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Energy sources for propulsion to, and for distributed use on, Mars

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MORE POWER IS NEEDED

Mars is the future. How do we know that? Because six times as many people signed up (202,586) for a one-way ride than did for the Affordable Care Act which means that people would rather buy a ticket to the vast unknown than get healthcare as they age. What is holding back the transport of humans to Mars, and its colonization, is energy. We need more powerful rockets to take people there quicker, and we need more accessible, more portable distributed power sources for exploring, making outposts on, and terraforming of, the Martian surface. This paper briefly discusses present and soon-to-be available energy sources which will make this possible.

The existing rocket technologies are simply too slow for explorations to the edge and beyond the solar system, and too ephemeral to support colonization of Mars. The reason for higher transit speed is too avoid unwanted irradiation of the colonists. NASA's Mars Science Laboratory in 2011 contained an onboard Radiation Assessment Detector which measured irradiation of the craft during its journey. The measured levels were significant and indicated that human transfer to Mars requires either decreased transit times (to minimize exposure to galactic cosmic rays from supernovae) or improved radiation shielding (to minimize exposure to solar particle events) or both. In terms of the exposure, on its way to Mars, the rover, Curiosity, in space, measured 1.8 millisieverts per day, with 97% from galactic cosmic rays and the rest from solar particles. This is a very high level which is associated with carcinogenesis and other unwanted effects. In Mars, this exposure decreased to circa 0.7 millisieverts per day, similar to the exposure received on the International Space Station.

Other dangers beyond the unwanted irradiation include biological changes from bone loss and muscle atrophy to electrolyte changes. The goal is to decrease the transit to Mars in less time than 3 months each way, compared to the 12 to 16 months, as it is now. Conventional chemical rockets are just too slow. New propulsion technologies are needed to make the trip faster, and thus safer, and that is why more specific impulse (Isp) is needed. Isp indicates the thrust per kilogram of fuel and thus reflects the efficiency. The actual propulsion power depends on the propellant's weight and velocity when ejected.

What exists today include conventional chemical technologies, fission and possibly fusion and photon drive systems. Figure 1 shows the energy density (related to Isp) of the fuels.

MORE POWERFUL DISTRIBUTED ENERGY SOURCES ON MARS

The problem for tomorrow is powering a human operated Mars station. Distributed power sources for the colonization and terraforming of Mars have been noted to be required, but as shown below, the energy levels are only sufficient for probes, not colonies. 3-5 kW seems an absolute minimal power requirement, and the environmental impact will be closely monitored.

As we have seen over last few decades, initially, the energy production and energy conversion systems will probably be a composite of conventional solar energy systems, fuel cells and nuclear energy systems. Some have proposed small hot fusion devices using inertial electrostatic confinement and cold fusion systems based on laboratory working systems. Others have sought speculative theoretical (more questionable absent lab bench setups) techniques like quantum vacuum propulsion, warp drive, space-time curvature and gravity control devices, and imagined faster-than-light (FTL) technologies.

What is needed is a cheap, plentiful, efficient energy production system, and these are the most likely candidates, listed below in alphabetical order.

ANTIMATTER CATALYZED FUSION PROPULSION

Antimatter propulsion (also called antimatter Catalyzed Fusion Propulsion) offers very fast accelerations and a large Isp. The first problem is that although only 1 kg of antimatter would get the ship to Mars in an incredibly short time, the present production rate of antimatter is only ~ 10 nanograms a year. The second problem is the need to consider what container to hold the fuel in, since antimatter reacts severely with anything of ordinary matter.

COLD FUSION (LANR, LENR)

Lattice assisted nuclear reactions [LANR, also known as cold fusion and LENR, low energy nuclear reactions] use hydrogen-loaded alloys to create heat and other products[1] by enabling deuterium fusion to form an excited *de novo* helium nucleus at near room temperature, under difficult-to-achieve conditions. The "excess heat" observed is energy derived from coherent de-excitation of short-lived ^{4}He* to its ground state via the lattice phonons. In cold fusion, the alphas (generated helium) are borne non-energetic, making the systems highly clean and safe.

Prof. George Miley (U. of Illinois) has been pivotal in suggesting and promoting cold fusion cells for use in outer space. These cold fusion devices which generate nanoscopic amounts of *de novo* helium (He^4) to produce portable devices in the watt to kilowatt range without the harmful penetrating radiation emissions and radioactive waste that characterize other (hot) fusion sources. His devices are multi-layered thin films of palladium and nickel in a heavy water solution. Superconducting quantum interference devices (SQUID) have confirmed ultra-dense states of deuterons within palladium crystal defects after repeated loading by deuterons from the heavy water.

Dr. Mitchell Swartz and his associates, at Nanortech, Inc., have crafted these LANR devices into actual portable components. These would be useful for spaceflight and distributed energy source because they are preloaded and driven by a DC electrical current. They have been shown in open demonstrations at MIT since 2012 and presently fabricated to perform at the multiwatt level. The excess energy gain compared to driving input energy is up to 20 times input; characterized by reasonable reproducibility and controllability.

Although small in size, the LANR excess power density is more than 19,500 watts/kilogram of nanostructured material - with zero carbon footprint. Once harnessed, they could easily be used to drive electric propulsion systems.

ELECTRIC PROPULSION SYSTEMS

Electric propulsion systems are of several types. Ion propulsion devices use materials, including noble gases, like xenon, which are ionized and sent out of the back of the spacecraft to obtain forward thrust. The problem is how to obtain the large power required (>10 megawatts). Hall thruster engines are similar, and move electrons using a magnetic field, creating a plasma thrust. Such plasma propulsion systems have already been tested on the asteroid-exploring Dawn spacecraft. Magnetohydrodynamic conversion can also generate electrical power from the moving ionized plasma. 50% conversion can be achieved theoretically, but like thermoelectrics this is experimentally closer to the 15%. The problem is the need for high operating temperatures and high electrical conductivity of the plasma.

A variant engine is the Variable Specific Impulse Magnetoplasma Rocket (VASIMR) which uses electromagnetic radiation to heat up and ionize argon, xenon or hydrogen which, in turn, is then directed by magnetic fields for thrust.

Guido Fetta has reportedly built a microwave thruster, based on Roger Shawyer's EmDrive, which produces thrust by amplification of radiation pressure of an electromagnetic wave in resonant waveguide. It provides very low thrust and is believed to be a nonclassical electromagnetic interaction.

FUEL CELLS

Alkaline fuel cells were used in Apollo and on the Space Shuttle. But they are not an efficient energy production or energy storage system (Figure 1). The problems include poor efficiency during storage and then release of that energy which wastes about half of the energy in that process.

NUCLEAR FISSION

Conventional nuclear energy production systems are of two types, fission and fusion. In fission, fissile elements (e.g. plutonium or uranium) have their heavy nuclei divide. Today, from Earth to the edge of the solar system, radioisotope thermoelectric generators (RTGs) provide heat which is converted to electricity on spacecraft, and these reactors have been shown to be useful in space for decades. One can obtain about 3 kilowatts of thermal energy for each 5.6 kilograms of radioactive plutonium, however RTGs have other materials including shielding which yields a useful specific power of about 25W/kg Plutonium. The Viking landers used 85 kg of hydrazine propellant to slow their descent, and should be compared with the 90 kg contained as scientific diagnostics/equipment and had Pu^{238} RTG (~14 kg) for 30 watts output. NiCd batteries (28 V, 8 Ahr) were used to store the energy, and to enable high power outputs when needed. In the Pathfinder, Sojourner, and Polar Landers, the RTGs were used solely for heating, with electricity provided by solar cells. In the Russian Mars 96 small station power systems, RTGs were used with the rechargeable NicCd and Lithium batteries. For example in their Penetrators, the RTG output was 0.5 W (3.5 kg). Unfortunately, the Pu^{238} RTGs are usually powered by plutonium, which is highly radioactive and expensive to prepare and shield.

The HOMER (heat pipe operated Mars Exploratic Reactor) is a proposed unit for Mars which uses fissile material driving a Stirling engine, all contained in a small tee-pee shaped tent system.

Larger nuclear fission systems include NERVA and Project Orion. Since the 1950s, NASA and U.S. Atomic Energy Commission (AEC) tested Nuclear Engine for Rocket Vehicle Application, or NERVA for use in space. It was canceled in 1972 for costs and because of the interest in stopping nuclear proliferation. Project Orion, Nuclear Pulse Propulsion, also uses fission. The nuclear thermal rocket (NTR) uses fissile material to generate heat, again to superheat materials which would then be ejected for thrust. Such nuclear thermal propulsion has hydrogen circle through the core of nuclear reactor, and the resultant hot gas provides the thrust. Like RTGs, environmental issues from potential contamination limit the use. As a result, although the Russians have launched more than thirty nuclear fission reactors, the US has only had SNAP-10A (System for Nuclear Auxiliary Power, launched in 1965).

NUCLEAR FUSION

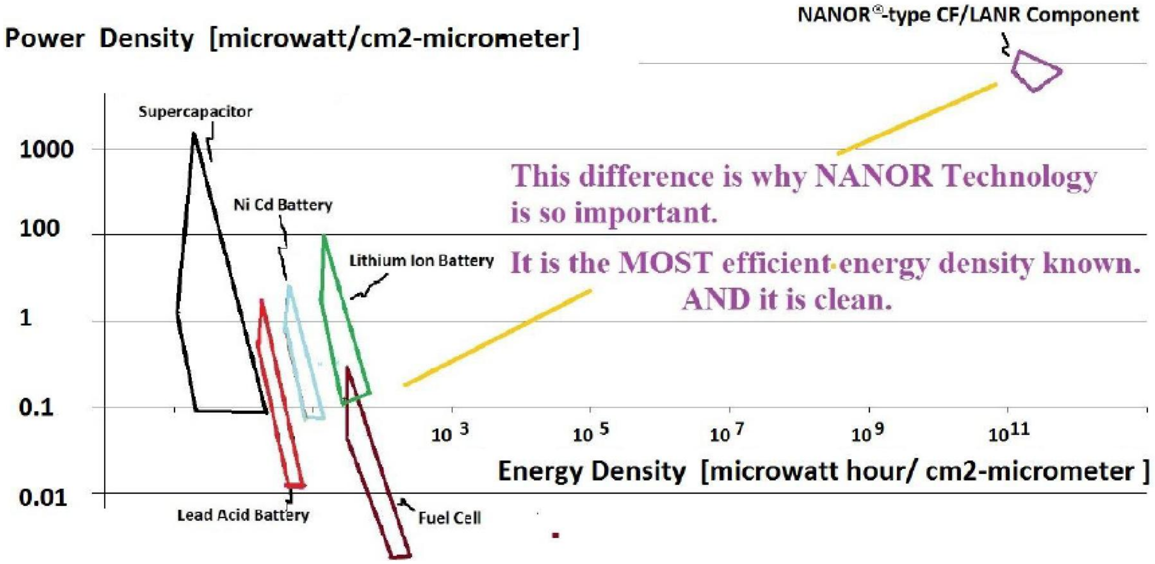

Figure 1 : Shown is a Rangone-type plot which quantitatively presents both the power density and energy density of typical energy production (and energy storage/energy conversion) sources and the NANOR®-type cold fusion (lattice assisted nuclear reaction) quantum electronic component. The latter is one of the most efficient energy density devices known, and it has zero carbon footprint

There are three types, magnetic confinement, internal confinement, and cold fusion (also called LANR and LENR, discussed above). Nuclear fusion energy production systems use low molecular weight nuclei, usually hydrogen, which combine to form heavier nuclei with release of energy. In fusion engines, deuterium and tritium, the heavier isotopes of hydrogen, are injected into the engine and fused to generate enough heat to superheat materials which would then be ejected for thrust.

IEC fusion is most important because whereas Tokomak and other magnetic confinement fusion devices have losses which scale as surface to volume, with IEC fusion the loses scale velocity transport of the materials. IEC can yield a plasma output stream (“plasma torch”). However, there are two problems. The fuel D-He^3 requires a helium-3 mining capacity. Second, internal confinement fusion requires megajoule lasers.

Dense plasma focus fusion devices using hydrogen-boron fuel (“focus fusion”) have been suggested. A p-B^{11} fuel is sought because their reactions are aneutronic and produce mainly energetic alphas. Prof. George Miley and Franklin Mead of Air Force Research Laboratory have begun research which indicates a possible energy gain of 3. Others have suggested using high intensity magnetic fields to reduce unwanted x-ray cooling of the plasma and to generate electricity at high efficiency.

SOLAR PROPULSION

Solar propulsion has long been considered in the inner solar system because of availability of solar irradiation. A massive solar sail is envisioned for spacecraft, being only 5 micrometers thick and spanning several km wide. The problem is the low thrust, requiring them to remain “on” for long periods for use in space. Takeoff systems would have to augment solar propulsion because a much high delta-v is required to achieve escape velocity. Solar electric propulsion has been used on the Dawn spacecraft to explore Ceres (10 kilowatts), and it is estimated that at least 100 to 200 kilowatts would be required for human exploration.

On the surface of Mars, solar arrays would be most efficient during the Martian Summer and probably limited to mid-latitude stations and habitations. The Pathfinder Lander had a solar array of 2.8 m^2, with peak output of 1200 Wh per day, with a rechargeable silver zinc battery. The Sojourner had a solar array of 0.2 m^2 (0.334 kg) composed of gallium arsenide on germanium, for peak power output of 16 W. Supplementation was by lithium thionyl chloride (non rechargeable) batteries, chosen for durable shelf life and temperature range.

CONCLUSION

The most efficient systems in the future will probably involve mixed systems for liftoff (which requires the highest delta-v to access escape velocity), transport, and include aneutronic fusion, hot or cold, which appears to be the most likely because of the high specific energy power densities and electric propulsion systems. They will probably be coupled to electric propulsion systems, with fuel cell systems for storage and *in situ* oxygen production. In summary, the energy hurdle needed to conquer Mars by exploration and then colonization -considering that energy production research is quite actively pursued in parallel with upcoming space exploration- will likely not deter the future passengers who are patiently and eagerly waiting their turn in line.

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