TECHNOLOGIES FOR MISSIONS TO OCEAN WORLDS. L H. Matthies, M. M. Abid, P. G. Backes, L. Del Castillo, B. H.Wilcox, M. A. Jones, P. M. Beauchamp, J. A. Cutts, Jet Propulsion Laboratory, California Institute of Technology, MS 321-550, 4800 Oak Grove Drive, Pasadena, CA 91109, Larry.H.Matthies@jpl.nasa.gov,

The FY16 Budget Proposal from the Appropriations Committee directed NASA to create an Ocean World Exploration Program whose primary goal is to discover extant life on another world using a mix of Discovery, New Frontiers, and Flagship class missions consistent with the recommendations of current and future Planetary Decadal surveys [1]. The prime targets of such a program are the outer planet moons Europa, Titan, and Enceladus. As part of a broad initiative to increase technology development activities in support of planetary exploration, NASA has established technology goals for these Ocean Worlds Exploration targets.

Since missions to the outer planets invariably take decades to come to fruition, these technologies will be needed for missions well beyond 2050. This paper describes the Technology Roadmaps developed for five of these Ocean Worlds Technologies. Four of these deal with the development of key capabilities for future Ocean Worlds missions: pin-point landing on Titan, subsurface ice acquisition and handling below 0.2 m on all targets, ice sample return with cryogenic preservation, and planetary protection, also for all targets. The remaining technologies deal with survival and operation of both electronic and mechanical systems in the environments of Ocean Worlds.

The focus of roadmapping effort has been on three time frames: Near Term, Mid Term, and Far Term, which broadly considered embrace the time for Planetary Science Visions 2050. Not included in this assessment are the technologies which are being employed in the Europa Mission that is currently under development, involving a Jupiter orbiter which makes repeated flybys of the moon, or the Europa Lander mission which is currently in a study phase.

Pin-Point Landing on Titan: For entry, descent, and landing (EDL) designs like the Huygens Probe, which had a relatively steep (-65°) entry flight path angle and a long (2.5 hour) parachute descent that started at 155 km altitude [2], landing dispersions are dominated by the effects of high velocity zonal (east-west) winds at high altitudes during the parachute phase [3]. Previous studies predict 3σ landing error ellipses with major axes of 300x70 km or more, depending on season, latitude, and delivery error at the entry interface [3]. This can fit in large seas at high northern latitudes; however, several other classes of landing site require more precise lander delivery. This includes landing in the more chemically diverse lakes at high southern latitudes, near shorelines, in dry lakebeds, on the flanks of dunes, and in river valleys or deltas. Such sites would significantly broaden our understanding of Titan's organic chemistry, geologic and climate history, and potential for prebiotic processes.

We distinguish three classes of landing sites, with different technology advances required to reach them:

1. Land anywhere in ellipses considerably smaller than those possible today, e.g. in a southern hemisphere lake. This may require EDL systems with large control authority, but relatively modest final targeting accuracy.
2. Land on or near a class of feature that is widely distributed throughout an ellipse, such as near a shoreline or on the lower flank of a dune. This may require smaller control authority, but much more accurate final targeting accuracy.
3. Land accurately near a single point target, which requires large control authority and accurate final targeting.

Technical approaches to enabling such landing sites include reducing the effect of wind through faster descent to low altitude and introducing control authority, like steerable parachutes/parafoils, other types of aerodynamic control surfaces, entry guidance, and/or propulsion. Terrain relative navigation will be needed in many cases and requires advances well beyond the capabilities developed for Mars and airless bodies.

Sub-Surface (> 0.2m) Ice Acquisition and Handling: Penetration and sampling of pristine ice at depth on Ocean Worlds is high-priority because discovery of macromolecules indicating that extant life that has evolved separately from life on Earth would be one of the greatest scientific discoveries of all time. Such macromolecules can be looked-for in water that periodically erupts onto the surface and freezes, or in convecting ice that periodically interacts with the liquid water ocean, or in the liquid water itself. Intermediate depths may also be of interest on some bodies, e.g. examining organic deposits on Titan. Also, Enceladus plume vents may be explored, including possibly down to liquid water, without actual penetration of the ice.

We can divide the ice penetration, sampling and handling also into three broad classes: shallow depths of 0.2 to 2 meters, intermediate depths of 2 to several 10s of meters, and deep – from several 10s of meters all the way to the liquid water ocean interface. Shallow sampling can be accomplished by many methods, e.g. circular or chain saws, heated blades that sublimate solid ice or simply penetrate porous ice. Intermediate depths can be reached with conventional drills that use a segmented liner to keep the hole from collapsing, or, use a wireline drill that does not line the hole (used in competent material where the risk of hole collapse is low) and therefore does not have a total system mass that grows linearly with depth. Deep penetration, within the limits of mass, power, and volume of plausible near-term missions is very challenging. It may be that some novel method of melting the ice that does not involve losing heat by conduction laterally through the bulk of ice will prove feasible. Using conventional approaches, deep drilling is often thought to be an "Apollo-scale" endeavor. Whichever technique will be employed, the power sources used will have to be compatible with the environment of the specific Ocean World.

Ice Sample Return: Return of samples from Enceladus or Europa would require new technologies to keep the samples in their pristine cryogenic state and to enable transfer and preservation of the samples while meeting back planetary protection requirements. Three classes of missions were considered to identify technology development needs:

1. Europa lander sample return mission which maintains the sample between 100K - 150K during return to Earth.
2. Enceladus plume, Enceladus lander, and Europa lander sample return missions which maintain the sample between 65K - 100K during return to Earth.
3. Enceladus plume, Enceladus lander, and Europa lander sample return missions which maintain the sample below 65K during return to Earth.

To enable the three classes of missions, two technologies would need to be developed, with each technology having three phases of development to support missions with the different return sample temperature ranges. An Integrated Cryogenic Chamber (ICC) would maintain the sample at cryogenic conditions during return to Earth and until retrieved on Earth's surface. Cryogenic back planetary protection (BPP) would provide a break-the-chain process where the sample is transferred into an Earth-clean Earth Entry Vehicle while maintaining the sample in its pristine cryogenic condition.

Additionally, a Comet Nucleus Sample Return mission would be enabled by the 100K – 150K Integrated Cryogenic Chamber technology, but a CNSR mission would not require the cryogenic back planetary protection technology required for the Ocean Worlds.

Planetary Protection: There are a number of multimission planetary protection technologies that need development for application to future ocean worlds exploration. The set of planetary protection requirements a mission would need to meet for Ocean World exploration are different given the target body, the planned science investigations, and often the method of spacecraft exploration (e.g., orbiter versus lander). Meeting the requirements for these missions has become increasingly challenging given the science objectives proposed for these types of missions, such as life detection and sample return.

Methods are needed to better clean organics from hardware as well as methods to validate cleanliness of that hardware at the sensitivity needed for these types of missions. Definition of models and tools, using a systems engineering approach, for establishing a quantitative assessment of sample contamination risk by transport pathways is also required. Alternative methods for sterilization of hardware, such as gamma radiation or plasmas, need to be validated and approved to deal with heat and vapor hydrogen peroxide sensitive hardware. Lastly, technologies for sample return functions to prevent backward contamination are required for future sample return missions. Containment assurance also requires methods to break-the-chain of contact with the sampled body. Any native contamination on the returned sample container and/or Earth return vehicle must be either fully contained or removed prior to return to Earth, therefore, technologies to mitigate this contamination are needed.

Component Technologies: Located in the outer solar system where the flux of the Sun is between 1% and 4% of that falling on the Earth, Ocean Worlds are extremely cold, ranging from an estimated 35K at the poles of Enceladus to no higher than 115K at the equator on Europa. Cloaked in a dense atmosphere, temperatures on Titan are around 95k. In addition, Europa is bathed in the intense radiation environment of the planet Jupiter.

The component technology assessment is developing roadmaps for low temperature-compatible, low power, rad-hard electronics and low temperature-compatible actuators/mechanisms, including lubricants, bearings. and actuators. These are vital for instruments and end-effectors outside a warm box.

Summary: Achieving the long range goals of the Ocean Worlds Exploration Program will require a comprehensive technology development effort. A key part of this effort involves coping with the extreme environment at these fascinating targets.

References: [1] Budget Proposal for FY16 from the House Appropriations Committee, May 2015. [2] Lebreton J.-P. et al. (2005) *Nature*, 438, 758-764. [3] Lorenz R. D. and Newman C. E. (2015) *Advances in Space Research,* 56, 190-204.