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Converting Water into Performant Propellants for In-Space Propulsion: Overview of the GreenSWaP project

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Abstract

Green SWaP (Green Solar-to-propellant Water Propulsion) is a project funded by the European Innovation Council (EIC) Pathfinder program which aims at developing the core technologies for a new class of in-space water propulsion. Water offers unparalleled handling and storage advantages both on Earth and in orbit, and through in-situ resource utilization on the Moon and other bodies, can become a renewable source of propellant. Moreover, water provides dual-use benefits in future human outposts by serving as radiation shielding and as a working fluid in life support systems. Green SWaP pioneers the direct onboard conversion of water into hydrogen peroxide and gaseous hydrogen using solar energy, yielding a propellant combination with superior storability compared to conventional water electrolysis systems. The project aims to increase the technology readiness levels of all key subsystems, including microgravity water conversion systems, concentration of hydrogen peroxide to rocket grade levels, and the safe storage of hydrogen in an inflatable tank. These propellants are then employed in two innovative thrusters: a 1 N hydrogen Solar Thermal Thruster (STT) for precise attitude control and a 200 N bipropellant engine that uses High-Test Peroxide (HTP) and hydrogen for main propulsion. By integrating these building blocks, Green SWaP lays the foundation for renewable, self-sustaining mobility in space, extends water-based propulsion to higher thrust regimes, and enables new mission architectures leveraging in-situ resources.

Keywords: Water-to-Propellant, Greener Propulsion, In-Space Propulsion, In-Situ Resource Utilization, Green SWaP Project, European Innovation Council

Acronym	Definition
CRM	Critical Raw Materials
EC	Electrocatalysis
HTP	High-Test Peroxide
ISRU	In-Situ Resource Utilization
NTO	Nitrogen Tetroxide
OOS	On-Orbit Servicing
PC	Photocatalytic
PV	Photovoltaic
PV/EC	PV-driven Electrocatalysis
PW	Plasma-based Water Contactor
STT	Solar Thermal Thruster
TRL	Technology Readiness Level

1. Introduction

The next generation of spacecraft operations relies critically on advancements in propulsion performance. These improvements must arise not only from identifying new mission opportunities or proposing innovative concepts but, above all, from the development and testing of enabling technologies. Over the past decades, space propulsion has diversified significantly, from traditional chemical thrusters to electric propulsion systems, with technologies like solar sails and nuclear propulsion approaching greater technological maturity. Each propulsion technology offers unique advantages for specific mission profiles, and the choice of the most suitable option requires balancing propulsive performance, compatibility, cost, reliability, storability, and overall system complexity. To enable longer on-orbit

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lifetimes and autonomous on-orbit services (OOS), spacecraft must move toward architectures that harvest local resources, minimize hazardous materials, and integrate power and propellant generation into their operational lifecycle.

Green SWaP (Green Solar-to-propellant Water Propulsion) addresses that challenge by developing an integrated, solar-driven value chain that converts water into high-value, storable propellants directly in-space while advancing the propulsive subsystems to efficiently exploit them.

Water is a uniquely strategic resource for long-term space operations. It is non-toxic, relatively abundant on many planetary bodies and can serve multiple roles simultaneously: a life-support fluid, radiation shielding, thermal mass, and a feedstock for propellant production. The project focuses on two principal chemical products: hydrogen (H_2) and hydrogen peroxide (H_2O_2). These propellants are produced from water using sunlight and were selected because they create a practical, bimodal propulsion opportunity: H_2 enables high-efficiency, low-thrust maneuvers, while concentrated H_2O_2 is a dense oxidizer for higher-thrust bipropellant operation without the extreme combustion temperatures of conventional water propulsion. Beyond propulsion, hydrogen can power fuel cells or efficient engines, and hydrogen peroxide can be used as an oxidizer, a source of oxygen for life support, or a chemical reagent. This versatility of downstream use increases the value of water-to-propellant conversion for a wide range of space missions.

By combining solar-to-propellant conversion with advanced storage and propulsion concepts tailored to these propellants, the project aims to close the performance gap between traditional chemical propulsion and electric propulsion across a wide range of missions. Green SWaP aims to create an integrated technology ecosystem covering solar harvesters and concentrators, chemical conversion concepts, storage solutions and the development of propulsion systems that maximize their use.

2. The Green SWaP Project

Green SWaP is a Horizon Europe project funded by the European Innovation Council (EIC) under the Pathfinder Challenges call "*In-space solar energy harvesting for innovative space applications*". It officially started on 1st of October 2024 under Grant Agreement N° 101161583.

Fig. 1. Green SWaP Logo

Green SWaP proposes a novel approach to water-based in-space propulsion. Its core idea is an innovative conversion process that cogenerates liquid hydrogen peroxide and gaseous hydrogen propellants directly in-orbit. These two propellants are then used in both main and secondary propulsion solutions to fulfill a wide range of space missions. By leveraging water's widespread availability in space, Green SWaP takes a step toward circular in-space propulsion and logistics.

The technical architecture of the whole system developed by Green SWaP is illustrated in Figure 1. Solar energy is collected and used to power the water conversion system, which outputs gaseous hydrogen and an aqueous solution of hydrogen peroxide. Hydrogen is stored in an inflatable, high-pressure tank, while the concentration of hydrogen peroxide is increased up to rocket-grade levels, i.e. >80% in weight. Excess water is fed back to the water storage to avoid waste. High-concentration hydrogen peroxide, also known as High-Test Peroxide (HTP) is then stored in a conventional tank. Precise attitude control of the spacecraft is achieved with a Solar Thermal Thruster (STT), and main propulsion with a bipropellant HTP/GH2 engine.

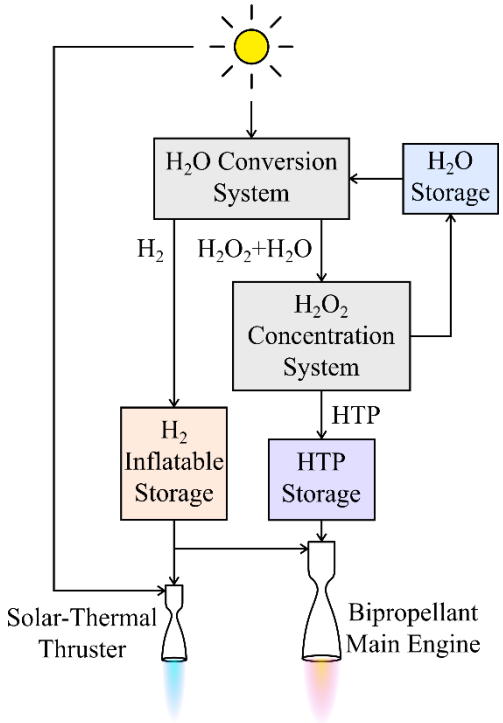


Figure 1: Technical scheme of the Green SWaP project structure.

Over the course of four years (2024 - 2028), the project consortium will increase the Technology Readiness Level (TRL) of these five key technologies: direct conversion of water into hydrogen peroxide and hydrogen, microgravity concentration of hydrogen peroxide, inflatable hydrogen storage tank, and space

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propulsion through a bipropellant main engine and a hydrogen solar thermal thruster for attitude control. Through integrated laboratory demonstrations and performance testing, Green SWaP will increase each subsystem's TRL to 4, demonstrating operational concepts and delivering validated, laboratory-tested prototypes.

Green SWaP brings together a multidisciplinary consortium of six European institutions spread across five countries and coordinated by the University of Pisa, as summarized in Table 1 and Figure 2.

Partner	Location
University of Pisa (UNIPI)	Italy
Delft University of Technology (TU Delft)	The Netherlands
European Research Institute of Catalysis AISBL (ERIC)	Belgium
University of Turin (UNITO)	Italy
Karlsruhe Institute of Technology (KIT)	Germany
Novaspace SAS	France

Table 1: The Green SWaP Consortium



Figure 2: Map of Green SWaP's European Consortium

3. Green SWaP Concept & Innovation

The enabling technologies developed within Green SWaP are summarized and compared with the current state of the art, in Table 2, highlighting the innovations introduced by the project. The following subsections present each technology in its core concept, beginning with the water conversion systems (the chemistry part of the project) before moving on to the propulsion subsystems and their development.

State of the Art	Green SWaP Innovations
No coproduction of H_2O_2 and H_2 for space applications	In-space production of H_2O_2 and H_2 from water through different approaches: - Photocatalytic - Electrocatalytic - Plasma-based
No H_2O_2 concentrator for space applications	H_2O_2 concentrator for in-space environment utilization
A few bimodal toxic propulsion systems used in space	Development of integrated bimodal propulsion systems
Solar Thermal Propulsion only theoretically studied	Development of a solar thermal propulsion concept
Toxic liquid bipropellant systems used in space	Development of a chemical propulsion system based on HTP and gaseous H_2
No inflatable tank for H_2 storage for space applications	Development of an innovative inflatable tank for H_2 storage

Table 2: Green SWaP Project innovations

3.1 Water Conversion Systems

Producing propellants from water directly in space increases mission autonomy and sustainability: instead of launching with the full supply of fuel & oxidizer onboard, they are generated on orbit using solar energy. This approach can facilitate ground operations, reduce launch mass and volume, especially with the use of inflatable storage, and open new flexibility for in-space logistics. The space environment, however, imposes specific constraints that shape both chemical and engineering choices. Indeed, in microgravity fluids behave differently, solar light includes unfiltered UV, and extreme variations of temperature, radiation, and vacuum conditions that stress materials and catalysts. Operating in closed-loop systems also requires strict control over leaks and outgassing. Green SWaP addresses these challenges by developing compact, power-efficient, and robust technologies tailored to the space environment.

Regarding the water conversion system, Green SWaP evaluates three complementary routes for the $2H_2O \rightarrow H_2O_2 + H_2$ synthesis:

1. Direct photocatalytic (PC) co-production
2. Photovoltaic-driven electrocatalysis (PV/EC)
3. Non-thermal plasma (PW) water contactors

Each method has its own strengths and challenges, and a key objective of Green SWaP is to identify which one is best suited to its mission concept. Photocatalysis is

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mechanically simple but generates propellant slowly, photovoltaic-driven electrolysis offers higher and more controllable production but requires more complex subsystems, plasma methods provide compact, on-demand production without catalysts but consume more electrical energy. To fairly compare them, all three are being developed in parallel as modular units with standardized electrical and fluidic interfaces, so they can be tested and compared on the same spacecraft platform. The most promising approach will then be selected based on experimental results and system-level criteria.

3.1.1 Photocatalytic approach

The photocatalytic route tries to do the chemistry directly with light: semiconductor materials absorb sunlight and use those photons to drive two complementary reactions at once, producing hydrogen on one side and hydrogen peroxide on the other. Materials under study range from well-known oxides (for example titanium dioxide) to more recently engineered composites and layered structures that encourage charges to separate and react where we want them to.

The attraction of this approach is conceptual simplicity: it needs no separate electricity-generating hardware, and the active material can, in principle, be a passive surface that converts sunlight into chemical products. In practice, however, photocatalytic systems today tend to produce only modest quantities per unit area, and they are often tested as powders or slurries in laboratory dishes. For space applications the key engineering questions are therefore practical:

- How to fix or contain the catalyst so it stays functional over long periods of time.
- How to efficiently couple sunlight to the material (direct illumination versus concentrating optics and fibers).
- How to separate and collect gases and liquids in microgravity.
- How to ensure the catalysts survive prolonged exposure to ultraviolet radiation and the space environment.

Photocatalysis remains promising because of its low system complexity but making it productive enough for spacecraft use will require significant advances in material immobilization, optical design and fluid management.

3.1.2 Electrocatalytic approach

The electrochemical (PV/EC) approach separates the sunlight-capture step from the chemistry: photovoltaic arrays generate electricity, and that electricity powers an electrochemical cell that intentionally produces hydrogen at one electrode and hydrogen peroxide at the other. Because photovoltaics and electrodes can be optimized independently, this architecture generally achieves higher production rates and higher concentrations than current photocatalytic systems. It also benefits from an obvious spacecraft advantage as satellites already carry solar panels that can supply the needed power.

The main challenge is system complexity. An electrochemical system needs electrodes, separators or membranes, pumps or channeling to move fluids, and power-conditioning electronics. In microgravity, liquid and gas handling need careful re-thinking, engineers must design capillary or forced-flow paths, so gases don't become trapped and so reactants and products are reliably separated. On the positive side, PV/EC systems have clearer scaling paths: improving solar cell area, electrode materials or flow design tends to translate directly into higher production rates, which makes this option attractive when spacecraft can afford the additional mass, volume and control systems.

3.1.3 Plasma-based interactions approach

Plasma-based methods use short, energetic electrical discharges to create highly reactive chemical species (for example hydroxyl radicals) at the interface with water. Those radicals recombine to form hydrogen peroxide or can lead to dissociation pathways that produce hydrogen and oxygen. Plasma reactors can be compact, start and stop quickly, and in some designs avoid the need for scarce catalytic materials entirely. Early bench work shows they can produce useful concentrations of H_2O_2 and react quickly when tuned properly.

Their main challenges are energetic, and systems-integration related. Non-thermal plasma generation requires pulses of high-voltage power, so the energy efficiency (grams of product per kilowatt-hour) must be improved for space use. The plasma-liquid interface must be engineered so the discharge stays stable, and the liquid is fed and removed reliably in low gravity, and care must be taken to manage heat, electromagnetic emissions and potential interference with other spacecraft electronics. If those issues can be overcome, plasma reactors offer a compact, flexible path to chemical production that complements the photocatalytic and electrochemical options.

3.2 Hydrogen Peroxide Concentration System

Producing hydrogen peroxide in situ typically yields relatively diluted solutions, so an efficient concentrator is needed to raise peroxide to the levels required for safe storage and use as a monopropellant or as an oxidizer in a bipropellant system. Green SWaP selected a micro-structured pervaporation concept as the reference concentrator because it combines compactness, low thermal inertia and a natural tolerance to the low-gravity environment of space.

Pervaporation is a membrane-based separation method that removes water by letting it pass selectively through a semi-permeable barrier and then converting that permeates to vapor on the far side (by applying a

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vacuum or a sweep gas). Unlike conventional distillation, which depends on boiling and therefore on gravity-driven vapor/liquid separation, pervaporation separates at the molecular level and is inherently much less sensitive to gravity, a decisive advantage for spacecraft applications. Embedding the membrane inside carefully engineered microchannels increases the surface area for transfer while keeping the device compact and quick to thermally respond, which fits the tight size, weight and power budgets typical of spacecraft hardware.

The module design couples small liquid feed channels, a robust membrane, and a compact thermal stage that drives the vapor-phase separation. Membrane chemistry and channel layout are chosen to maximize water transport while retaining hydrogen peroxide and avoiding its decomposition: the goal is good throughput, strong selectivity for water over peroxide, low energy consumption per kilogram of water removed, and long-term material stability against oxidation. Micro-structured channeling helps shorten fluid residence times and provides high area-to-volume ratios, so the unit can be both small and fast to control.

Microgravity eases some aspects of pervaporation but creates others that must be engineered carefully. That is evident in a technical NASA report published in 1974 [1]. On the permeate side the system must handle vapor condensation or sweep-gas management without relying on buoyancy, and the feed side must avoid trapped gas bubbles that can foul the membrane. To address these needs the module architecture includes capillary-compatible condensers or sweep-gas loops, surface-tension-based separators and sensors to monitor temperature, vapor pressure and peroxide concentration for closed-loop control. Robust seals and vapor-tight interfaces are essential because hydrogen peroxide is a strong oxidizer and both safety and leakage control are paramount.

Materials and thermal design are central to reliable operation: membranes, channel substrates and gaskets must resist oxidative attack, and heaters must be regulated to prevent local hot spots that accelerate peroxide breakdown. Candidate membrane approaches range from dense polymer films with protective coatings to more aggressive ceramic-lined options where chemical resistance is critical. The project's early test program will therefore characterize membranes and module geometries in terrestrial labs (including tests at different orientations) to map operating windows, measure flux and selectivity, and assess durability. Those results will feed an optimized prototype intended to demonstrate gravity-independent operation and to raise the concentrator towards TRL 3-4 during the project's first phases.

Performance metrics to be tracked during development include permeate flux, water/H_2O_2 selectivity, energy consumption per unit H_2O removed ($kWh.kg^{-1}$), achievable product concentration, and membrane lifetime under oxidizing conditions. Integration considerations include thermal coupling to the synthesis module (heat reuse where possible), interface control for feed purity, and safe downstream storage/conditioning of the concentrated H_2O_2.

3.2 Bimodal Space Propulsion System

Green SWaP propulsion system is based on bimodal propulsion (also sometimes called "multimode" or "dual mode"), a term that refers to the integration of two propulsive modes into a single spacecraft propulsion system, with shared propellants and tanks. For bimodal propulsion, the shared propellant feature offers significant benefits which, in the most typical cases studied in the literature, range from enabling new missions to allowing for mission flexibility and in-situ adaptability. A wide variety of bimodal systems have been proposed in literature, ranging from entirely chemical to entirely electric or, in some cases, combinations of chemical and electric propulsion. The few bimodal propulsion systems actually used in space so far are typically entirely chemical and based on a bi-propellant thruster for orbital control and a smaller mono-propellant thruster for attitude control. Not many systems of this type have been used in space as of today, and they were mostly based on toxic propellants (such as hydrazine and NTO, for the system used by the BepiColombo mission). Green SWaP will design and develop for the first time, demonstrating to TRL 4 its main building blocks, a bimodal system based on a Solar Thermal thruster (for attitude control) and a bipropellant chemical thruster (for orbital control), using as shared green propellants hydrogen (H_2) and hydrogen peroxide (H_2O_2) generated by the conversion process of water using solar energy as input power source.

3.2.1 Liquid H_2O_2/H_2 Main Bipropellant Engine

The main engine thrusters provide the energy to perform the main orbital maneuvers of a mission such as orbit raising or inclination changes. In larger spacecraft, such as space stations, these engines can also be used to perform station keeping or even attitude control.

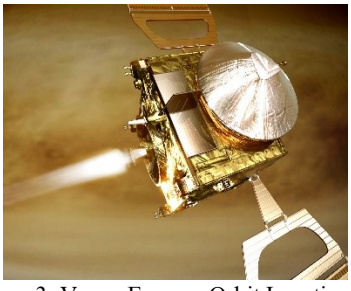


Figure 3: Venus Express Orbit Insertion [2]

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Green SWaP main engine will provide a vacuum thrust level of a few hundred Newtons and will run using highly concentrated hydrogen peroxide, also known as High-Test Peroxide (HTP), as oxidizer and gaseous hydrogen (H_2) as fuel. Hydrogen peroxide is a pale blue liquid, slightly more viscous and 40% denser than water. It is a metastable molecule that can decompose exothermically into water and oxygen according to the following reaction:

$$H_2O_2 \rightarrow \frac{1}{2}O_2 + H_2O$$

For this reason, hydrogen peroxide is always found in an aqueous solution with a certain mass concentration in water. The higher the concentration, the better the oxidizing performance. Concentrations above 80% are generally referred to as high-test peroxide (HTP) or rocket-grade hydrogen peroxide (RGHP).

To accelerate this decomposition, chemical propulsion systems pass HTP through a catalytic bed. Catalytic beds come in different configurations, depending on the shape of their catalyst. The industry standard is catalytic pellet beds, which contain numerous pellets made of porous and resistant materials such as alumina (Al_2O_3) coated with a catalyst such as platinum as shown in Figure 4.



Figure 4: Example of Pt/α-Al_2O_3 pellets [3]

The decomposition of HTP yields a hot gaseous stream of water vapor and gaseous oxygen. Higher HTP concentrations produce more oxygen and at a higher temperature. The trade-off is that higher temperatures are harder for the system to withstand, increasing thermal stress on the catalytic bed, tubbing, and combustion chamber, and requiring more robust materials and careful design.

Once the decomposition is achieved, the goal is to inject and ignite this hot and gaseous oxidizer with gaseous hydrogen inside the combustion chamber of the main thruster. Figure 5 illustrates a simplified schematic of the bipropellant main engine.

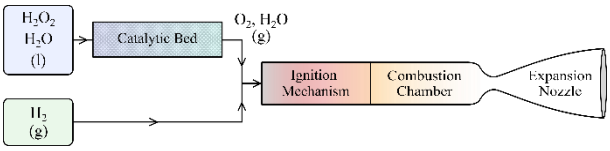


Figure 5: Schematic of Green SWaP Bipropellant Main Engine [4].

During the four-year duration of the project, Green SWaP will design, manufacture and test two prototypes of this bipropellant thruster at the Space Propulsion Laboratory chemical propulsion facilities of the University of Pisa. The main topics of investigations are summarized as follows:

- HTP catalytic decomposition with conventional and alternative, non-critical raw materials.
- Gas–gas injection and ignition between HTP decomposition products and gaseous hydrogen (no prior literature available).
- Combustion characterization: instabilities, chamber parameters, operating range.
- Propulsive performance, proof of operation and TRL increase to 4

3.2.2 Solar Thermal Thruster for Attitude Control

A key innovation in Green SWaP is the use of a solar thermal thruster (STT) as the spacecraft's auxiliary attitude-and-reaction-control system. Rather than carrying all propellant from launch, Green SWaP's architecture produces hydrogen in orbit from harvested water and uses that hydrogen both as a high-performance working fluid and as part of a bimodal propulsion solution: a H_2O_2/H_2 bipropellant main engine handles orbital transfers and large Δv, while STTs provide efficient, sustainable attitude control and wheel desaturation. The project's objective for the STT activity is to mature the concept to a flight-relevant demonstrator (TRL 4) and to show that a hydrogen-fed solar thermal device can be practical for auxiliary in-space propulsion.

The STT operates on a straightforward thermodynamic idea: sunlight is collected and concentrated, the concentrated light is converted into heat in a receiver or heat exchanger, and that heat is transferred to a light propellant (hydrogen) which is then expanded through a nozzle to produce thrust. This direct conversion of solar thermal energy to propulsive power gives STTs a distinctive performance niche: far higher propellant efficiency than chemical thrusters, and higher steady thrust than typical electric systems. When combined with in-orbit hydrogen production, this efficiency can materially reduce the need to launch large propellant masses, supporting the project's sustainability goals. Figure 6, taken from [5], shows a simplified illustration of the STP concept.

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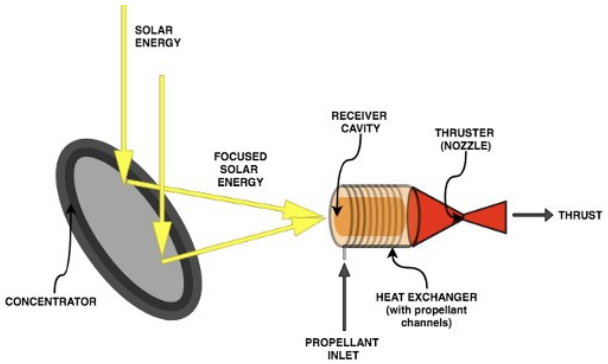


Figure 6: Schematic of a Solar Thermal Thruster.

Turning the concept into a usable attitude control system requires system-level engineering trade-offs. Solar thermal propulsion depends on heating physical hardware to very high temperatures and on managing concentrated sunlight; those characteristics produce operational behaviors that differ from conventional cold-gas or chemical RCS jets. In practice, thermal inertia and heat-transfer dynamics make STT firings longer and less impulsive than millisecond chemical pulses, which means precision pointing must be handled by a hybrid approach: momentum/reaction wheels address fine, fast disturbances while STTs provide slews, momentum dumps and coarser corrections. Likewise, integrating STTs into a spacecraft requires careful attention to layout and redundancy, hydrogen handling and sealing, plume interactions with nearby structure, and solutions for periods without sunlight (for example through thermal storage or insulation strategies). These are engineering challenges, not obstacles in principle, they simply require co-design across propulsion, thermal, control and systems engineering disciplines, so the thrusters complement the rest of the vehicle.

Green SWaP addresses those challenges by coupling STT development to the project's other enabling technologies:

- Fiber-optic or distributed concentrator concepts which reduce dependence on a single large deployable mirror and ease pointing constraints
- In-orbit hydrogen production and compact storage concepts (such as inflatable tanks under study in the project) which ease the hydrogen logistics that previously limited STP concepts
- A focused maturation program to assess receiver concepts, nozzle integration and materials choices with hydrogen compatibility and repeat-cycle durability in mind.

By demonstrating a hydrogen-fed STT suitable for auxiliary propulsion, Green SWaP seeks to close an important technology gap: providing a reusable, high-efficiency attitude control option that leverages sunlight and in-situ propellant production. If successful, the demonstrator will show how solar thermal propulsion can be integrated into a practical, sustainable spacecraft architecture, bridging the performance gap between chemical and electric propulsion and contributing to greener, longer on-orbit operations.

3.2.3 Inflatable Hydrogen Tank

The use of hydrogen for in-space propulsion has historically been limited, due to the very low density of this propellant when in gaseous form (0.08375 kg/m^3 at 298 K and 1 bar) and, consequently, the need to liquefy it under cryogenic conditions at temperatures as low as 20 K. This, in turn, brings long-term storage issues mainly due to the risk of boil-off due to various possible physical mechanisms such as ortho-para conversion, heat leak, sloshing and flashing. In Green SWaP, the hydrogen propellant will be directly available as product of the chemical conversion of water, but it is unfeasible to liquify it in-space under cryogenic conditions, due to the extremely high-power level required to bring hydrogen to liquid conditions and keep it at the required temperature for long periods. Therefore, the use of conventional rigid tanks is not recommended, since it would lead to extremely high tank volumes. To tackle this issue, Green SWaP will conceptualize, manufacture and test an innovative concept of inflatable tank, offering reduced volume at launch and being able to increase its volume "on-demand", based on the required amount of hydrogen stored in the tank, while keeping the internal pressure in the tank always lower than 50 bar.

4. Green SWaP Reference Mission Scenario

Because Green SWaP is designed as an enabling technology, its potential applications span a wide range of space missions. Early on in the project, an extensive survey of candidate mission concepts was carried out to ensure alignment with project objectives and emerging market needs. A comparative evaluation process, detailed in [6], was applied to downselect the most promising scenarios. From this activity, a reference mission use case, shown in Figure 8, was defined to serve as the baseline for system development.

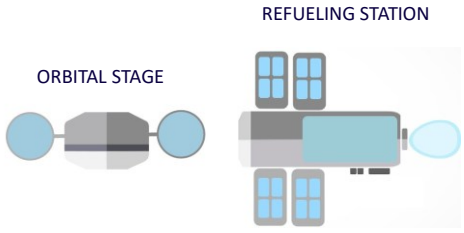


Figure 7: The Green SWaP Kick Stage and its Orbital Refuelling Module

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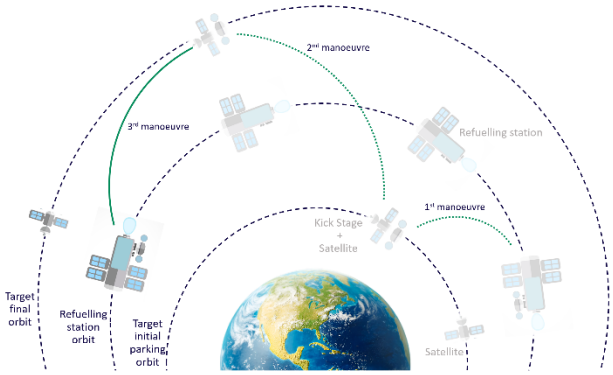


Figure 8: Green SWaP Reference Mission Scenario

The selected case is centered on a reusable orbital kick stage supported by an in-orbit refueling module, as illustrated in [6] and Figure 7. The refueling station, operating in Sun-Synchronous orbit, demonstrates the use of water-based propulsion and energy conversion, while the reusable kick stage provides orbital transfer capability for satellites [7]. This combined system illustrates how Green SWaP technologies could enable more sustainable and flexible operations in Earth orbit. Figure 7 illustrates the preliminary configuration of the refueling station to which the Kick Stage will attach.

This scenario was identified as the most representative, balancing feasibility with innovation while also imposing challenging constraints on performance and design margins. Additional figures of merit, such as environmental impact, propulsive efficiency, reliability, and cost, as suggested in [8], will be incorporated later on in the project to fully assess the exploitation potential of the technologies developed in Green SWaP, both within this mission scenario and across the wider set of mission use cases explored within the EIC Space Portfolio.

5. Objectives and Expected Impacts

The Green SWaP project is innovative and ambitious, aiming at producing and storing in-space propellants before using them in two separate technology blocks that perfectly integrate and could offer not only improved performance, but also versatility to the spacecraft. The project aims to develop and advance a wide range of cutting-edge enabling technologies that will go beyond the current state of the art, including solar water-conversion systems, H_2O_2 concentrators, and bimodal propulsion thrusters.

Green SWaP will develop these technologies with two sequential design and testing loops shown in Figure 9. The first loop focuses on defining requirements, selecting a mission Use Case, developing and testing propellant production and propulsion technologies at component and subsystem level. Lessons learned from this phase feed into the second loop, which involves further refining the design, manufacturing of lab-scale prototypes, and performance validation in line with in-space operational conditions. Both loops are coordinated through systems engineering to ensure harmonization and iterative improvement reach a final evaluation that defines the roadmap to higher TRL levels and full system qualification.

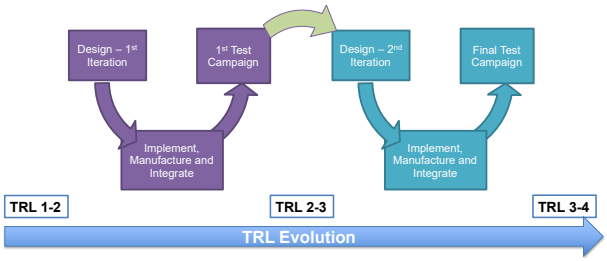


Figure 9: Green SWaP Phases in Increasing the TRL

In April 2025, the Green SWaP consortium held its System Requirement Review (SRR) to consolidate the technical direction of the project. This review established the baseline configuration of the system and defined the key performance targets to be pursued during the subsequent design and testing phases. The agreed parameters, summarized in Table 3, represent the reference framework guiding technology development across the different project domains, namely system, chemistry and propulsion.

TECHNOLOGY	OBJECTIVE OF GREEN SWAP
Conversion System Integration	- Compact, lightweight unit: **< 200 kg** & **< 2.5 m³** - system shall not exceed **1.5 kW** of electric power
Solar Harvesting	Solar collection limited to **< 15 m²** panel area, providing all energy for water-to-propellant conversion
Propellant Production	On-orbit generation of **> 200 g/h** of usable propellants (combined H_2O_2 and H_2)
Propellant Quality	High-performance green propellants: - H_2O_2 concentration **> 85%** - H_2 purity **> 98%**
Attitude Control (RCS)	Solar-thermal thruster - Thrust **> 1 N** - Specific impulse **> 500 s**
Main Propulsion	H_2O_2/H_2 Bipropellant thruster: with - Thrust **> 100 N** [200 N] - Specific impulse **> 340 s**
System-Level Innovation	First demonstration of a bimodal propulsion system (chemical + solar thermal) operating with in-space produced propellants

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Table 3: Green SWaP System Requirements and Performance Objectives. Developed in more details in the companion IAC 2025 paper focused on the propulsion system [9].

The expected impacts of the Green SWaP project are reported in Table 4, mapping technical outcomes to broader benefits for space operations, policy objectives, and terrestrial applications.

Expected Impact	Green SWaP Contribution
Design and laboratory validation of new concepts for energy harvesting in space	Laboratory validation of solar-driven water-to-H_2O_2/H_2 reactors and concentrators up to TRL 4.
Innovative green propulsion solutions	First demonstration of a GH2 solar-thermal thruster and HTP/GH2 bipropellant engine.
Increase of EU strategic autonomy	Establishes a unique European technology line with no equivalent in other regions, supporting autonomy in green space transportation.
Fuel cost savings and in-space clean energy solutions	Reduces ground handling costs of toxic propellants, enables long-duration missions with clean solar-derived fuels.
Spin-offs in terrestrial markets	Electrochemical/plasma-assisted synthesis, H_2 storage, and concentrator technologies have applications in green chemistry and energy.
Improved spacecraft mobility, lifetime extension, and debris management	Enables in-space refueling, reusable kick stages, and active de-orbit decommissioning services for satellites, high-thrust water-based propulsion.

Table 4: Expected Impacts of the Green SWaP Project

6. Conclusions

The EIC Green SWaP project introduces an innovative type of in-space water propulsion system based on hydrogen peroxide and hydrogen and develops for the first time all the necessary technologies behind it. The novel propellant combination will be directly co-produced in space starting from simple water, greatly reducing propellant costs and handling risks and unlocking unique opportunities such as in-situ resource utilization and coupling with human life support systems.

The consortium is evaluating three different water conversion approaches: photocatalysis, photovoltaic-driven electrolysis, and plasma-based methods. Efforts are also spent to develop the first hydrogen peroxide concentration device able to operate in microgravity conditions.

Moreover, two unique propulsion systems will be developed and tested to produce thrust from hydrogen peroxide and hydrogen. A bipropellant main engine providing 200 N of thrust and a 1 N solar thermal thruster for attitude control. The main engine will operate with high-test peroxide and gaseous hydrogen, while the STT will operate with pure hydrogen, the best possible gas for this type of engine. Green SWaP will also develop an inflatable tank for efficient storage of gaseous hydrogen in space.

Over its four-year duration, the Green SWaP project aims to advance breakthrough technologies and novel system integrations to Technology Readiness Level 4, paving the way toward circular propulsion and sustainable in-space logistics. Successful demonstrations will significantly strengthen the feasibility of producing hydrogen peroxide and hydrogen from water in space and using them as propellants to generate thrust and fulfill missions. Complementary papers at IAC 2025 present the initial propulsion subsystem design, estimated performance [9], and detailed mission analyses with supporting trade studies [6].

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