Astrofuel – An Energy Source for the 21st Century

J.F. Santarius and G.L. Kulcinski

July 1989

UWFDM-794

Wisconsin Professional Engineer 30:6 (1989) 14

FUSION TECHNOLOGY INSTITUTE

UNIVERSITY OF WISCONSIN

MADISON WISCONSIN

ASTROFUEL - AN ENERGY SOURCE FOR THE 21ST CENTURY

J. F. Santarius and G. L. Kulcinski

Fusion Technology Institute
Department of Nuclear Engineering and Engineering Physics
University of Wisconsin-Madison
Madison, WI 53706

July 1989

UWFDM-794

Helium-3, a form of the element helium, is extremely rare on Earth but exists in enormous quantities on the Moon. It has been deposited in lunar soil by the solar wind from the Sun over billions of years. Lunar soil samples from the United States Apollo and Soviet Luna missions have verified its abundance (Fig. 1). **Astrofuel** is our name for this newly discovered energy source.

Astrofuel could make the Moon a more important source of energy in the 21st century than the Persian Gulf is in this century. In fact, vastly more energy can be supplied by Astrofuel than by oil from the Persian Gulf.

The nation that develops technology to retrieve Astrofuel will be in a commanding economic and strategic position in the next century. Astrofuel will provide the basis for:

- Economical and inherently safe fusion reactors to supply electricity for the world;
- Efficient spacecraft to transport humans and cargo throughout the solar system;
- Generating stations to power large bases on the Moon, on planets, and in orbit; and
- Larger settlements to exist on the Moon. By-products of Astrofuel mining, including oxygen and water, will eliminate the need for resupply of life-support substances from Earth.

To understand the impact Astrofuel can have on world energy supplies, consider the amount of energy that could be released by just one ton of it. When combined in a fusion reaction with a form of hydrogen extracted from water, one ton of Astrofuel would supply the electrical needs of a city of 10 million people for a year.

This extremely high power density means that only 28 tons of Astrofuel (approximately the payload of a current U.S. Space Shuttle) could have supplied the entire electrical demand of the U.S. in 1987. Even allowing for a selling price of $1 billion a ton (which would suggest a healthy profit for the developers of this fuel), the energy cost of this fuel is equivalent to oil at only $7 per barrel (Fig. 2).

The most important resource for the next century, whether on Earth or in space, is a reliable, safe and clean energy supply. Societies depend on energy for their very existence. Without it, the Earth cannot support its present population of 5 billion people and certainly not the 8 to 10 billion people likely to inhabit the earth under the "equilibrium" conditions in the 21st century. Our societies have long passed the time when most humans can live off the land.

By the mid-21st century the remaining fossil fuels will be difficult and costly to recover and use, and such fuels will play a rapidly diminishing role. It is also possible that environmental problems such as acid rain, the carbon dioxide "greenhouse" effect, or wars over the last remaining fossil fuel deposits will limit the useful lifetime to even less than that determined by resources alone. In addition, fossil fuels will be of increasingly greater value as chemical feedstocks for non-fuel products to sustain the quality of life.

For a combination of reasons, then, somewhere in the mid-21st century fossil fuels will no longer be a significant part of our energy budget. Mankind will have to rely on renewable energy sources (solar, wind, hydro, geothermal, and biomass) and nuclear energy sources to survive. And the 21st century is almost upon us. Students of middle school age or less today will be alive in the year 2050 if they live the average life expectancy of the 1980s.

The use of nuclear energy in fission reactors is already widespread. Nearly 400 reactors in 26 countries provide one-sixth of the world's electricity. By the year 2000, this fraction will increase to one-fifth. However, this source of energy has generated public opposition in some countries, and there are major concerns over the storage of long-lived radioactive wastes and reactor safety questions. The basic problem is how to safely handle large amounts of radioactive material for centuries to come.

Fortunately, another form of nuclear energy, fusion, can provide an even more environmentally acceptable and safe solution to the world's long range energy problems. The fusion of certain light elements into heavier ones at high temperatures can release enormous amounts of energy. Fusion reactions power the Sun and stars.

Nuclear fusion research programs in recent decades have moved closer to the practical application of this energy source. But the fusion reactions under study present difficult engineering problems because they produce great numbers of neutrons, atomic particles which damage the reactor itself and produce radioactive wastes.

However, a fusion reaction that can be carried out using helium-3 -- Astrofuel -- releases as little as 1 percent of its energy in the form of neutrons (Fig. 3). This greatly simplifies safety design features of reactors and reduces radioactivity to levels that do not require elaborate radioactive waste facilities. Furthermore, since 99 percent of the energy can be released in the form of charged particles, this energy can be converted directly to electricity via electrostatic means with efficiency up to 70 percent. This is approximately twice the efficiency of fossil fuel or fission power plants.

Why has no one made use of this Astrofuel fusion reaction? Because the total amount of accessible Astrofuel on Earth is on the order of a few hundred pounds. To provide a significant fraction of the world's energy needs would require dozens of tons of Astrofuel per year.

University of Wisconsin-Madison scientists provided a solution to the fuel resource problem in 1986 by pointing out that, over the past 4 billion years, several hundred million tons of Astrofuel from the Sun have impacted the Moon's surface. The analysis of U.S. Apollo and U.S.S.R. Luna samples showed that over 1 million tons of Astrofuel still remain loosely imbedded in the surface of the Moon. A small fraction of this could provide the entire world's electricity needs for centuries to come. Ten times more energy exists in Astrofuel on the Moon than in all recoverable fossil fuels on Earth.

The return to the Moon to collect this enormously valuable fuel will not only insure our future quality of life on Earth, but will also help push back the frontiers of space. This fuel is the first direct economic justification for a major thrust into space.

Because 99 percent of the energy released from Astrofuel is in the form of non-radioactive particles, the Astrofuel cycle is much safer than current fission reactors. Other benefits include:

- High efficiency (up to 70 percent net conversion to electricity).
- Much easier licensing and siting requirements, relative to other nuclear cycles.
- Potentially lower costs of electricity.
- A shorter time to commercialization than for the main fusion cycle currently pursued around the world.
- Less waste heat, due to the high efficiency, is dumped to the environment than with fossil fuel or fission plants. This will reduce siting problems and the facility's size.

Because there are only small amounts of radioactivity associated with this fuel cycle, early construction and testing will be possible. Furthermore, materials for the reactors can be chosen for easier maintenance, decommissioning and ultimate disposal of the reactor components. This means that, although the physics requirements are somewhat more difficult, the

Astrofuel approach is likely to be commercialized much faster and with less government research investment than other proposed fusion cycles.

The lack of **any** radioactivity in the fuel means that it can be delivered over city streets with no more precautions than required to deliver refrigerated food today. The extremely small amount of radioactive isotopes inside the plant means that in the event of a catastrophic accident (e.g., earthquake, tornado, plane crash) there will be **no** offsite fatalities even if all the radioactivity were to be released at once. These safety advantages should greatly facilitate the licensing process (shorter construction time) and allow power plants to be located close to load centers, thus eliminating the need for high voltage power corridors. The cumulative effects of high efficiency, very low radioactive content, inherent safety (meltdowns are impossible), easier licensing, and urban siting should also result in lower electricity costs in the future.

The commercial attractiveness of this fuel is illustrated by the following example. In 1987, the U.S. alone spent $40 billion to buy coal, oil, natural gas and uranium to produce electricity. That same electricity could be produced from 25 tonnes of Astrofuel. That much condensed Astrofuel could fit into the cargo bay of a spacecraft roughly the size of the U.S. Shuttle (Fig. 4). One shipload of fuel could supply the entire U.S. demand for electricity in a year and be worth $25 billion dollars! Astrofuel is the only known substance worth bringing back from space for economic reasons.

The University of Wisconsin-Madison has several programs at the forefront in space research, and other strengths that will help make it a leader in Astrofuel research and development. University of Wisconsin-Madison scientists in 1986 conceived the idea of mining and using Astrofuel from the Moon. The university began a strong fusion program in 1963 and since then has granted 186 PhDs in fusion, which we believe is more than produced by any other U.S. university. During the past six years, it has granted an average of one PhD per month in fusion-related topics and this will continue into the forseeable future. In addition to experimental and theoretical physics research, the UW-Madison's Fusion Technology Institute (FTI) has completed 19 fusion reactor designs which scientists in more than 15 countries outside the U.S. have requested. Currently, the FTI staff has more than 200 person-years of fusion-related experience.

The UW-Madison's Space Science and Engineering Center has been active for more than 20 years. Program staff have made special contributions to weather satellites, lunar material research, and orbital mechanics.

NASA recently chose the university as a Center for the Commercial Development of Space with particular emphasis on automation and robotics. This is the Wisconsin Center for Space Automation and Robotics (WCSAR), which now has more than 40 faculty, scientific staff, and students working on space-related activities.

The university's overall reputation in agriculture is well known and the research conducted here in closed-cycle food growth and atmosphere control is unique in the country. The university's Biotron allows scientists to control environments to simulate almost any condition needed for space activities.

The combination of fusion, space, and life support research puts the University of Wisconsin in a unique position to consider the mining and use of Astrofuel. The student body of 43,000 and a strong College of Engineering (3600 undergraduates plus 1200 graduate students) is a talent pool that can be tapped for future leaders in this area. Finally, the UW-Madison ranks among the nation's top universities in evaluations of quality. This high standing reflects the university's ability to attract scholars of national and international reputation.

Conclusions

In summary, Astrofuel will provide:

- A nuclear fuel which contains no radioactive isotopes, and produces only a small amount of radioactive products.
- Energy released in a form that can be converted directly to electricity with efficiencies up to 70 percent. Today's electric power plants fueled by coal, nuclear fission or other energy sources have efficiencies of 30 to 40 percent.
- Completely and inherently safe reactor operation. In the event of the worst conceivable accident, no meltdown can take place and no offsite fatalities will occur. This will not depend upon careful design or operation; the process itself simply cannot lead to a devastating accident.
- Radioactivity of the reactor so low that the facility can be disassembled at the end of its life and disposed of as low level waste (similar to radioactive medical wastes today). There is no need for deep geologic waste repositories.
- Astrofuel-powered fusion rockets that can shorten trip times and increase payloads to the rest of the solar system.

Astrofuel (helium-3) has enormous potential and is critically important to the future of this nation and the world (Fig. 5). The United States should move ahead forcefully to take the lead in the recovery of Astrofuel from the Moon and its use on Earth and in space. The initial steps required are:

- To demonstrate the safety and economic advantages of fusion power plants on Earth by bringing the present U.S. fusion research program to a successful conclusion;
- To implement modifications to the direction of fusion research that would allow full utilization of the unique features of Astrofuel (helium-3);

- To develop the techniques and equipment required for Astrofuel mining operations on the Moon;
- To identify initial Astrofuel mining sites by extending present plans for the U.S. Lunar Base and orbiting satellites to include an Astrofuel resources survey;
- To design and test the Astrofuel power and propulsion systems required to create the space infrastructure envisioned by the U.S. National Commission on Space; and
- To show that life can be supported on the Moon and in space through the utilization of lunar gases from Astrofuel mining and lunar soil without requiring any raw materials from Earth.

The use of Astrofuel from the Moon will have a critical impact on life here on Earth, in orbit, on the Moon, and even to the outer reaches of the Solar System. No nation can ignore such impact in the 21st century. The U.S. now has the opportunity to take the lead in this area for the benefit of all mankind.

Selected References

Selected references pertinent to space development in the 21st century:

Pioneering the Space Frontier (Bantam, NY, 1986), National Commission on Space.

Leadership and America's Future in Space (Aviation Week and Space Technology, Peoria, IL 1987), Sally K. Ride.

Lunar Bases and Space Activities of the 21st Century (Lunar and Planetary Institute, Houston, TX 1985), W. W. Mendell, ed.

Technical references to Astrofuel and its applications:

Lunar Source of He-3 for Commercial Fusion Power, Fusion Technology 10, 167 (1986), L.J. Wittenberg, J.F. Santarius, and G.L. Kulcinski.

Soar: Space Orbiting Advanced Fusion Power Reactor, in Space Nuclear Power Systems (Orbit, 1987), J.F. Santarius, G.L. Kulcinski et al.

The Moon: An Abundant Source of Clean and Safe Fusion Fuel for the 21st Century, presented at the 11th International Scientific Forum on Fueling the 21st Century, 2; 9 September-6 October 1987, Moscow, U.S.S.R., G.L. Kulcinski and H.H. Schmitt.

The Commercial Potential of D-He3 Fusion Reactors, proceedings of the 12th Symposium on Fusion Engineering, Monterey, CA (October 1987), G.L. Kulcinski, I.N. Sviatoslavsky, G.A. Emmert, H. Attaya, J.F. Santarius, M.E. Sawan, Z. Musicki, and L.J. Wittenberg.

Lunar He-3, Fusion Propulsion, and Space Development (Second Symposium on Lunar Bases and Space Activities of the 21st Century, Houston, TX, April 1988), J.F. Santarius.

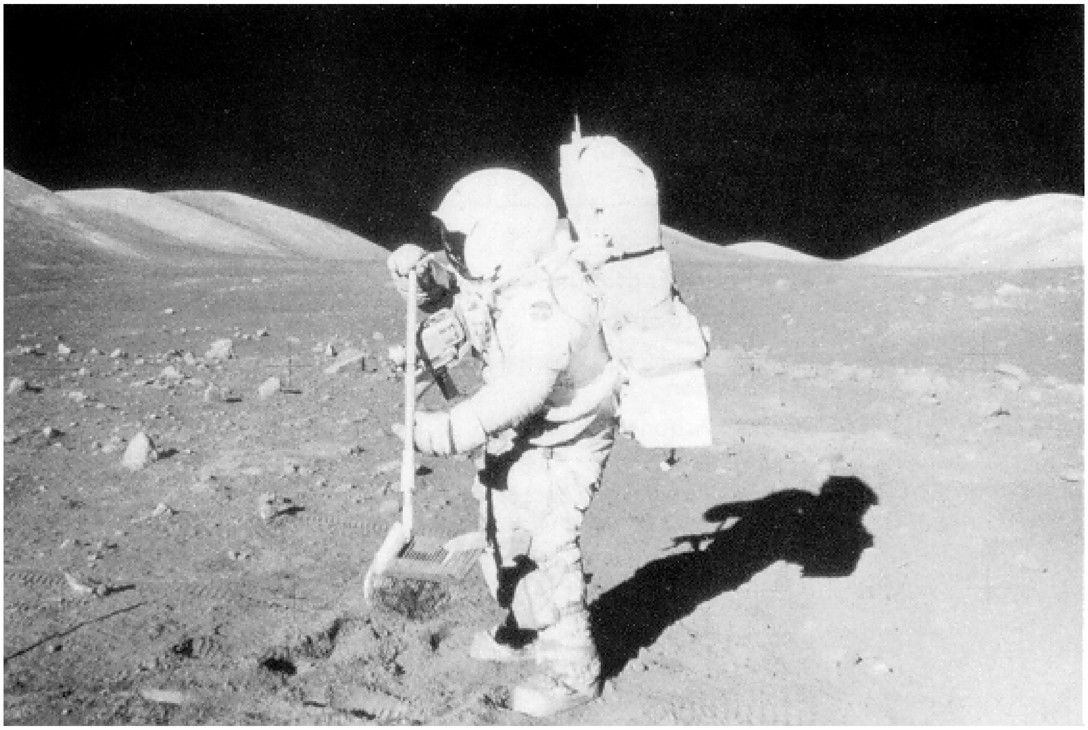

Figure 1. Astronaut and former U.S. Senator Harrison H. Schmitt collecting some of the samples which verified the lunar Astrofuel resource.

Figure 2. The equivalent cost of energy in Astrofuel at $1 billion per ton is equal to $7 per barrel of oil.

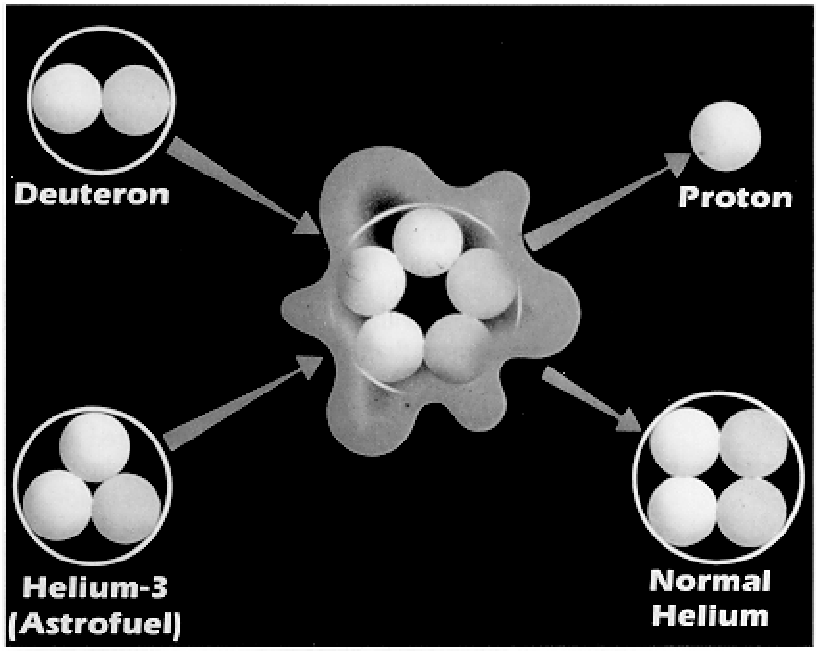

Figure 3. The Astrofuel fusion reaction, which releases 18.4 MeV of energy per event.

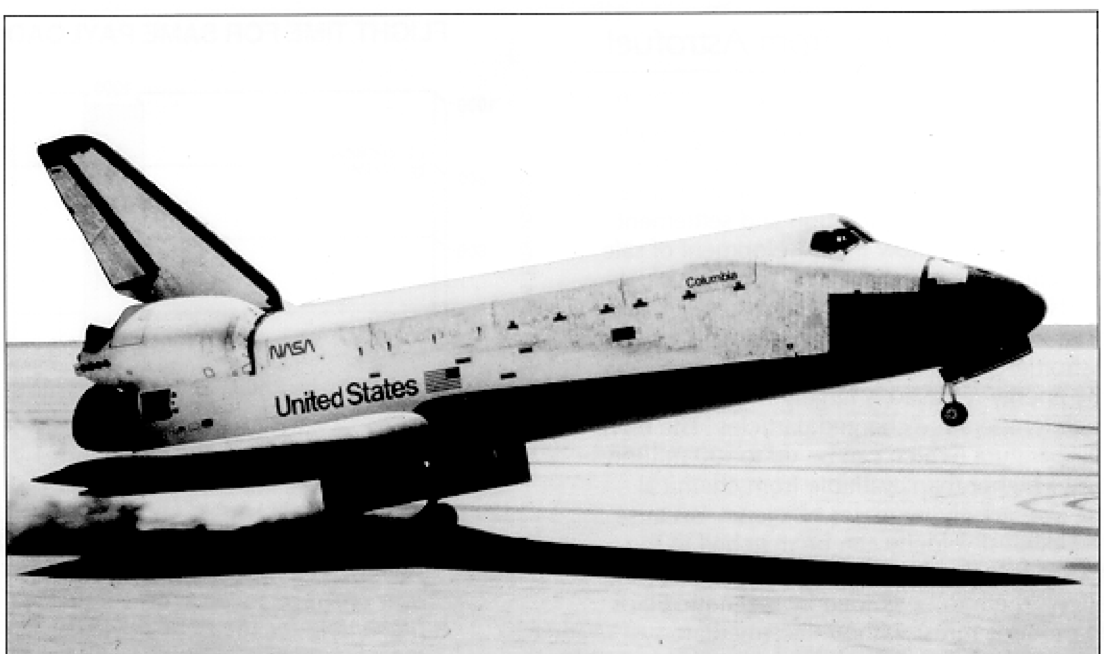

Figure 4. One space ship roughly the size of the U.S. Space Shuttle could hold the fuel needed to provide all the electricity used in the U.S. in 1987.

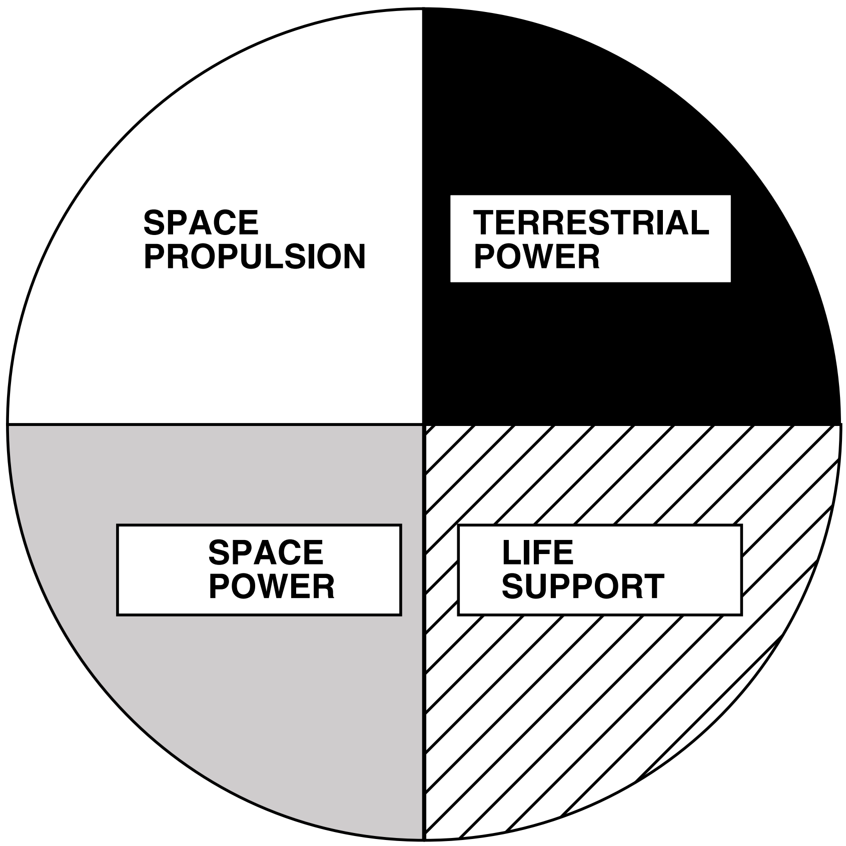

Figure 5. Impact of Astrofuel on 21st Century