e		e	e	
Aerocapture		E		E					
Communications									
Expanded Ka capability	e	e	e	e			e		e
Improved proximity links	e				e	e	e	e	e
Improved UHF systems	e				E	e	E	e	e
Planetary protection measures	e							e	e
Mobility and Landers	E								e
Autonomy	e							E	E
Extreme environments	e				e	e	e	e	E
Entry systems (includes TPS)	e	E		e	e	E	E	E	E
Planetary probe S/C technologies					e	e	E		
***In situ* sensing of surface and atmospheres**	E				e	E	E	E	E
Components and miniaturization	E	e	e	e	e	e	E	E	E
Remote sensing	e	e	e	e	e	e	e	e	e

Legend: E = enabling, e= enhancing (reduces cost and/or risk, increases performance) Spacecraft Systems); *need RPS or radio science for carrier-relay spacecraft that delivers probe.

Table 1. Technology Priorities for Outer Planet Exploration.

	Technology	Priority	Comments
Spacecraft Systems	**Power**	UP	Radioisotope power systems would be needed for the next Titan/Enceladus Flagship mission, requiring a sufficient supply of ^{238}Pu. Advances in power conversion efficiencies would reduce the quantity of ^{238}Pu needed for a given power requirement, along with a mass savings.
	Transportation	1	Electric propulsion would be strongly enhancing for most OP missions, including a Titan/Enceladus Flagship, and aerocapture technologies would enable a Neptune orbiter mission. These technologies provide rapid access, increased mass and/or lower mission risk.
	Communications	1	The science return from every mission would benefit from improvements in communications infrastructure, including Ka band and direct-to-Earth communications. *In situ* exploration with orbital assets would be greatly enhanced by improved proximity links.
	Planetary protection	2	New planetary protection approaches and technologies will be required to meet the anticipated requirements for *in situ* exploration to targets of interest for astrobiology.
In Situ Exploration	**Mobility and landers**	1	Access is critical to *in situ* exploration central to a Titan Flagship mission concept, making various types of mobility systems enabling, e.g., montgolfière balloons for Titan. Advances in autonomous mobility technologies could also provide alternatives for various New Frontiers mission concepts. Landers required with sampling acquisition and handling for Titan lake, dune & cryovolcanic regions.
	Extreme environments	1	The proposed missions span a number of diverse environments, requiring technology advances in fields ranging from low T and P, to high heat flux and pressure during atmospheric entry. *In situ* sampling and instruments would benefit from technology program.
	Entry systems	2	New propulsive landing systems would enable operations on satellites without atmospheres. Investments required in key technologies for entry systems and planetary probes :extreme environment systems, miniaturized and low power integrated sensors, transmitters, and avionics, thermal materials, power management systems, entry/descent/landing technologies & on-board processing.
Instruments	***In situ* instrument systems**	1	New technologies and instruments would be required for improved science return to targets of astrobiological interest, enabling the proposed Titan/Enceladus Flagship mission. The instrument technologies would require associated development in sample acquisition and handling systems. Advances in thermal management are critical. Instruments required for Atmospheric probe missions.
	Components and miniaturization	1	Every mission is either strongly enhanced or enabled by improvements in miniaturization and advanced component design. A Titan/Enceladus Flagship mission would be strongly enhanced by development of miniature long-lived, low power cryogenic electronics.
	Remote sensing instrument systems	2	All missions with orbital or extended aerial operations would be strongly enhanced by improved technologies for passive and active remote sensing and radio science. High resolution and sensitivity instruments that are low in mass and power are required for a Titan/Enceladus Flagship.

UP Ultimate priority—Without new Pu-238, no further exploration beyond Jupiter will occur subsequent to EJSM.

1 Highest priority—New developments are required for all or most future OP missions.

2 High priority—Either the applications are more limited or NASA could effectively leverage existing work.

Specific OPAG Recommendations

POWER

OPAG strongly recommends that NASA work with the relevant agencies to ensure that Pu-238 production provides enough material for future OP missions, and fully support the validation of the ASRG system for OP applications, including the development of small (milli-/multi-watt) radioisotope power generators for sensor networks. In addition, NASA should adapt and complement industry-developed advanced solar cell and array technology program, advanced battery technology, and advanced power conversion and distribution technologies program for OP missions.

TRANSPORTATION

SMD should continue its development of EP components and consider development of an off-the-shelf multi-mission SEP module (not only for the OP missions) that would be available to users with acceptable cost and risk constraints. Aerocapture development should focus on needs identified for Titan and Neptune, and risk reduction resulting in flight readiness is strongly encouraged to open up this mission enhancing, and for Neptune, enabling technology.

COMMUNICATIONS

NASA should expand the funding of communication and radio science technologies required for the OP, especially making Ka-band operational and furthering proximity and direct-to-Earth communication technologies.

PLANETARY PROTECTION

OPAG strongly recommends that PP requirements to the OPs be defined early, especially for Titan and Enceladus, and that investments be made to jointly develop solutions and technologies for PP and contamination control.

IN SITU PLATFORMS

OPAG recommends a sustained investment in this decade that would result in the demonstration of technical readiness for launch of a Titan balloon, and that NASA support the development of key autonomy capabilities required for a Titan balloon. Further, OPAG recommends that NASA invest in focused studies of Titan lander concepts and associated entry, descent and landing technologies, and mature the technologies necessary for surface sampling in different environments.

ENTRY SYSTEMS AND PLANETARY PROBES

OPAG recommends investments be made in key technologies for entry systems and planetary probes; extreme environment systems, miniaturized, low-power integrated sensors, transmitters, avionics, thermal materials, power management systems, entry, descent and landing technologies, and onboard processing.

EXTREME ENVIRONMENTS

OPAG recommends that NASA fund a technology program focusing on designing and testing low (and high) temperature components and subsystems that could be used throughout the spacecraft (or probe) and instruments. Initiating this program as soon as practicable would have a major impact on the feasibility of a Titan Flagship mission and would also enable New Frontiers missions.

SCIENCE INSTRUMENTS

OPAG recommends that NASA initiate a well-funded instrument development program that goes beyond the present low TRL instrument development programs. To prepare for future OP missions, NASA should establish a focused program that matures in situ and remote sensing instrument system concepts to TRL > 6.

Mars Technologies

Multi-element MSR Campaign Technologies

- **Tall pole technologies**
  - Defined as ***key*** technologies that require ***significant*** development
  - Sample acquisition and encapsulation (MAX-C)
  - Mars ascent vehicle (MSR lander)
  - Back planetary protection (MSR orbiter)

- **Other key challenges**
  - Round trip planetary protection (MAX-C)
  - Mobility capability (MAX-C and MSR fetch rover)
  - Terrain-relative descent navigation (MAX-C and MSR lander)
  - Rendezvous and sample capture (MSR orbiter)

Sample Acquisition and Encapsulation

Target Requirements

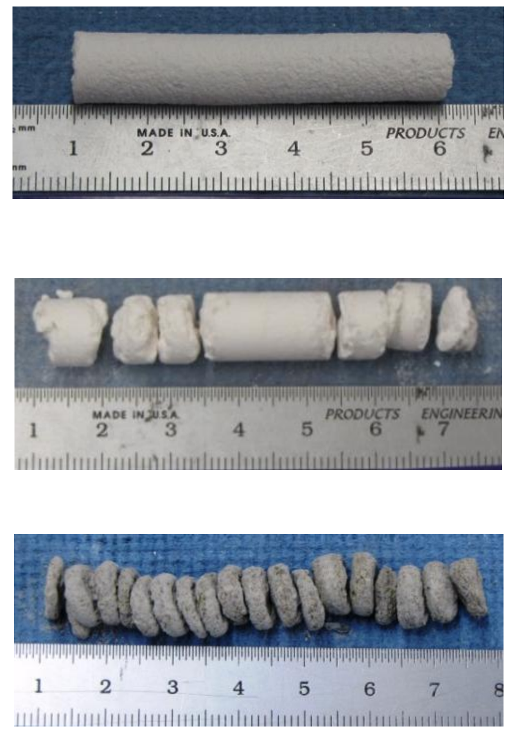
Consistent with MEPAG Next Decade Science Analysis Group (ND-SAG)

Science

- Acquire~ 20 rock cores with dimension approximately 1 cm wide by 5 cm long
- Store and seal samples in individual tubes
- Provide capability to reject a sample after acquisition
- Measure the sample volume or mass with 50% accuracy

Engineering

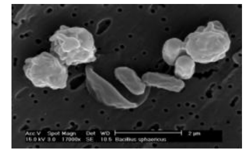
- System mass to be ~30kg
  - Includes robotic arm
- Sample on slopes up to 25 degrees
- Sample from a ~300kg rover



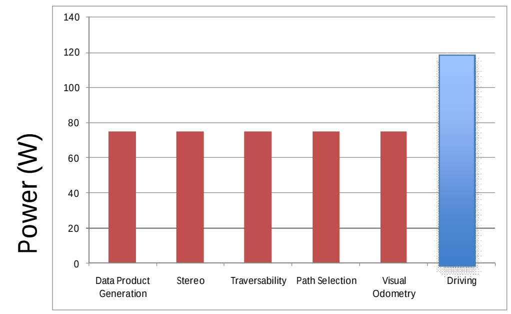
Examples of acceptable samples

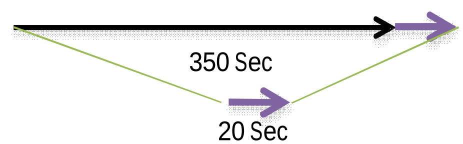
Other Key Challenges for Mars Missions

- Round trip planetary protection (MAX-C)
  - Objective: Avoid false positive life detection
  - Approach: Clean assembly, bio-barrier, analytical tool to compute overall probability of contamination
- Mobility capability (MAX-C and MSR fetch rover)
  - Objectives: Increase average rover speed and develop lighter/smaller motor controller
  - Approach: Use FPGAs as co-processors and develop distributed motor control
- Terrain-relative descent navigation (MAX-C and MSR lander)
  - Objective: Improved landing robustness
  - Approach: Use terrain-relative navigation approach for avoiding landing hazards. Leverage NASA ALHAT project
- Rendezvous and sample capture (MSR orbiter)
  - Objective: Locate, track, rendezvous, and capture OS in Mars orbit
  - Approach: Update system design, develop testbeds, and perform tests. Leverage Orbital Express capability

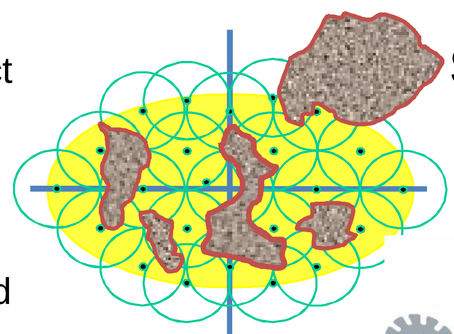


Round Trip PP

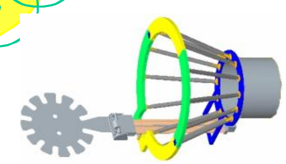




50 cm rover move timeline



Safe Landing



Sample Capture

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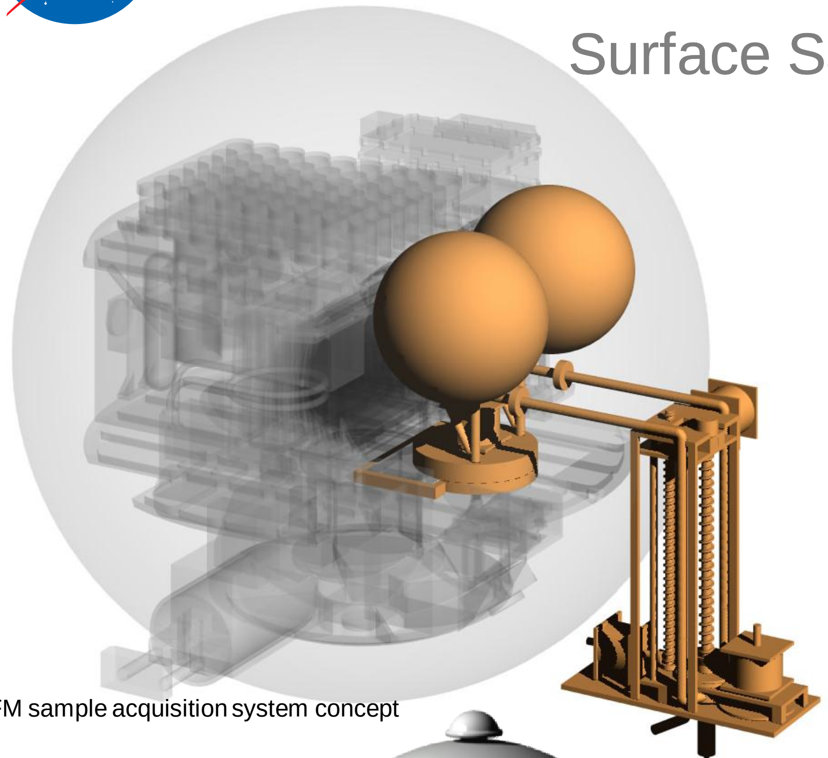
Technologies For Future Venus Missions

High Priority Technologies



VFM sample acquisition system concept

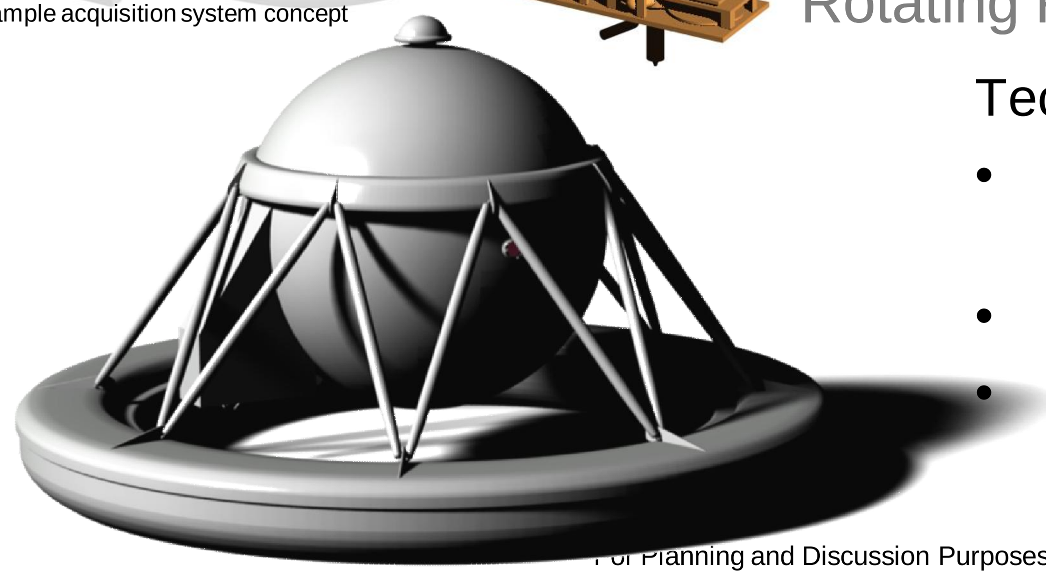
Surface Sample Acquisition & Handling (VDRM)

Technology Development Needs

- surface sample acquisition system at high temperatures and pressures
- requires development for NASA

TRL 2 to 3 Priority HIGH

Rotating Pressure Vessel (VDRM)

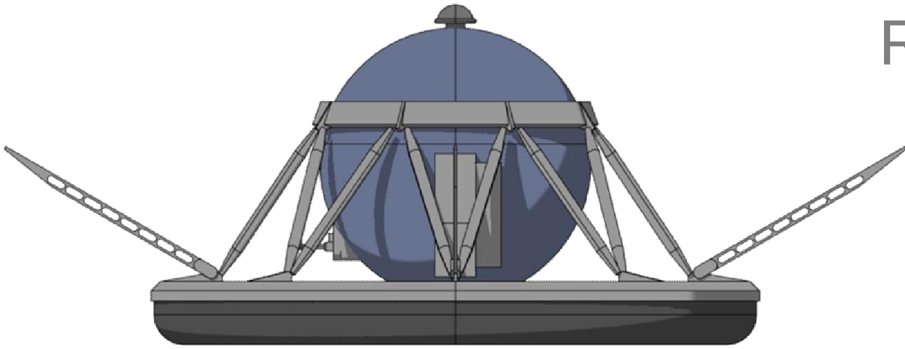


Technology Development Needs

- full scale design and testing needed
- with a driver motor and
- mounted sampling system

TRL 2 Priority HIGH

High Priority Technologies



VFM lander with outriggers

Rugged-Terrain Landing (VDRM)

Technology Development Needs

- design and test a landing system
- accounting for a large variety of unknown landing hazards
- using parachutes

TRL 2 Priority HIGH

Small JPL Venus environmental chamber for testing materials and components (with window and electrical ports)

Venus Test Facility (VDRM)

- large test chamber doesn't exist
- full scale *in situ* elements testing (probe/lander)
- transient conditions and composition

TRL 2 to 6 Priority HIGH

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VEXAG Conclusions & Recommendations

- VEXAG recommends investments in key technologies to enable future Venus missions.
- The highest priority technology items, in line with the VDRM, are:
  - a sample acquisition and handling system,
  - a rotating pressure vessel,
  - a rugged-terrain landing system, and
  - a large scale Venus test chamber facility.
- A future Venus Flagship Mission could be further enhanced by
  - longer operating lifetimes on the surface.
- For this, development of additional technologies are needed, including
  - a Venus specific Radioisotope Power System, coupled with active cooling
  - high temperature tolerant components (e.g., sensors, actuators, and electronics)
- Other mission architectures could be enabled by technologies for
  - Seismometry; metallic bellows for near surface mobility; and a multi-balloon system for a future Venus sample return mission

Small Bodies Technology Recommendations

Primitive Bodies technology requirements vary with destination

- For primitive bodies such as comets and asteroids, the technologies required relate to the type of object studied and the mission scenario that enables the discoveries. For NEO Sampling, need
  - deployable assets (e.g., penetrators, rovers) for microgravity environments.
- Technologies for Main Belt Asteroids and Trojans investigations center on:
  - propulsion,
  - telecommmunications
  - Sensing and landing packages,
  - proximity operations
  - sampling mechanisms.

Small Bodies Technology Recommendations

- The strategy for Comet Exploration involves a strong technology development program that can enable sampling from depth in the nucleus, improved in situ analysis, and the return of nucleus material to Earth. Improvements should be developed
  - in S/C power systems,
  - propulsion technologies,
  - low power/lightweight instruments, including those that probe structure of the nucleus.

- The small satellites missions require new technologies in:
  - propulsion,
  - sensing,
  - guidance and control,
  - sampling
  - autonomy

Small Bodies Technology Recommendations

- The exploration strategy for the Ice Dwarf Planets would hasten development of mission-enabling technology in areas similar to the outer planet technology recommendations:
  - Electric power - ASRGs,
  - ^{238}Pu production;
  - Navigation - long distance ranging, autonomous GN&C;
  - Low mass flight systems and instruments and maintaining very deep space communications capabilities.
- Centaurs and TNOs missions require improved power systems for outer-SS trips.
  - Nuclear power would facilitate multi-object missions.
- Interplanetary Dust investigations require development of technologies for :
  - IDP collection and analysis and instruments that can monitor and accurately measure the zodiacal light.

Summary of AG Recommendations

Technologies required vary considerably with mission destination. Critical items are:

- development of power and propulsion systems that can take experiments to the far reaches of the solar system
- development of capabilities to ensure Mars samples can be returned to Earth safely
- Development of ‘program’ specific technologies including in situ technologies that can enable experiments on Titan, Venus, small bodies and eventually Europa.
- Aerocapture and planetary probe technologies also need to be advanced in order to provide a wider range of mission concepts to the scientific community

Additional Recommendation being considered outside of the AG's.

- Although none of the community assessment groups have high-lighted the need to re-develop nuclear reactors for space applications, it is clear that this is an alternative path in the event that ^{238}Pu production is not immediately forthcoming.
- Small nuclear fission reactors, using ^{235}U rather than ^{238}Pu are feasible for many robotic missions and recent developments in thermoelectric technology should allow simpler and more mass-efficient design.
- Use of such a reactor could enable more capable missions and allow use of electric propulsion at extreme solar distances, which could facilitate rendezvous and orbit insertion and possibly increase delivered mass for many missions.
- In addition, it could obviate the need for gravity assists to outer planets and provide frequent launch opportunities.
- Nuclear thermal propulsion, using hydrogen as the working fluid, is also being considered for the manned mission to Mars and if we see robotic exploration as a first step toward combined human-robotic exploration then the development of high Isp, high thrust propulsion is also required.

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