Initial Assessment of In-Situ Resource Utilization for Human Missions to Titan

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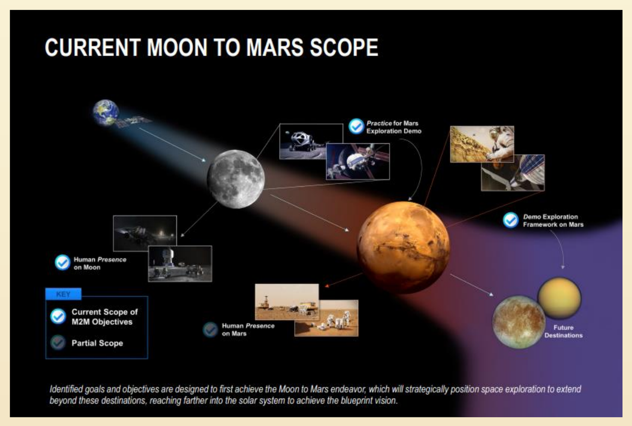
Purpose

As we follow NASA's blueprint [1] for extending human presence deeper into the solar system in-situ resource utilization will be become even more critical that it is for inner solar system travel. The leading candidate for human exploration in the outer planets is the moon of Saturn, Titan [2]. In this research we identify and characterize the ISRU options that Titan could offer to a human mission to its surface.



	Titan
Air Pressure	1.45 atm (145%)
Air Density	5.55 kg/m³ (430%)
Temp Hi/Low	-179C
Atmosphere	95% N_2, 4.9% CH_4
Solar Constant	15.04 W/m² (1.1%)
Surface Material	Water Ice, Methane (CH4), Ethane (C2H6)

Human Mission Architecture

The skeleton of a human mission to Titan begins with an Earth to Titan phase that must be made as short as possible to avoid the detrimental effects of long-term deep space travel, including radiation dosage and physical deconditioning from the microgravity environment. Nuclear propulsion systems being considered for reduced travel time to Mars could also be considered for Titan missions [3]. The second phase is landing on the surface of Titan which must be made as safe as possible through a deep and dense atmosphere. The third phase is living on the surface which will require a breathable atmosphere and comfortable environment of a spacecraft cabin or habitat. The fourth phase is extravehicular exploration of the Titan surface with possible use of mobility vehicles such as rovers or flying machines. The fifth phase is liftoff and return to space. The final phase is the return trajectory back to Earth.

In this heavily simplified starting point of an architecture, we can identify several consumable needs. They are similar to those identified in studies for missions to Mars [4] and are pursued in order to make human missions more feasible and sustainable. The cost of sending mass to Titan will be even higher than Mars missions therefore ISRU is assumed to be needed from the start. Use cases for ISRU include rocket engine propellants and oxidizers for the transit spacecraft and lander, water, oxygen and nitrogen for the crew, and power generation for the lander/habitat, and possibly for mobility vehicles as well.

ISRU Habitat and Suit Air

Titan's 95% Nitrogen atmosphere can be used for make–up gas in the lander and habitat cabin. Since the habitable atmosphere will be maintained at approximately 80% Nitrogen, losses from normal leakage and airlock purges could be replenished using warmed, filtered Titan air.

ISRU Power Generation

Titan offers several options for ISRU power generation. Hendrix & Yung [6] evaluated pros and cons of the concepts including nuclear, chemical, hydropower, wind, solar and geothermal [6]. Wind power is best used when harnessing higher windspeeds found in the higher atmosphere. Of the power generation options using exothermic reactions of available compounds found in the atmosphere, Table 1, hydrogenation of acetylene or nitrogen appear to be the most attractive options for early missions [6].

Name	Exothermic Reaction
Hydrogenation of Acetylene	$C_2H_2 + 3H_2 \rightarrow 2CH_4$
Sabatier Process	$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$
Methane Combustion	$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
Ethane Combustion	$2C_2H_6 + 2O_2 \rightarrow 4CO_2 + 2H_2O$
Nitrogen Hydrogenation	$N_2 + 3H_2 \rightarrow 2NH_3$

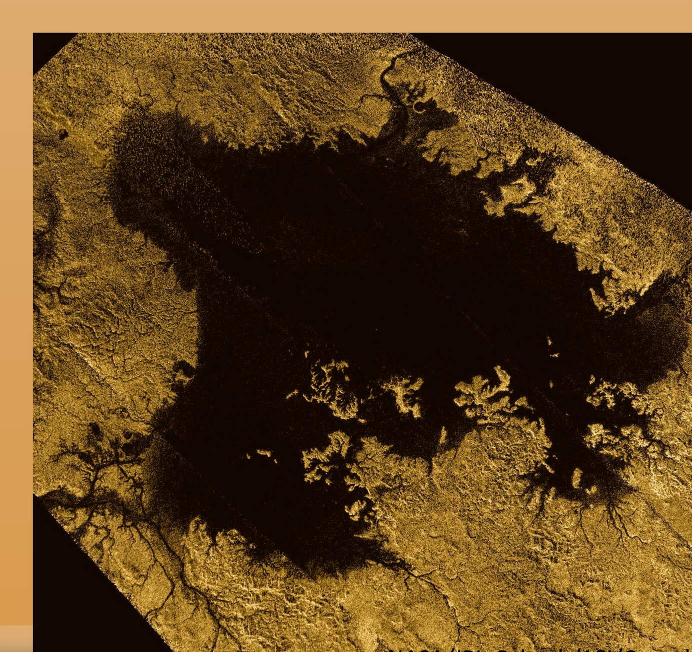
ISRU Water


ESA/NASA

Titan is an ocean world having a liquid interior within a water ice shell. Similar to the hunt for water on the Moon and Mars, water ice on the surface of Titan can be mined. Huygens found cobbles of water ice no the surface. Processes water could be used by the crew while on the surface and even transported back to the transit vehicle for use during the return trip to Earth. It could also be electrolyzed to provide habitat cabin makeup gas as well used in combustion of methane for power generation [6] or as propellant oxidizer. Extracted hydrogen could be used for power generation or as a propellant for nuclear thermal propulsion systems.

ISRU Propellant

Liquid methane is found abundantly in the northern latitudes of Titan in rivers, lakes and seas. The methane on Titan could be used as an ascent vehicle propellant or as fuel in a power production plant. Alternatively, more hydrogen could be extracted from Methane and ethane to add to propellant generation capabilities. The result are options for powering surface mobility systems, ascent vehicles and the orbital transit spacecraft. In a longer-term scenario, methane rivers and lakes could multiple be used to generate power just as we use them here on Earth [6].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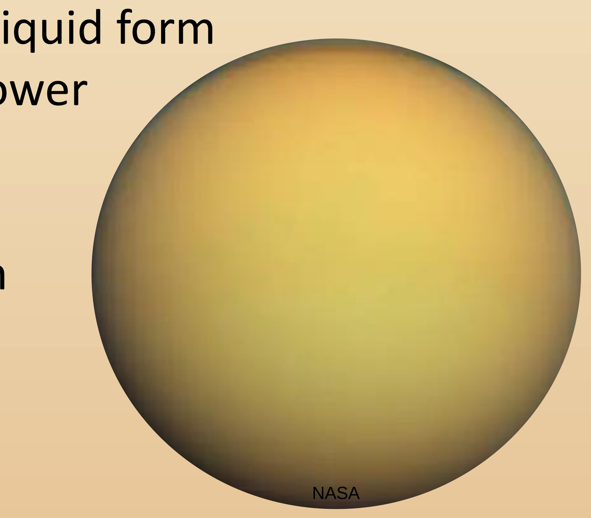
ISRU 3D Printing Materials

Tholins are generated by exposure of atmospheric hydrocarbons and nitrogen to UV radiation and subsequently combining to form polymer-based particles [5]. These ingredients spark the potential for use in forming plastics. These plastics could then be utilized as construction material and 3D printing of components.

Conclusions

Titan is likely to be the next destination for human exploration after Mars, and even though it is much further away than Mars, its atmosphere and surface are rich in resources. These resources will enable early missions to be more self sufficient than other destinations in the solar system. Abundant and accessible nitrogen, water ice and methane are leading options to support human missions. Early assessment of in-situ power generation options using hydrogen and nitrogen or acetylene are attractive. Mining of water ice, readily available across the globe, can support human operations in numerous ways, including the return trip to Earth. Methane, readily available as a gas in the atmosphere and in liquid form on the surface, can support power generation and propulsions systems. Finally, it should be noted that the surface of Titan is perfect for storage of liquid hydrogen, oxygen, methane and ethane


NASA

Next Steps

Further research should be done to explore the potential for Titan as a human destination, and particularly how ISRU systems developed for the Moon and Mars could be adapted to this fascinating world in the outer solar system.

Next Steps in this project include:

1) Development and testing of water ice processing systems at simulated Titan surface conditions.
2) Development and testing of hydrogenation processes, starting with hydrogen extraction, at simulated Titan surface conditions
3) Development of processes to create plastics from simulated tholins.

References

[1] NASA, "NASA's Moon-to-Mars Strategy and Objectives Development," NASA, Washington, DC, P-2023-03-3115-HQ, 2023. Accessed: Nov. 23, 2024. [2] Explore Titan, "Explore Titan," Explore Titan.org. Accessed: Nov. 22, 2024. [3] W. O'Hara and Fernandez-Tous, "Nuclear Fission Propulsion System Sizing for a Greatly Accelerated Human-Class Mission to Titan," in *56th Lunar and Planetary Science Conference*, Houston, TX, Mar. 2025. Accessed: Mar. 16, 2025. [4] G. B. Sanders *et al.*, "Mars ISRU for Production of Mission Critical Consumables - Options, Recent Studies, and Current State of the Art," in *AIAA SPACE 2015 Conference and Exposition*, Pasadena, California: American Institute of Aeronautics and Astronautics, Aug. 2015. doi: 10.2514/6.2015-4458. [5] M. L. Cable, S. M. Hörst, R. Hodyss, P. M. Beauchamp, M. A. Smith, and P. A. Willis, "Titan Tholins: Simulating Titan Organic Chemistry in the Cassini-Huygens Era," *Chem. Rev.*, vol. 112, no. 3, pp. 1882–1909, Mar. 2012, doi: 10.1021/cr200221x. [6] A. R. Hendrix and Y. L. Yung, "Energy Options for Future Humans on Titan," *Astrobiol Outreach*, vol. 05, no. 02, 2017, doi: 10.4172/2332-2519.1000157.