Outer Planet Assessment Group (OPAG) Technology Priorities for Outer Planet Exploration

Decadal Survey Giant Planets Panel Meeting October 26th, 2009

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Topics covered

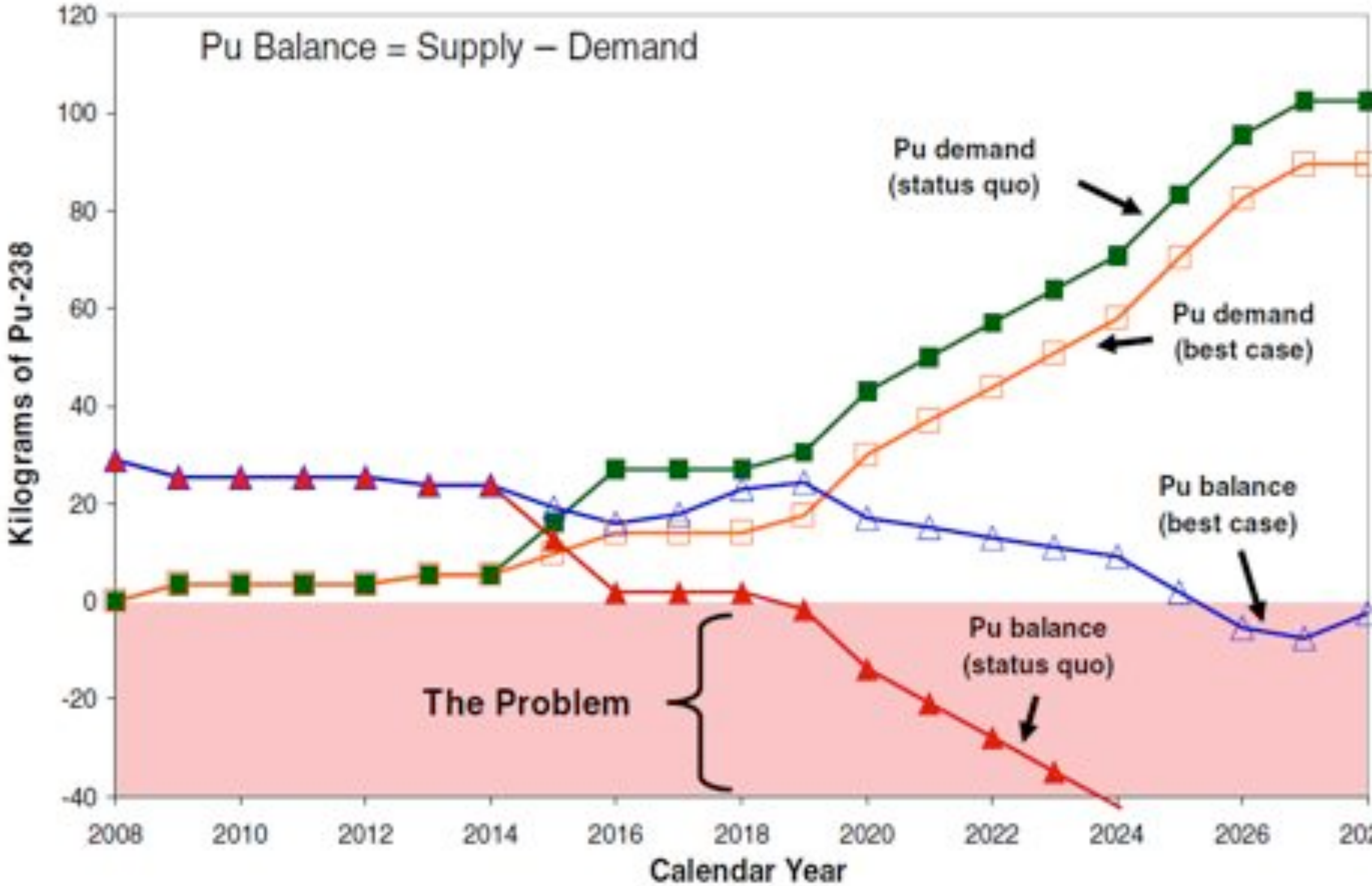
- Summary of OPAG Science Recommendations
- OPAG Top Seven Technology recommendations
- Priorities
- Summary
- Specific List of OPAG Recommendations

OPAG Science Recommendations

- **OPAG recommends that the Decadal Survey explore the possibilities for a program structure/categorization that could allow 'small flagship' class missions to be considered.**
- **OPAG strongly endorses the prioritization by NASA of the Jupiter Europa Orbiter (JEO) as the next Outer Planets Flagship and as part of the Europa Jupiter System Mission (EJSM) with ESA.**
- **OPAG strongly endorses approval by NASA of the Cassini Solstice Mission, including the Juno-like end-of-mission scenario.**
- **OPAG advocates the need for a focused technology program for the next Outer Planet Flagship Mission, which should be to Titan and Enceladus, in order to be ready for a launch in the mid-2020s.**
- **New Frontiers class missions that should be considered in the interim include (but *not in priority order)* a shallow Saturn probe, an Io observer, a Titan *in-situ* explorer or probe, a Neptune/Triton/KBO flyby and a Uranus Orbiter**
- **Support for underlying Research & Analysis, Laboratory Studies, and Earth-based observations should continue.**
- **Effective international involvement is strongly encouraged in the planning, development, and analysis phases of all space missions to the Outer Solar**

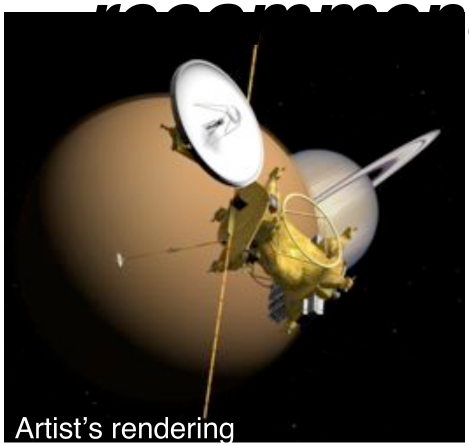
OPAG Top Seven Technology recommendations

1. NASA should work with the relevant agencies to ensure that Pu-238 production is restarted and provides enough material for future outer planet missions. In particular, NASA should flight-qualify ASRG power systems.



(Hoover et al. 2009. *Radioisotope Power Systems: An Imperative for Maintaining U.S. Leadership in Space Exploration. National Academies Press, ISBN 0-309-13858-2)*

OPAG Top Seven Technology recommendations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2. A focused technology program for the next Outer Planet (OP) Flagship mission should be initiated to ensure readiness for launch in the mid-2020s. Current planning indicates a mission to Titan/Enceladus will be highest priority. NASA should fund:

- **risk reduction of the montgolfière balloon element**
- **autonomy capabilities to maximize science return of balloon element at Titan**
- **landing technologies required for sampling the high latitude lakes, dunes and cryovolcanic regions**
- **components for operation in the 90 K Titan environment**
- **in situ sample acquisition and sample handling in 90 K Titan environment. Also instruments (see #7).**

OPAG Top Seven Technology recommendations

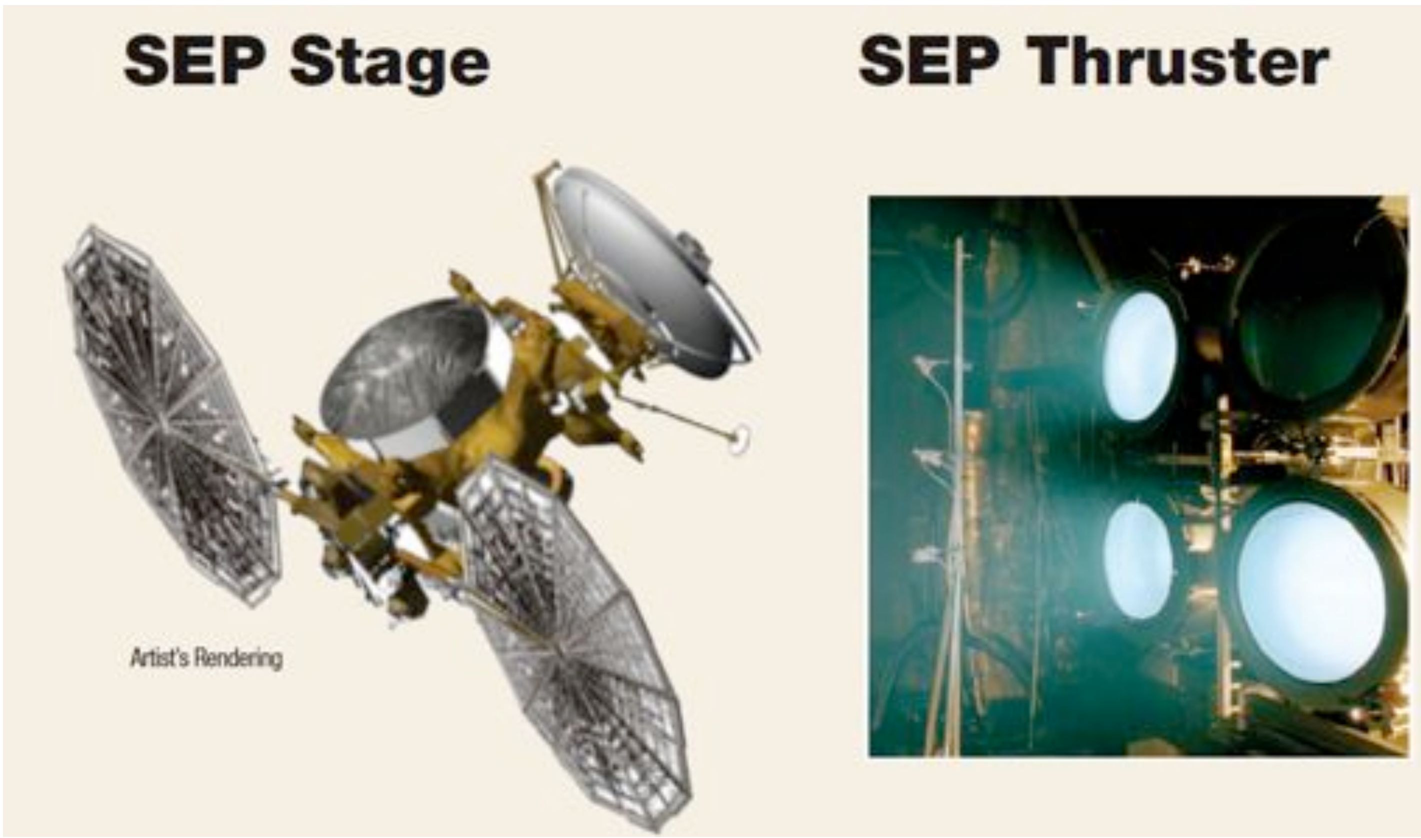
3. NASA should expand the funding of communication and radio science technologies required for the outer planets, especially making Ka band operational and furthering proximity and direct-to-Earth communication technologies. In addition, it should also sustain and accelerate DSN antenna arraying.

Meeting the Challenge of Outer Planets Telecom

- Ka-band (higher frequency)
- Larger ground and space antennas (and arrays)
- Higher power flight transmitters
- Next generation flight transponders
- Precision Radio Science integrated into Telecom
- Optical Communications

OPAG Top Seven Technology recommendations

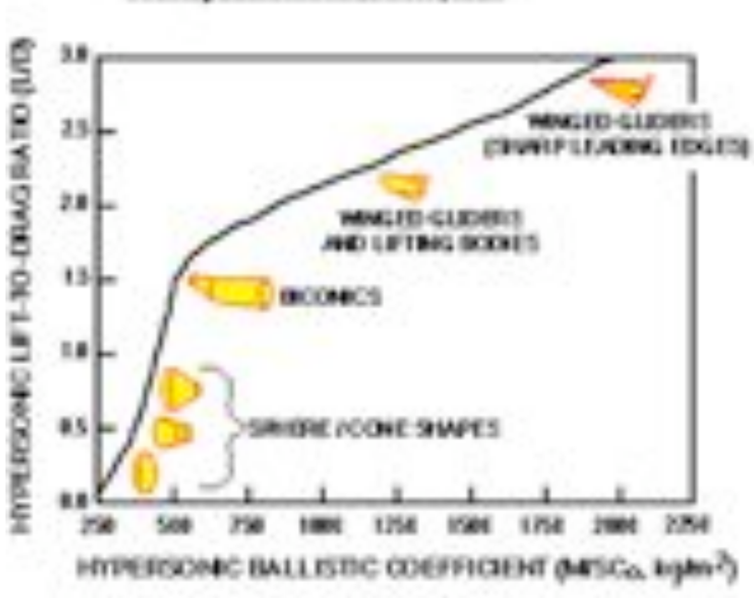
4. NASA should continue to invest in development of underlying technologies (thrusters, power and control, propulsion technologies) for solar electric propulsion, to bring these systems to flight readiness and to make the capability affordable to and within the risk postures of different mission classes.



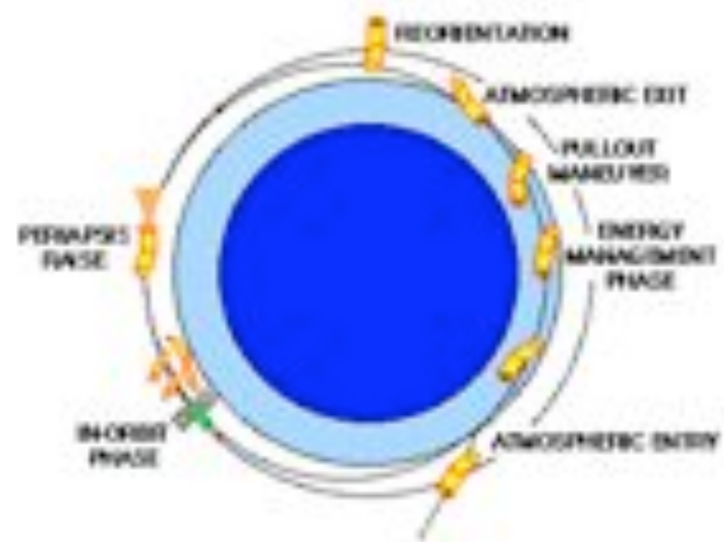
OPAG Top Seven Technology recommendations

5. NASA should invest in aerocapture technologies and consider a space-flight validation of aerocapture in advance of the decision points of identified missions.

Entry Vehicle Shapes



Aerocapture Flight Plan



Ref: Advanced Space Propulsion Concepts, JPL Website.

OPAG Top Seven Technology recommendations

6. **For planetary probes, OPAG recommends investment in the development of alternative thermal protection systems (TPS) materials, and periodic limited manufacturing and testing demonstrations to ensure heritage TPS manufacturing is kept current.**

Table 1. Candidate ablative TPS materials for Outer Planet probe applications

Density	TPS	Supplier	Flight Qual or TRL	Potential Limit		Mission Set				
				Heat flux, W/cm²	Pressure, atm	Saturn Pro-grade	Saturn Retro-grade	Neptune Direct	Neptune Aerocapture	Jupiter High Latitude (Pro-grade)
FOREBODY HEAT SHIELD										
Low-Mid	PICA	FMI	Stardust	~ 1200	< 1	✖	✖	✖	✖	✖
	Avcoat	Textron	Apollo	~ 1000	~ 1	✖	✖	✖	✖	✖
Mid	ACC	LMA/ C-Cat	Genesis	> 2000	> 1	◡	✖	✖	✖	✖
	Mid-density carbon phenolic (0.8-1.0 g/cm³)	Several capable, none active	TRL 3	> 2000 < 5000	> 1	◡	✖	✖	✖	✖
	PhenCarb family	ARA	TRL 5-6	> 2000 < 5000	> 1	◡	✖	✖	✖	✖
High	3D Woven QP	Textron	DOD TRL 3	≥ 5000	> 1	◡	✖	✖	✖	✖
	Heritage Carbon Phenolic (TWCP & CMCP)	Several capable, none active	Venus, Jupiter	10,000-30,000	>> 1	●	●	●	●	✖

Ref: WHITE PAPER TO THE NRC DECADAL SURVEY OUTER PLANETS SUB-PANEL Thermal Protection System Technologies for Enabling Future Outer Planet Missions *by* Ethiraj Venkatapathy* (Lead), James Arnold**,Bernard Laub*, Helen H. Hwang*,Christine E. Szalai***, Joseph L.

OPAG Top Seven Technology recommendations

7. NASA should achieve a better balance between component development, in situ and remote sensing (active and passive) instrument definition, and instrument development, with a focus on demonstrating complete instrument systems and bridging the gap to flight. An OP instrument program should focus on developing and maturing low mass/power instrument systems that have high resolution and sensitivity, raising the TRL to >6.

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.