Helium-3 Fusion

by Natalie Lovegren

It can be argued, conservatively, that at least an eight-fold increase in annual [energy] production will be required by the middle of this century. That includes a two-fold increase to account for the increase in the world population from 6.3 to 12 billion and a four-fold increase to meet the major aspirations of four-fifths of the world's peoples whose standards of living are far below those of developed countries. Even an eight-fold increase would not bring the rest of the world to the current average per capita energy use in the United States of about 62 barrels of oil per year equivalent...that would take at least an eleven-fold increase, not counting the demands of new technologies…
— *Harrison Schmitt, Return to the Moon, 2007*

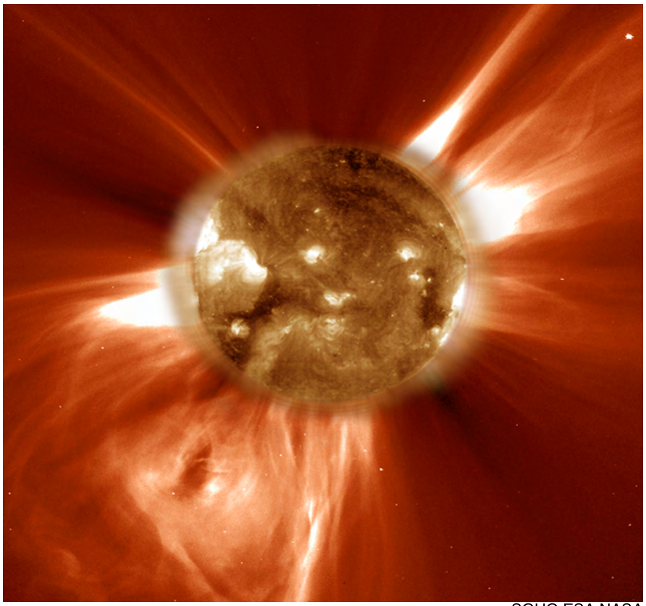
An 11-fold increase in energy availability is only possible by means of the greater power present in controlled thermonuclear fusion. No other energy source— or "portfolio" of various weaker fuels— in terms of energy density or quantity of energy potential can compare to fusion.

The moral imperative for bringing the majority of the human population up to human standards should be enough of an impetus to commit to its achievement. But this is not all that fusion offers. Far from simply increasing the quantity of energy and then using it in the same way that energy is used in the currently collapsing Transatlantic economic system, the *fusion economy* represents a qualitative change in the potential for human progress.

Helium-3 fusion reactions represent the most advanced form of energy that is currently within our grasp. Helium-3 fuels are the most energy dense out of any currently in use or under experimentation, and have the highest electrical conversion efficiency of any form of electricity, making them unparalleled as an energy source. This is due to the fact that reactions using helium-3 are largely aneutronic. This means that instead of yielding neutrons, which deliver their energy as heat, and must be sent through a steam cycle to generate electricity, helium-3 reactions generate charged particles which can be converted into electricity directly. This difference represents a doubling in electrical conversion efficiency. In addition, they are an ideal fuel source for propulsion, providing fuel efficiency advantages superior to any chemical, nuclear or even other potential fusion rockets, thus opening up mankind's access to hitherto unreachable regions of the cosmos. It is, in all respects, the ideal fuel of the future. And the future must begin now.

In 1985, fusion scientists at the University of Wisconsin's Fusion Technology Institute[1] also realized the superior value of helium-3 for nuclear fusion reactions, and wondered where it could be obtained. Unlike the more common isotope, helium-4, helium-3 is extremely rare on Earth. It soon occurred to them that the Sun, a giant nuclear fusion reactor, which produces helium as a byproduct of fusing hydrogen, might be a useful source of helium-3.

The Sun emits hydrogen, helium and other charged

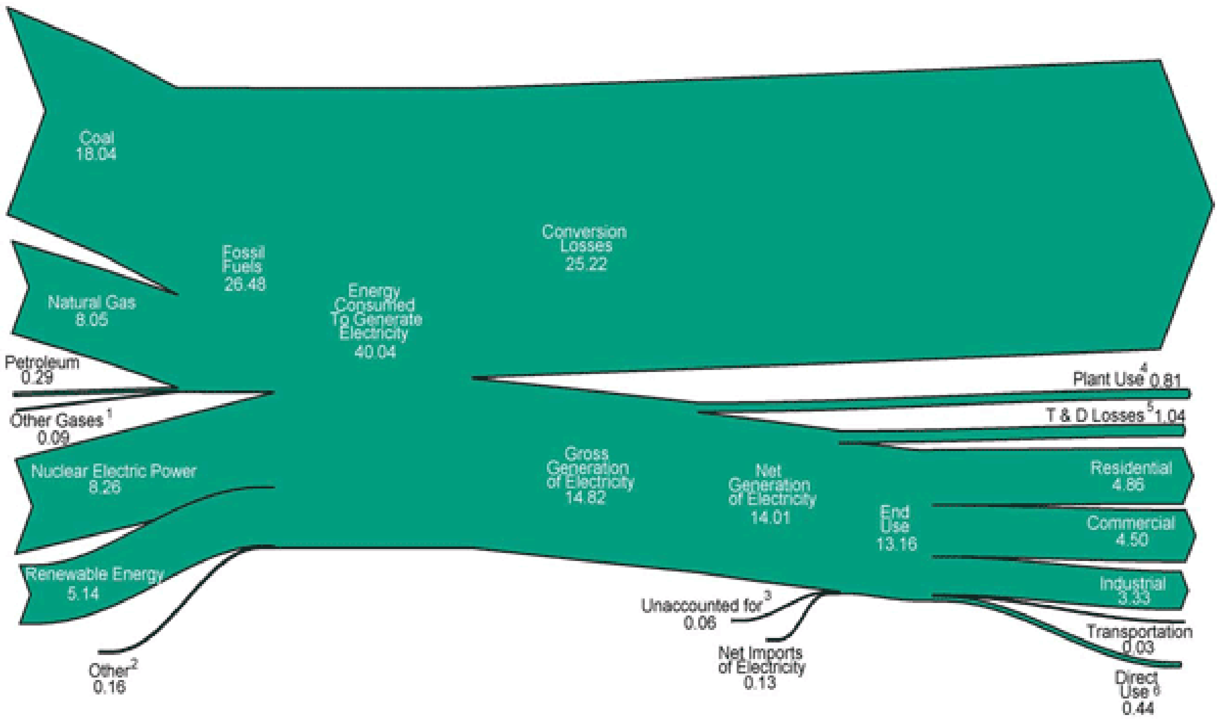


SOHO,ESA,NASA

A coronal mass ejection, an especially massive burst of solar wind. The solar wind is a plasma that consists of a stream of hydrogen, helium, and other ions, formed as a byproduct of nuclear fusion.

1. See interview with Fusion Technology Institute Director Gerald Kulcinski, published in the September 5, 2014 issue of *Executive Intelligence Review*, entitled "Will the United States Join the Helium-3 Fusion Revolution?".

Electricity Flow, 2011 (Quadrillion BTU)



Source: EIA

Approximately two-thirds of energy is lost during the conversion to electricity. The left side shows total energy input by type.The top represents conversion losses, and the bottom represents net generation of electricity.

particles into the solar system, in the form of a far-reaching plasma called the solar wind. While the Earth is largely shielded by an atmosphere and a strong magnetic field, the Moon is exposed[2], and vulnerable to space weather such as the solar wind. The Wisconsin fusion scientists made the hypothesis that helium-3 could be found on the Moon. In 1986, they made a trip down to NASA's Johnson Space Center in Houston, to scour the records of Apollo lunar samples. Indeed, records showed helium-3 to be present in every lunar sample. Lunar scientists whom they queried about the rare isotope were puzzled. They said that they had known since 1970 that there was an abundance of helium-3 on the Moon, but were not aware that it was useful for anything. Of course, it was not useful for anything in 1970, because the discovery of its vital importance as a fusion fuel had not yet been made.

Since then, researchers have found that helium-3 is held in the dust on the surface of the Moon and could be extracted relatively easily. Scientists at the Wisconsin Center for Space Automation and Robotics have designed vehicles to separate helium-3 from the lunar soil.

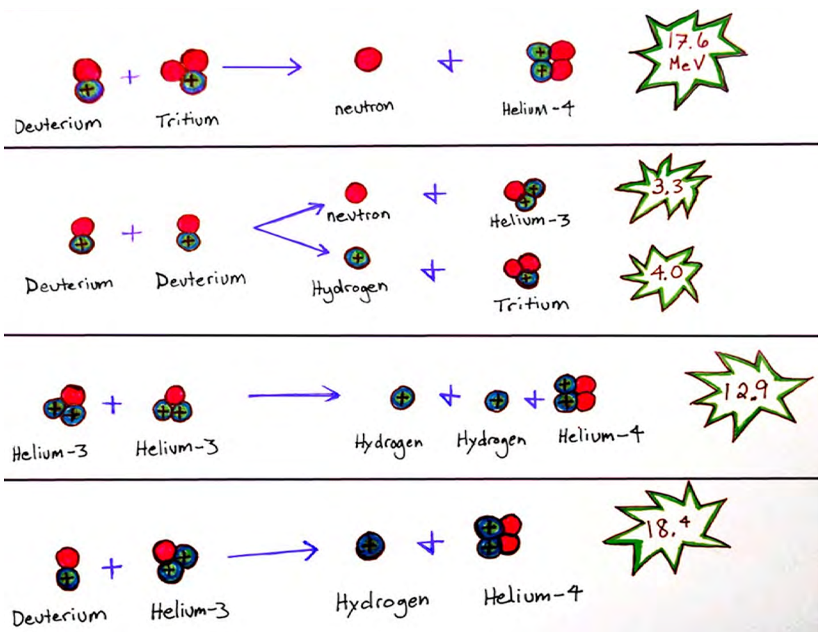
It can be released from lunar soil by heating it to temperatures of 600-700°C, and recooled into a liquid during the cold lunar night. This can be done by concentrating solar energy with mirrors, or by using microwave energy, which has a unique coupling effect with lunar soil,[3] that allows it to be heated very efficiently with microwave energy. The potential reserves of helium-3 are estimated at one million tons, which could power the

Energy Source	**Conversion Efficiency with a Steam Cycle**
Wood Derived Fuels	23%
Coal	31%
Nuclear Fission	33%
Petroleum	35%
Total	**31%**

Source: 2011 EIA Data for NH

2.But not completely and always exposed. In 2009, the Indian Chandrayaan-1 spacecraft found a 360-km wide mini-magnetosphere on the Moon, formed above the strong magnetic anomaly near the Crisium antipode. The Moon is also temporarily protected by the Earth's magnetotail as it orbits behind the Earth, out of direct reach of the Sun. This is when it appears to us as a full moon.

3. See "Chemistry on the Moon, the Quest for Helium-3," in this report.



21st Century

Fusion reactions with helium-3 yield positively charged hydrogen nuclei (protons) and positively charged helium-4 nuclei (alpha particles). The second generation D–^{3}He reaction produces the greatest amount of energy out of the four reactions: D + ^{3}He → p (14.7 MeV) + ^{4}He (3.7 MeV), totalling 18.4 MeV.

Earth in fusion reactors for 1,000 years. This fossil of the Sun is magnitudes more energy dense than any petroleum product, such that less than two shuttle loads could supply the entire U.S. with electricity for one year.

Helium-3 Electricity

Helium-3 fusion reactions represent a qualitative power increase, in terms of both the energy density of the fuel, and also the increased efficiency of energy conversion. Since the beginning of the modern era of electricity production, with the advent of the steam-powered turbine in 1884, the primary source of energy has been based on rotary motion to drive an electrical generator. Today, approximately 90% of all electricity generation in the United States comes from thermal power plants, which use steam turbines. During the process of using heat from burning fuel to boil water to make steam to spin a turbine in a magnetic field to induce an electric current, a significant portion of energy is lost.[4] On average, this loss represents 60-70% of total energy. Helium-3 fusion reactors offer the potential to liberate us from this 130-year old technology, by eliminating the turbine altogether, thus doubling the efficiency of energy conversion, and moving us into the next era of electricity production.

Helium-3 Reactions

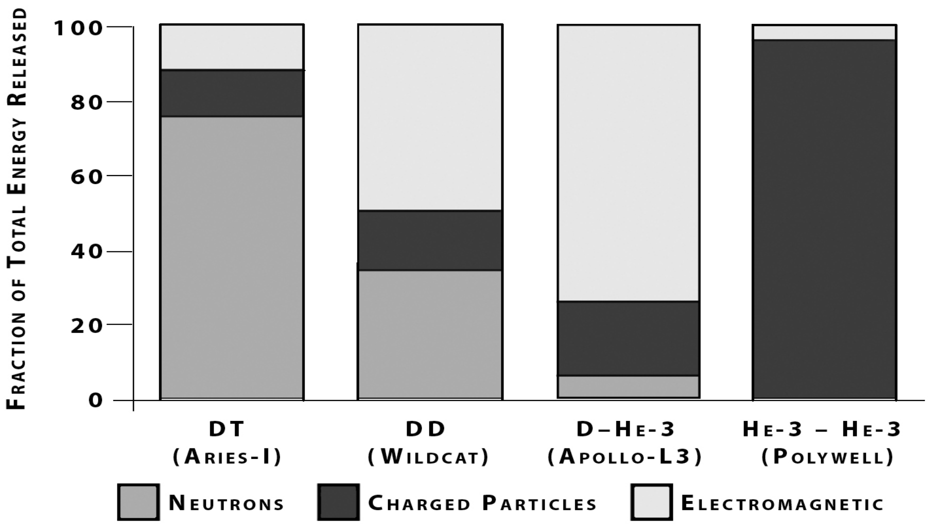
In order to understand this, we must further examine what sets this fuel apart from other fusion reactions, as well as nuclear fission and chemical fuels. When the nuclei of different types of light atoms are forced together in the process of thermonuclear fusion, they make various products. Among those products may be found: positively charged particles, neutral particles, and different forms of electromagnetic radiation. The types of charged particles, neutrons, and photons that are emitted depend on the types of reactants and types of motion the products undergo as a function of the reactor type. The various products serve different purposes for energy production.

A first-generation[5] fusion reaction involves two isotopes of hydrogen—deuterium and tritium (DT). When these isotopes fuse, the reaction generates neutrons, photons, and charged helium nuclei (alpha particles). Eighty percent of the energy from this reaction is released in the form of kinetic energy from the motion of the high-energy neutrons. Although the energy released per unit mass of this fusion fuel is higher than in fission reactions, the same physical process is at play. Because neutrons are neutrally charged they do not respond to a magnetic field, and are thus very hard to control. Therefore, the only way to extract energy from them is to use them to power a steam cycle. Because neutronic forms of fusion such as DT would use a steam cycle, which is the same method by which we extract energy from almost all of our fuels, its electrical conversion efficiency is roughly the same.

A second generation reaction, using helium-3 and deuterium, generates very different fusion products. A reaction between a helium-3 and deuterium ion will yield

4. Coal, nuclear, oil, geothermal, biomass, solar thermal electric all use a steam cycle. Hydroelectric, wind and photovoltaic solar do not. Natural gas can be used with either a steam turbine or a gas turbine.

5. These fuels are ranked according to the difficulty with which they are thought to be able to achieve fusion. While first generation DT reactions are so classified because they are considered the easiest to achieve in terms of the temperature, pressure and confinement times required for magnetic confinement fusion, this practical approach (often a response to budget cuts and bad economic policy) may not be the fastest way to achieve commercial fusion, after all. A side effect of using an aneutronic helium-3 reaction is that we will avoid the extra engineering, maintenance and fuel-processing challenges that come with the nuclear radiation of DT reactions. We will not have to deal with the high-energy, out-of-control neutrons that wreak havoc on reactor walls and other metallic components, and require radiation shielding and cooling towers. By eliminating the time and expenses required to develop these materials, we may concentrate our resources on plasma physics.



Adapted from: Kulcinski, G.L. and Schmitt, "Nuclear Power Without Radioactive Waste—The Promise of Lunar Helium-3" (2000)

Fusion reactions release energy that can come in three forms: the motion of neutrons, the motion of charged particles, and electromagnetic radiation (photons, or forms of light). The type of energy released depends not only on the fuel input, but on the design of the reactor, which may enable different kinds of motion of charged particles, resulting in various forms of electromagnetic radiation. This diagram indicates energy release breakdowns for several proposed fusion reactor designs.

a proton and an alpha particle (helium-4 nucleus). But these ions do not always pair up perfectly, and sometimes there are reactions between two deuterium ions, which yield a neutron and a helium-3 ion. Reactions yielding neutrons may be suppressed by controlling the plasma temperature and by keeping a lower ratio of deuterium ions compared to helium-3 ions in the fuel. Through these measures, very few neutrons may be produced (1-5% of energy).Thus, the majority of the products will be in the form of charged particles (protons and alpha particles) and photons. Because charged particles—as opposed to neutrons[6]—respond to a magnetic field, they can be controlled and directed. Instead of having to convert the heat generated from neutrons into electricity, the charged particles and electromagnetic radiation may be directly converted to electricity. Direct conversion methods yield efficiencies of 60-70%.

A third generation fusion reaction uses helium-3 as both agents in the reaction. In an electrostatic[7] device, 99% of the resulting energy is in the form of charged particles, which can be directly converted into electricity, yielding an electrical conversion efficiency of 70-80%. A ^{3}He–^{3}He reaction yields a ^{4}He ion and 2 protons. There are no neutrons or radioactivity produced in a ^{3}He–^{3}He reaction.[8]

Direct Conversion

Magnetohydrodynamics—the dynamics of electrically conducting fluids[9]—can be exploited to generate electricity directly. A moving charge under the influence of a magnetic field, will be deflected. By passing a charged particle plasma (which conducts current) through a magnetic field, the charge is deflected to one side by the magnetic field, creating a potential difference and the flow of current.

In addition to charged particles, electromagnetic radiation can also be converted into electricity. When charged particles are accelerated in a tokamak, the interaction of the curved motion with a magnetic field emits electromagnetic radiation called "synchotron radiation." This radiation can range over the entire electromagnetic spectrum and can be tuned to make use of specific wavelengths for conversion into electricity or for non-electrical applications.[10]

6. It should be noted that neutrons are not inherently bad things. They are very efficient at transmutation, which is necessary for the production of life-saving medical isotopes, and for the reprocessing of spent nuclear fuel. See "Fusion: Basic Economics" in this report. In a process such as desalination, where heat may be used for evaporation, a neutron-producing fusion or fission process can both generate electricity, while using waste heat for the desalination process.

7. Kulcinski, G.L. and Schmitt, H.H., "Nuclear Power Without Radioactive Waste—The Promise of Lunar Helium-3," 2000.

8. Kulcinski,G.L. "Helium-3 Fusion Reactors—A Clean and Safe Source of Energy in the 21st Century," 1993.
While ^{3}He- ^{3}He is perfectly aneutronic, the energy yielded is less than the D-^{3}He reaction (12.9 Mev as compared to 18.4 MeV).

9. E.g.: plasmas, liquid metals, and salt water or electrolytes.

10. One method for converting radiative energy into electricity uses a rectifying antenna called a "rectenna" to convert microwave energy into direct current electricity. The inventor of this device, William C. Brown, reported to NASA's Second Beamed Space-Power Workshop in 1989 that he had demonstrated an 85% electricity conversion efficiency. Freeman, Marsha, "Mining Helium on the Moon to Power the Earth" 21st Century Science & Technology, Summer 1990. The design for the Apollo-L3 1,000 MWe D-He-3 tokamak fusion power plant estimates that synchotron radiation in the form of microwaves can be converted to electricity via rectennas at 80% efficiency. (G.L. Kulcinski, G.A. Emmert, J.P. Blanchard, L.A. El-Guebaly, et al. "Apollo-L3, An Advanced Fuel Fusion Power Reactor Utilizing Direct and Thermal Energy Conversion," *Fusion Technology* **19** (1991) 791.

Helium-3 Fusion Non-electric Applications

The high energy protons (14.7 MeV) obtained from D-^{3}He reactions are a unique product that can be used for the transmutation of elements necessary in medical isotope production and in the reprocessing of spent fuel from nuclear fission reactors.

Recycling Fission Products

Nuclear fission is the highest energy density source of electricity currently commercially available and its use must be greatly expanded to immediately serve the needs of the world population during the transition to a fusion economy. The full recycling of used nuclear fuel (UNF) will be an important part of this transition, as it will greatly increase fuel efficiency and reduce the wasteful and hazardous accumulation of valuable radioactive spent fuel.[11]

The purpose of recycling is to recover the unused portion of fissile materials (e.g., uranium and plutonium) so that they are not wasted and can be used as fuel. These materials account for approximately 97% of what is referred to as "nuclear waste."[12]

Some of the long-lived fission products present in the remaining 3% of spent fuel are not useful as fuel and are currently stored under high security so that they can slowly decay without harming the biosphere. A better option than storage for centuries would be to transmutate these long-lived actinides into shorter-lived isotopes that will decay more rapidly, making them less hazardous, or even making them valuable in medicine or industry.

Some of these fission products have a small neutron cross section, meaning it is difficult to transmute them using neutrons. However, the high energy protons produced in D-^{3}He reactions may be uniquely capable of the transmutation of these tricky isotopes, and offer us a potential for efficient disposal of long-lived fission products.

Medical Isotopes

Positron emission tomography (PET) is a radiology procedure widely used by oncologists, neurologists and cardiologists to diagnose conditions and track changes symptomatic of disease in the brain, central nervous system, heart, and other organs. It is a major diagnostic of cancer, and has proved its superiority to other imaging methods (MRI, ultrasound, etc.) by being able to detect unsuspected metastases.

PET works by using a radiotracer that can be imaged when it decays. The radiotracer is made by attaching a radioactive atom to substances that are normally metabolized by a particular organ, such as glucose. When the radionuclide emits a positron, and this positron (the "antimatter" of the electron) comes into contact with an electron, they are both annihilated, and their masses are converted into energy in the form of gamma rays. The two "annihilation" photons that are produced each have the precise energy of 0.511 MeV, which is detected by PET scanners.

One of the most important radiotracers used for this technology is ^{18}F, used to make ^{18}F-fluorodeoxyglucose (FDG). This is based on the fact that cancer cells become inefficient at converting glucose into energy, and require 20-50 times more glucose than healthy cells. The cancer becomes a glucose magnet, and the FDG, which can be thought of as a type of "glow-in-the-dark" glucose, "lights up" as the cancer concentrates it.

Parent Isotope	Production Reaction	PET Isotope	Half-Life in Minutes
^{18}O	(p,n)	^{18}F	110
^{94}Mo	(p,n)	^{94m}Tc	52
^{14}N	(p,α)	^{11}C	20
^{16}O	(p,α)	^{13}N	10
^{13}C	(p,n)	^{13}N	10
^{15}N	(p,n)	^{15}O	2

The above isotopes can be transmuted using protons (p) to yield neutrons (n) or alpha particles(α), and short-lived radioactive elements that can be used in medicine.

The production of this special glucose requires that fluorine-18 be generated by transmutation of an oxygen-18 isotope. When the stable oxygen-18 atom (10 neutrons, 8 protons) is bombarded by a proton, it takes in that proton, and releases a neutron, becoming fluorine-18 (9 neutrons, 9 protons). But the type of proton required to achieve this effect must be high energy—10 MeV or greater.

The fusion of deuterium and helium-3 produces a 14.7 MeV proton.[13] Fusion of these ions in a small Inertial Electrostatic Confinement (IEC) device[14] provides an efficient source of these high energy protons.[15]

11. While France obtains 17% of their electricity from reprocessed UNF, the United States does not reprocess it at all.

12. More aptly named "wasted nuclei."

13. For comparison, the average energy of the neutrons effective in inducing fission is approximately 2.8 Mev.

14. Inertial electrostatic confinement uses an electric field to heat a plasma. Electric fields can be used to heat up charged particles (either ions or electrons) to fusion conditions.

15. A 1 watt IEC fusion power source could make the equivalent of

Furthermore, high energy protons generated by a small, compact fusion device such as an IEC can be made on site, in a hospital room, to produce even shorter-lived radioisotopes for PET scans.

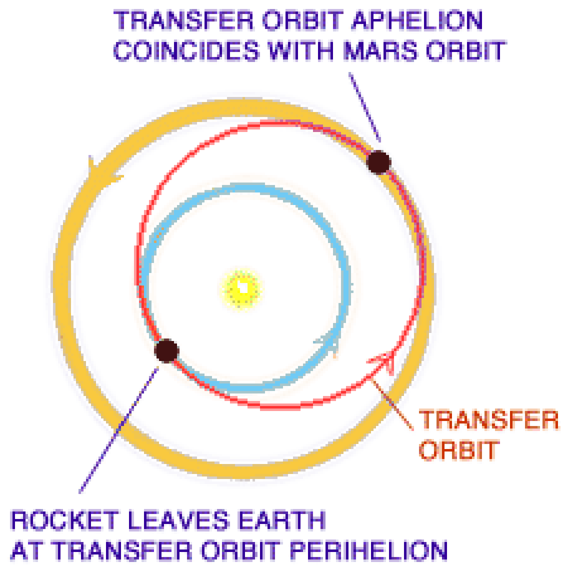
Doctors would prefer to have isotopes with the shortest possible life so that the patient is exposed to the least amount of radiation possible. Without a device to generate them on site, these isotopes must be transported from afar, and would decay before reaching the patient. While the ^{18}F radioisotope has a half-life of 110 minutes, there are even more valuable isotopes that can be produced with high energy protons from a D-^{3}He fusion device.

Helium-3 Fusion Rockets

Helium-3 will change our relationship to the Cosmos. Helium-3 will greatly facilitate our development of the Moon itself as a base of operations. The development of helium-3 fusion reactors on the Moon would give us a unique power for industrial and agricultural applications that could take advantage of the low gravity, near vacuum, extreme temperature changes, and other conditions. This is an ideal fuel for use on the Moon and other space applications, because it is available on site, and because the direct conversion to electricity mitigates thermal losses.

Whether for robotic deep-space missions or manned interplanetary space travel, the future of space exploration requires thermonuclear fusion propulsion. As stated by fusion scientist John Santarius, "Fusion will be to space propulsion what fission is to the submarine."

Fusion fuel far exceeds the energy density of chemical fuel, allowing for much less fuel mass, and, crucially, making it possible to fly missions that simply could not be undertaken with chemical propulsion, such as reducing the transit time to Mars from many months down to mere weeks, as well as enabling an effective strategy for planetary defense.[16] Higher travel speeds and shorter trip durations reduce astronauts'exposure time to the deleterious effects of cosmic radiation and low gravity. Using



Source: NASA

Earth to Mars via Least Energy Orbit. A new orbit is made between Earth's orbit and Mars' orbit. The rocket leaves the Earth at the new orbit's closest point to the Sun (the transfer orbit perihelion), and it arrives in Mars' orbit at its farthest point from the Sun (aphelion). This allows for the least expenditure of energy. Because Mars and Earth are both moving, a minimum-energy transfer orbit to Mars is only possible about every 25 months. With a fusion rocket, we could use more than the least amount of energy and could arrive at Mars via a faster and more direct route.

Exhaust Velocities for Different Rocket Fuels

Chemical	3,000 m/s
Fission	50,000 m/s
Fusion	100,000,000 m/s

One of the major factors that determines how fast the spacecraft is able to travel is the speed at which the propellent is ejected as exhaust. Chemical rockets burn liquid hydrogen and liquid oxygen, and the vapor that comes out as the exhaust travels at three thousand meters per second. Nuclear fission provides much faster-moving exhaust particles—fifty thousand meters per second—but fusion will provide an order of magnitude increase in exhaust velocity, to one hundred million meters per second.

1-10 useful doses for the diagnosis of a wide range of cancers. These reactors have demonstrated feasibility in the US and Japan. According to the 2003 FESAC report, "These devices have already produced small quantities of ^{94m}Tc isotopes by bombarding ^{94}Mo with protons from a D-^{3}He reaction. The PET isotope ^{13}N has also been produced using the D-^{3}He reaction. The current cost estimate of an IEC device designed to just produce PET isotopes is in the $50-100K level."

R. P. Ashley, G. L. Kulcinski, J. F. Santarius, S. Krupakar Murali, G. Piefer, and R. Radel, "D-^{3}He Fusion in an Inertial Electrostatic Confinement Device", p. 35 in the 18th IEEE/NPSS Symposium on Fusion Engineering, Oct. 1999, Published by IEEE, 99CH37050, and R. P. Ashley, G. L. Kulcinski, J. F. Santarius, S. Krupakar Murali, G. Piefer, and R. Radel "Steady State D-^{3}He Proton Production in an IEC Fusion Device", Fusion Technology, Vol. 39, p. 546 (2001).

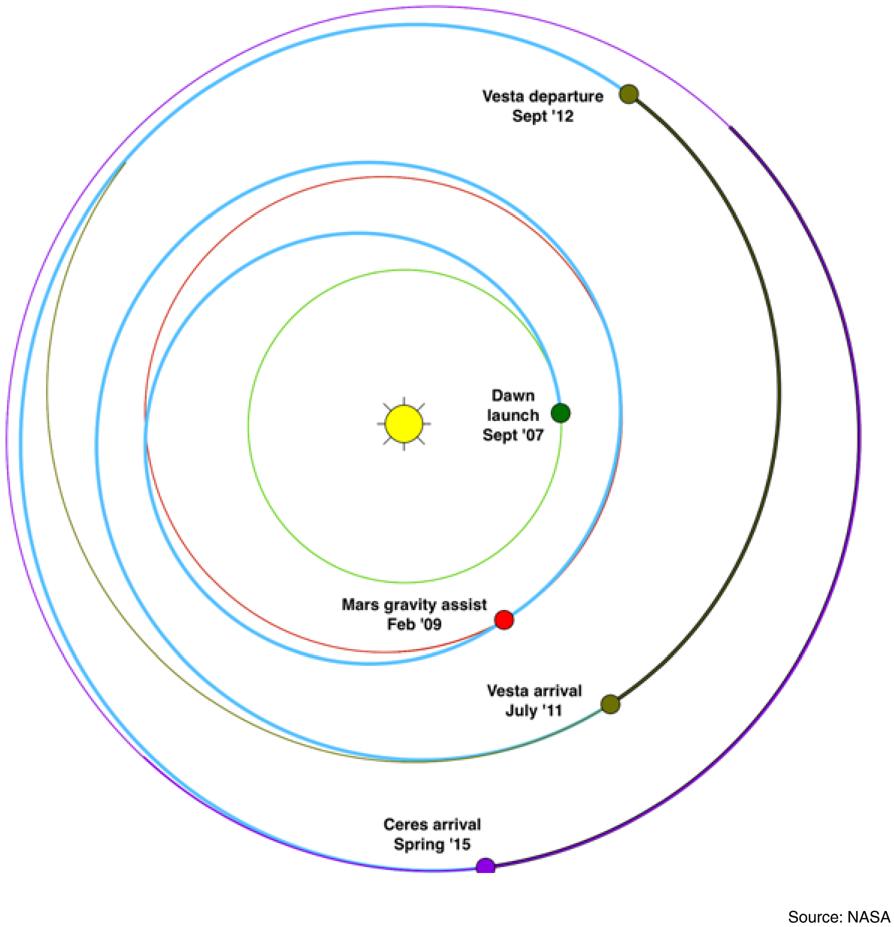
16. See the special report on planetary defense: 21st Century Science & Technology, Fall/Winter 2012–2013

the aneutronic helium-3 fuel also eliminates the need for the heavy radiation shielding, which becomes unwanted added mass in space. On Earth we are not as concerned with the weight of the protective shielding that must be added to nuclear reactors that use radioactive materials. But in space, any increase in mass that the spacecraft must carry requires more energy, and therefore even more fuel.

Transfer Orbits

The routes currently used for interplanetary travel— *Hohmann transfer* orbits—are charted out by creating an elliptical orbit that is tangent to the orbit of the Earth (or other planet of departure) and the orbit of the destination body.

This approach conserves fuel by allowing the spacecraft to essentially coast in its own orbit. It may be compared to a slow boat which reduces or eliminates fuel use by taking advantage of ocean currents to carry it. This simple elliptical trajectory may be augmented to to use "gravity assists" from other planets, thus requiring multiple revolutions around the Sun. These routes are planned out far in advance to coincide with the positions of each planet as the spacecraft passes it, so that it may take advantage of the gravity of these bodies. As the spacecraft approaches a planet, the gravity of that planet changes the speed and trajectory of the spacecraft, giving it a boost. The orbits of each planet, and the gravitational forces associated with them in relation to the Sun and other planets create a system of predictable "currents" that are utilized for this purpose. This "slow boat" approach, while conserving fuel, requires very circuitous routes to accommodate the orbits and gravitational forces of each planet encountered—anything but the least distance to arrive at the destination.



NASA's Dawn spacecraft has had to make multiple revolutions of the Sun on its journey to reach the asteroids Vesta and Ceres.

Specific Impulse for Different Rocket Fuels

Chemical	450 seconds
Fission	1,000 seconds
Fusion	100,000 seconds

Another way of comparing different propulsion fuels is by measuring their specific impulse. This figure, measured in units of seconds, describes the efficiency of the fuel used—it is the impulse per unit weight of the rocket propellent. Fusion promises an order of magnitude increase over both chemical and nuclear fission fuels.

A trip to Mars using the Hohmann orbit requires 260 days—a duration which exposes humans to dangerous levels of cosmic radiation, (not to mention the added payload needed to sustain human life for eight months).

With the higher energy density of fusion fuels, as new type of space travel is possible—constant acceleration—allowing Mars to be reached in a matter of weeks.

Magnetic Nozzles

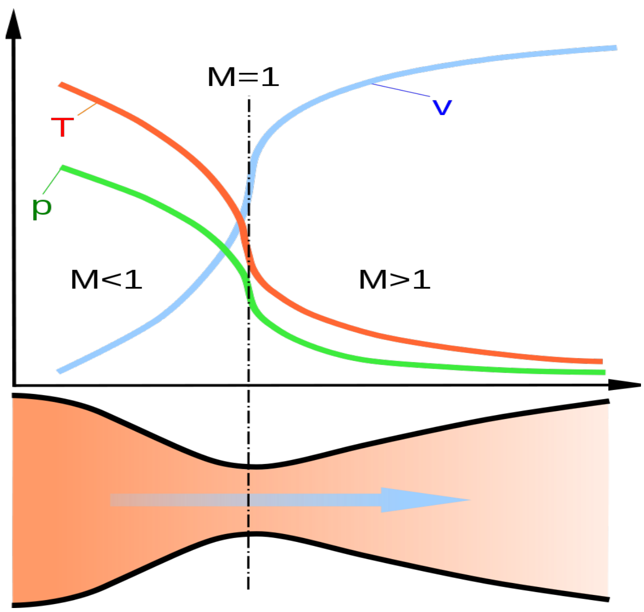
A common water hose nozzle accelerates and focuses water by forcing the constant stream of water through a smaller area. Because the flow from the source remains constant, the water particles that reach the narrower part of the nozzle must speed up to get out of the way of the water particles coming behind it.

A rocket engine nozzle works in a similar way. Except, in a rocket, we are not dealing with water at a common temperature, but very hot, pressurized gases, that behave differently when they are traveling below and above the speed of sound. The de Laval nozzle, used for rockets and supersonic jet engines, relies on the difference in behavior between gases moving at subsonic and supersonic speeds.

The nozzle is shaped like an hourglass, with one end more slender than the other. This nozzle is also called a convergent-divergent (CD) nozzle, because after leaving the combustion chamber, the gases, which are traveling slower than the speed of sound, converge at the nozzle's throat—traveling at the speed of sound—and then diverge into a bell section, accelerating to faster than the speed of sound.

A regular rocket nozzle would not function in a fusion rocket, because the extremely high temperatures of a fusion plasma would destroy the solid walls of the nozzle. The magnetic nozzle would use magnetic fields instead of solid matter to imitate the shape of the converging-diverging nozzle, and direct the hot plasma, expanding and accelerating it to supersonic speeds.

A helium-3 fusion rocket would emit charged particles as exhaust, therefore allowing the fusion products to also be controlled by magnetic fields. Researchers in the 1960s realized that deuterium-helium-3 fuels in a fusion rocket would thus allow for not only the greatest power density, but for a more manageable exhaust, and therefore greater degrees of control over the rocket itself.



Source: Kaboldy

As the gas is accelerated through the nozzle from subsonic to supersonic velocities, temperature and pressure decrease.

A 1966 paper by Dwain Spencer entitled, "Fusion Propulsion for Interstellar Missions" described a D-^{3}He burning rocket engine whose combustion chamber was lined with superconducting magnetic coils to contain the plasma. In theory, the exhaust from such a rocket could be accelerated to propel the spacecraft up to speeds of three-fifths the speed of light, making it possible to reach our next nearest star in fifty years.[17] The British Interplanetary Society's Project Daedalus studied a helium-3 fueled interstellar spacecraft that would also reach a star in 50 years. This rocket would reach Barnard's Star, the fourth closest star to our Sun, at 5.9 light years away. The study began in 1973, before the fusion from helium-3 on the Moon connection had been made, and the project proposed to mine helium-3 from the atmosphere of Jupiter, over the course of 20 years.

The importance of mining helium-3 from the Moon for fusion energy is not simply for the unparalleled energy increase that it will provide for planet Earth. It is the next step in scientific progress itself. As we gain mastery of the atomic nucleus, and learn how to wield its powers, we open up new possibilities for progress as a species, from advances in medicine on Earth to voyages into deep space that will expand our knowledge and mastery of the universe itself.

"The great French Marshall Lyautey once asked his gardener to plant a tree. The gardener objected that the tree was slow growing and would not reach maturity for 100 years. The Marshall replied, 'In that case, there is no time to lose; plant it this afternoon!'"

–John F. Kennedy

17. Glister, Paul. *Centauri Dreams: Imagining and Planning Interstellar Exploration*. New York: Copernicus Books, 2004.