*State of Play*

# EMERGING, IN-SPACE PROPULSION TECHNOLOGIES

## *Commercial Technologies and New Programs*
## *Summer 2021*

Change is coming to in-space propulsion. This edition of state of play looks at what's happening with emerging technologies for nuclear, electric, and solar propulsion.

### Overview

The marketplace has arrived at a point where multiple companies have advanced technology for nuclear, electric, chemical, and solar propulsion that could dramatically improve Earth-centric space operations and interplanetary exploration in the years and decades to come. Below we survey technologies and the market's "state of play" for insight into near and medium-term developments.

### Key Technologies and Developments

**Nuclear Propulsion—What Is It?**

Nuclear propulsion derives from two atomic processes, fission and fusion. In ***fission***, a "hot rock" of uranium atoms releases high-energy neutrons to create heat. Hydrogen propellant is then passed through the reactor for propulsion. The term "Nuclear Thermal Propulsion" (NTP) generally implies fission. For ***fusion***, atoms of deuterium or tritium (isotopes of hydrogen) are forced together to become heavier atoms which in turn releases tremendous heat. This process creates hot fusion plasma, which either has propellant directed around/through it, or is directly exhausted out a nozzle for propulsion.

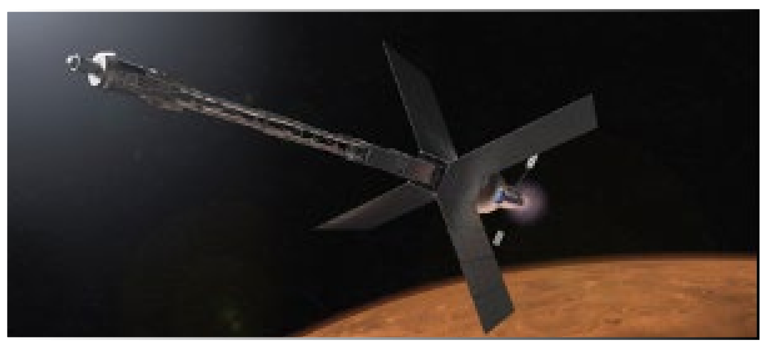


Illustration of a Mars transit habitat and nuclear propulsion system that could one day take astronauts to Mars. Credit: NASA/Advanced Concepts Laboratory.

**Nuclear *fission* propulsion** offers more propulsive energy with less propellant compared to conventional chemical combustion systems. This is an attractive option for cis-lunar and interplanetary missions. In April 2021, DARPA awarded contracts for an NTP spacecraft (**Blue Origin, Lockheed**) and reactor design (**General Atomics**) as part of its DRACO program focused on "space domain awareness in cis-lunar space." Meanwhile, NASA is seeking space engine reactor design concepts from industry and working with the Department of Energy targeting a round trip, crewed mission to Mars of two years. **Nuclear *fusion* propulsion** development companies have received significant venture capital funding to pursue this "green" technology. Due to the temperatures achieved, fusion propulsion has a very high efficiency compared to chemical and fission systems.

Spacecraft propelled by nuclear fission or fusion are now being researched as a faster means of traveling the solar system. Illustration: NASA.

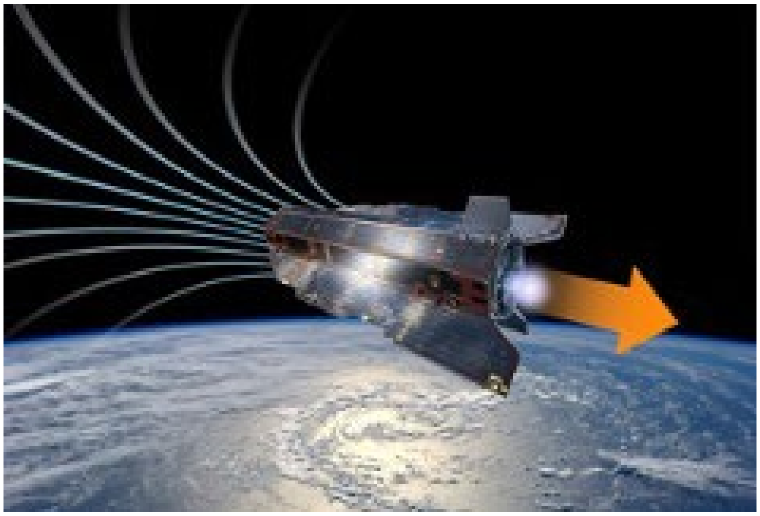
For example, the Space Shuttle has 440 sec specific impulse (Isp), whereas nuclear fusion propulsion may enable an Isp in the high thousands of seconds. The downside is that fusion propulsion does not produce as high thrusts and accelerations as fission or chemical concepts, thus potentially increasing travel time. Fusion may enable even more payload transported to Mars as well as non-standard trajectories to anywhere in the solar system.

Numerous companies are pursuing fusion propulsion concepts, including Caltech spinoff Helicity Space, which is developing a scalable pulsed concept that directly exhausts the fusion products. Other companies include TAE Tech with an $880M investment by Goldman Sachs and others, **Commonwealth Fusion** Systems with $250M by Gates and others, General Fusion in British Columbia with $200M from Jeff Bezos and others, Helion Energy with $80M from angel investors, and Zap Energy with $10M from Chevron. Given that sustained, long-duration fusion has not been realized even at the laboratory scale, fusion is still appreciably immature compared to NTP systems. Based on its enabling mission advantages, however, commercial companies' use of newer design and rapid-production techniques, and their recent validation with venture capital funding, fusion propulsion may eventually become a credible technology of the medium- to far-term future.

**Nuclear electric** propulsion (NEP) is being researched as a viable alternative for solar- or battery-powered electric propulsion. Instead of solar or battery systems providing direct electrical energy to a conventional electric propulsion system, NEP uses a nuclear fission- or fusion-based reactor to heat a working fluid to produce electricity. The electricity then directly powers the EP system. A February 2021 study by the National Academy of Sciences notes that Nuclear Electric and NTP both need to overcome technical hurdles on the path to a crewed mission to Mars in the 2030's.

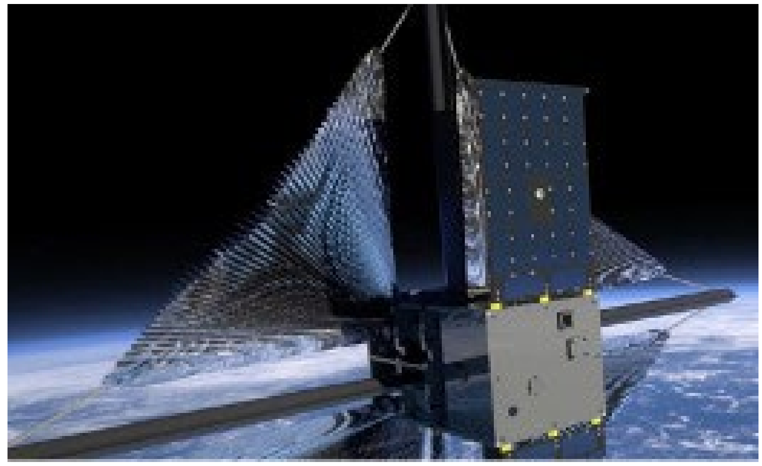
**Electric propulsion** uses electrical energy to accelerate ions to produce a low thrust. For specific applications, electric propulsion provides excellent in-space capabilities. In December 2020, French startup ThrustMe performed the first on-orbit tests of an **iodine fueled electric propulsion** system, proving its ability to change a CubeSat's orbit. According to the company, the system was tested during two 90-minute burns and resulted in a total altitude change of 700 meters. ThrustMe claims that iodine propellant allows propulsion systems to be "delivered completely prefilled to customers and allows for a simpler satellite integration process." Iodine-Fueled Electric Propulsion uses a Hall thruster with iodine as the propellant. Another novel approach is taken by Momentus, developing a microwave electrothermal system using water as the propellent. Should there be supplies of water on celestial bodies, this could be significant.

**Air-scooping electric propulsion (ASEP)** is a cutting-edge concept for spacecraft propulsion that does not require any propellant at all. An ASEP ingests scarce air molecules from the upper atmosphere for propellant. This extends the lifetime of satellites in very low Earth orbits by providing periodic reboosting to maintain orbital altitudes. Although an ASEP spacecraft has not yet flown, recent **Japanese and European Space Agency** experiments have demonstrated that electric propulsion can effectively counter atmospheric drag, including this recent ground test. **The Aerospace Corporation** recently extended the state-of-play with this paper focused on ASEP design and atmospheric challenges, as well as new applications and mission opportunities.



Artist's concept, air-scooping electric propulsion satellite. Image Credit: ESA.

**Solar sailing** is a method of spacecraft propulsion using mechanical pressure exerted by sunlight on large mirrors, similar to wind pushing a sailboat. High-energy laser beams could be an alternative light source to exert greater force than sunlight (known as "beam-sailing"). A solar sail-propelled spacecraft could reach distant planets and star systems much more quickly than a rocket-propelled spacecraft because of the continual acceleration that solar sailing provides. In 2010 Japan's IKAROS was the first spacecraft to successfully demonstrate solar sail technology with a Venus fly-by. In 2019, **The Planetary Society's** LightSail 2 launched a solar sail spacecraft that uses sunlight to change its orbit. In November 2021, **NASA** will launch NEA Scout, a low-cost, solar sail CubeSat that will demonstrate the capability of a small spacecraft in cis-lunar space to perform reconnaissance of an asteroid.



Solar Sail. Image credit: NANOAVIONICS/NASA.

## Future Outlook

We expect the pace of change to accelerate, and the number of new commercial space technology companies to continue to grow for at least the 3–5 year timeframe. This is due to increasing government and commercial demand for propulsion technologies; new, low-cost, rapid methods of developing and testing emerging technologies; and continuing availability of investment capital, both from the private sector and U.S. Government agencies. Overall, we are likely to see new market entrants in virtually all of these in-space propulsion technologies. In particular we expect to see an increase in efforts to find a breakthrough case for nuclear fusion propulsion, and we expect increasing coordination among the U.S. Government space-faring organizations of NASA, USSF and others where it comes to funding technologies with overlapping mission benefits. Advances in electric and chemical propulsion are expected to move at a slower rate than nuclear propulsion, while for niche missions, solar sailing is slowly being mainstreamed by virtue of its JAXA and Planetary Society space heritage, and NASA's upcoming NEA Scout program.


## By Laura Speckman with Aerospace Corporation Contributors:

Andrew Cortossi
Thomas Curtiss
Andre Doumitt
Tom Heinsheimer
Andrea Hsu
Patricia Maloney
Greg Meholic
Julie Reiss
Slava Spektor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