**NEW TECHNOLOGIES FOR POWERING A SURFACE MISSION ON TITAN: CAPTURING ENERGY FROM TITAN'S WINDS FOR SCIENCE EXPLORATION (CETIWISE).**

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**Summary:** Titan is the largest moon of Saturn with a gravity approximately 1/7 of Earth and an average surface temperature of ~94°K (-180°C) near the triple point of methane [1]. Titan's atmosphere is four times as dense as Earth's atmosphere, is composed of ~95% nitrogen and ~5% methane, and has a surface atmospheric pressure one and a half times that of Earth [2]. Extensive dunes on the surface suggest winds (at least seasonally) with aeolian transport of sediments [3]. Fluvial systems and lakes/seas of liquid hydrocarbons with lower viscosity than liquid water exist [4]. Exploration of this environment requires technologies capable of surviving cryogenic temperatures and hydrocarbon liquids. Solar power is not feasible for Titan surface operations due to the persistent haze that blocks the faint sun. Nuclear powered systems generate waste heat that could envelop an instrument in a methane gas cloud, or sink a hulled vessel from reduction in buoyant force as the hydrocarbon liquid boils.

The goal of this proposal is to develop long lived planetary exploration platforms that operate at extremely cold temperatures using in situ resources for power, thus eliminating the need for a surface nuclear power source. We propose exploration of the Titan surface by harvesting wind energy. This technology proposal has been submitted to the NASA Innovative Advanced Concepts (NIAC) Phase I Step B process in Nov. 2017 with the slogan "going green on an orange moon".

The concept is to develop a Mobile Science Platform (MSP) that captures wind energy and converts it to electricity that is stored in a cryogenic superconducting capacitor, then to use the electrical energy to power a suite of instruments, communications equipment, and a propulsion system for the MSP (see Figure 1). Alternate propulsion systems are proposed for 1) solid surfaces with a Ground Rover Base (GRB), 2) liquid surfaces with a Lake Vessel Base (LVB), or a combination of both with an Amphibious Base (AB). This proposal includes many novel and exciting technologies for exploring Titan, including:

- Energy capture from the atmospheric winds
- Cryogenic electrical energy storage using superconductive materials
- Biology instruments to detect possible microbial life in liquid hydrocarbons, lakebed sediments or lakeshore regolith
- Scientific instruments to measure liquid hydrocarbon lake profiles, meteorology and subsurface, geological structures

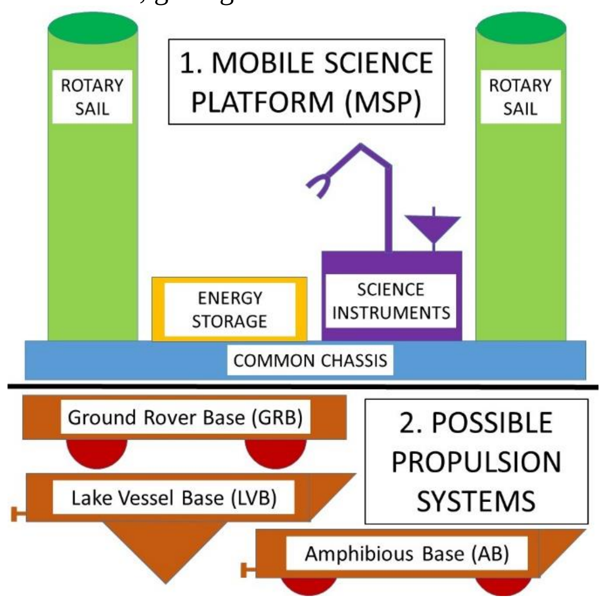


Figure 1: CETiWiSE Concept

**Surface Wind Energy Capture:** Titan experiences long seasons, diurnal heating, and infrequent storms with methane rainfall [1]. A Titan General Circulation Model (GCM) of the near surface environment suggests wind speed thresholds of 0.4-0.7 m/s at an altitude of 10m [5]. This proposal includes additional modeling of localized surface atmospheric winds and lake wave properties as input to the engineering designs.

Traditionally, wind energy can be harvested using flexible, rigid, or rotating sails; however, a rotary sail is desired since it captures wind energy from any direction and drives a generator to create electricity. The rotating sail also creates a "Magnus Effect" propulsive force perpendicular to the wind direction [6, 7]. Successful terrestrial marine applications of rotary sails include the Flettner Rotor Concept [8-10]. Compared to Earth, the use of a rotary sails on Titan is appealing due to higher atmospheric density (more force) and lower gravity (less structural weight).

**Cryogenic Electical Energy Storage:** Electrical energy can be stored in a chemical form in a battery, in a magnetic field in an electrical coil, or in an electrical field in a capacitor. A typical, chemical, terrestrial battery requires temperatures from -20°C to +100°C with optimum performance around 20°C [11]. On cryogenic Titan, batteries are less desirable since they require energy consuming heaters to operate. Below a critical temperature, $T_c$, certain materials will exhibit zero electrical resistance [12]. Recent advances in materials have identified "high temperature" superconducting ceramic oxides with a $T_c$ at 127°K. On the Titan surface at 94°K, superconducting wires in a coil configuration could support a persistent current thus storing energy in the resultant magnetic field. Superconducting wire can also be used to create a direct drive electrical generator eliminating mechanical rotational components and mass. These techniques have been demonstrated at colder temperatures [13, 14] and will be investigated with new "high temperature" superconducting wire types for the Titan surface.

**Biology Surface Instruments:** A common organic molecule in Titan atmosphere could be a source of biologic energy for microbial life in surface hydrocarbon lakes [15]. The MSP includes a spectrometer atop the rotary sails to search for color changes in the nearby surface as an indicator of possible microbial blooms [16]. The propulsion system delivers the MSP to the possible bloom location. Once there, the robotic arm (designed to function in cryogenic temperatures) captures liquid or solid samples and places them in a new instrument. This instrument, based on the ISS mini-DNA sequencer [17], can identify polarity in repetitive patterns indicating the presence of a charged particle "backbone". This "backbone" have been suggested as a potential marker for identification of life on Titan [15, 18, 19].

**Other Surface Science Instruments:** The MSP also includes camera equipment and meteorology insturments for measuring atmospheric temperature, pressure, humidity, winds and precipitation. The LVB and AB option includes oceanography instruments to measure bathymetry, liquid surface waves and currents, liquid chemical and physical profiles at depth, and a sediment grabber to capture samples from the lake floor for biological analysis. The GRB and AB option includes deployable geological instruments to measure surface and subsurface structures with seismometers and a magnetometer.

**Mission Architecture:** A solar powered Titan Orbiter (TO), modeled from the NASA JUNO mission, includes relay equipment for communications between the Titan surface and Earth, and scientific instruments for surface radar mapping and atmospheric studies. The planned Space Launch System (SLS) lifts assets from Earth and delivers the TO and one lander to Titan orbit. The lander is composed of the MSP on a propulsion platform, which could be a GRB (for solid surfces), the LVB (for liquid surfaces), or an AB (for both solid and liquid surfaces). The lander descends through the atmosphere with a parachute and captures wind energy to charge batteries for MSP deployment, which then captures surface wind energy to power the scientific instruments and propulsion platform. The minimum mission design life is 5 Titan days (80 total Earth days).

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