Renewable Energy for Spacecraft Propulsion and Operations

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 Several new developments have occurred over the past few years with different types of renewable energy on earth and for spacecraft operations. Solar energy is already being used for spacecraft operations within the suns reach. Although solar energy as a primary source for power in space operations has been successful, there are still boundaries within its use. In 2018 Kepler and Dawn spacecraft extended missions were shortened due to fuel shortages. Both missions were a success, but how much more data could have been received if each could have continued on (1, 3)? In 2019 Mars rover Opportunity’s batteries were covered with dust, and was unable to recharge eventually ending the mission (6). Most recently, a similar fate awaits Mars lander Insight (2).

 Currently there are 7 types of renewable energies utilized on earth: Solar, wind energy, hydroelectric, ocean, geothermal, biomass and hydrogen (5). This paper will specifically discuss solar, biomass and hydrogen.

 The Haber-Bosch process involves mixing hydrogen and nitrogen to create ammonia at elevated pressure and heat with a catalyst. The by-product is carbon dioxide. Recently the technique has been improved upon for a more efficient conversion requiring less heat and pressure with the use of a more efficient catalyst (4). Hydrogen and carbon dioxide converts to methane and water (methanation process) through the Sabatier reaction and hydrocarbons/syngas using the Fischer-Tropsch process. Other conversions of hydrogen and carbon dioxide exist, including methanol and oximethylene ethers (7). Methane can convert to other useful fuels (7). Hydrogen can also convert to fuel cells, which can assist in the production of power/electricity (4).

 Methane or hydrocarbons such as ethylene can be used as fuel for propulsion and as building blocks for more complex molecules. Solar is already being used for power but could aid in water electrolysis for conversion to hydrogen (7). Ammonia can be recycled as a heat source for the Haber-Bosch and Fischer-Tropsch processes, thermal source, and life-support (4). The key is to make all sources efficient, stable, and if possible, recyclable for long duration missions.

 Within several decades, with the expansion of space exploration, the above mentioned seven forms of renewable energy may evolve. Combining several different adaptive types of energy will create a renewable energy best suited for the space environment not practical on earth. Also, each planet and exo-planet with their own unique environments may produce adapted forms of renewable energy.

**Goal**

 Utilizing spacecraft solar arrays and hydrogen fuel cells, power generated will convert water to hydrogen using electrolysis. A portion of the hydrogen will then mix with nitrogen to create ammonia, mostly for storage. More importantly, conversion will create carbon dioxide which will mix with parts of hydrogen to create methane or convert if needed to ethylene or other hydrocarbons. Methane, hydrocarbons or carbon dioxide will become the propellant for propulsion. The ammonia will crack into hydrogen which will divert over to the methane production process and remaining cracked nitrogen will replenish existing nitrogen reserves. The entire process is designed to improve materials efficiency, for spacecraft propulsion and operations, beyond ninety percent throughout the duration of missions.

**Test and adapt newly researched renewable energy for spacecraft propulsion and systems.**

First attempts of adapting researched renewable energy will be to ensure function and reliability. Later the technology can be modified and improved. At this point, renewable energy technology will have been proposed, researched and tested on earth and then later to test different propulsion configurations and systems with the electro fuels or hydrocarbons to confirm each works in the appropriate environment. Investigations should also include storage material test in NASA Glenn Research Center’s Glenn Extreme Environment Rig (GEERS). Testing for propulsion systems should include reactions to adaptive chemicals inside and outside vacuum chambers along with NASA Glenn Research Center’s microgravity drop tower.

**Test electro fuels, syngas, ammonia, methane, hydrocarbons along with all conversion methods.**

* Test environments: A few examples of test facilities identified for ground tests are University collaborators and NASA Glenn Research Center.
* GEERS.
* Vacuum Chambers.
* Microgravity drop tower.
* Test various chemicals, blends and gas reactions in specific environments for:
	+ Burn and thrust rate.
	+ Adaptability/convenience.
	+ Fluid separation in micro-gravity.
	+ Storage.
	+ Catalyst.
* Miniaturize Haber-Bosch and Fischer-Tropsch reactors.
	+ Reduce to a usable size best suited for spacecraft operation.
	+ Test conversion rate.
* Efficiency: Test conversion systems for efficiency in the space environment. Example: Can the conversion system of hydrogen and carbon dioxide create methane in microgravity and deliver methane at a useful rate for propulsion needs?
* Test all developed materials for potential radiation barrier use while stored.
* Test electro fuels, syngas, hydrocarbons, chemicals and gasses for material transfer in micro-gravity. Having a supply of water, hydrogen, nitrogen, methane and hydrocarbons onboard a spacecraft will be required but research new methods for chemical and gas transfer for a possible separate specific refueling spacecraft.

**Test for applications in microgravity or deep space.**

Test the modified technology in microgravity with microgravity simulation, microgravity drop towers, reduced-gravity flights, onboard International Space Station (ISS) or onboard robotic deep space flight. This stage will provide initial data for operation in a space environment.

Investigations during this phase will provide scientific data of the technology in a space environment. This data is to be used as a guide and to further improve the technology that will result in an efficient technological outcome for future missions.

**Improve technology for optimal performance in space operations.**

Once established technology has been tested in a space environment, improve specific areas for operations. This stage is currently being developed with the ion thruster and solar energy. As an example, current goals for solar power onboard a spacecraft is for solar panels to provide 400 kwh. The goal for all renewable energy during this stage is to improve performance, sustainability, durability, reliability and efficiency.

Comparisons between previous and improved performance in technology will be conducted. These investigations will commence by testing in vacuum chambers then progressing to other platforms such as testing onboard ISS, Artemis and deep space.

* Improve burn and thrust rate.
* Improve conversion rate of chemical reactors.
* Improve spacecraft components for specific fuel and power needs based on renewable energy.
* Improve efficiency regarding cost.
* Improve water, hydrogen, nitrogen, ammonia, methane and hydrocarbons storage methods for potential use as a component in radiation barrier systems.

 Improve technology to the point of extreme efficiency in cost to weight and thrust to pounds ratios. Improve renewable energy and materials performance, sustainability, durability and efficiency to the extent where it is cost effective beyond current spacecraft operations. The following questions will assist in the direction of investigations: Will it cost more to use electro fuels and synthesize needed fuels? Is it easier to refuel hydrogen and nitrogen in space, extending missions, saving money and resources? Can a thruster using electro fuels or hydrocarbons produce more thrust than conventional fuels? Can electro fuels or hydrocarbons provide longer missions?

**Synergize and Synthesize**

During this stage, the objective is to bring all researched and tested technologies together attempting to synergize electric power, newly developed thrusters, life support systems, and synthesize required fuels. Investigations will need to focus on combining technologies where possible. By-products of one system going to another system and continue the chain until all waste onboard a spacecraft is being utilized to provide maximum performance, sustainability, durability, reliability and efficiency while creating a recyclable atom economy. Expanding research into this field will create a wake of new technology while further advancing procurement of affordable renewable resources for struggling economies and countries on earth improving the lives of millions, which is also a SMD priority.

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