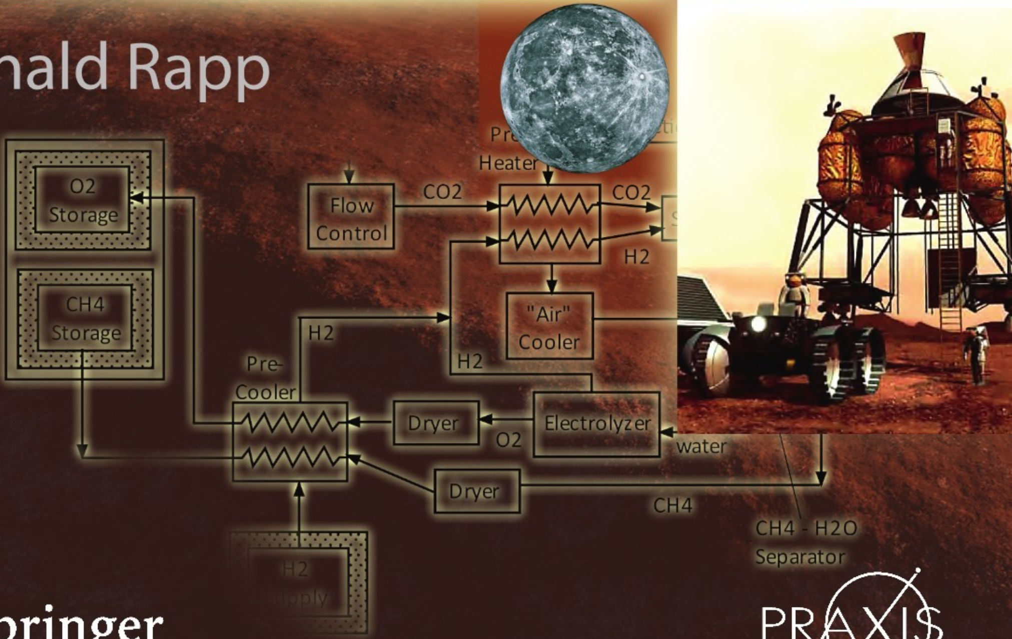
Use of Extraterrestrial Resources for Human Space Missions to Moon or Mars

Donald Rapp



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Preface

Since the earliest expeditions of humans into space, visionaries have contemplated the possibility that extraterrestrial resources could be developed and civilization could eventually move into space. An important early paper (Ash, Dowler, and Varsi, 1978) proposed that propellants for ascent be produced on Mars. Thus the term *in situ* propellant production (ISPP) was coined, and this provided a focus for a couple of decades. ISPP on Mars was the most obvious choice for utilization of extraterrestrial resources because it provided an important need and it appeared to be more technically feasible than most other possibilities.

As time went by, visionaries looked beyond the near term and imagined the transfer of the industrial revolution and the electronic revolution to planetary bodies. Metals would be produced and fabricated into objects, concrete building blocks would be assembled into structures, and electronics would be created from indigenous materials. Thus, ISPP became an obsolete term and it was replaced by *in situ* resource utilization (ISRU) to allow for a wider range of applications than mere propellant production.

Robert Zubrin is a prominent Mars technologist and advocate of Mars exploration and is founder and president of the Mars Society. His book *Entering Space* provides a contemplative roadmap for humans to settle in space.

Zubrin contemplates finding ‘‘fossils of past life on its surface,’’ as well as using ‘‘drilling rigs to reach underground water where Martian life may yet persist.’’ He believes that there is great social value in the inspiration resulting from a Mars venture. He also said: ‘‘the most important reason to go to Mars is the doorway it opens to the future. Uniquely among the extraterrestrial bodies of the inner solar system, Mars is endowed with all the resources needed to support not only life, but the development of a technological civilization . . . In establishing our first foothold on Mars, we will begin humanity’s career as a multi-planet species.’’

Zubrin has support from a good many Mars enthusiasts. (The goal of the Mars Society is ‘‘to further the goal of the exploration and settlement of the Red Planet.’’)

More than 10 years ago, they believed that we could send humans to Mars "in ten years" and begin long-term settlements. Each year, the *International Space Development Conference* hosts a number of futurists who lay out detailed plans for long-term settlements on Mars. The Mars Society often describes settlements on Mars as the next step in the history of "colonization", and warns not to make the same mistakes that were made in colonizing on Earth. For example, the Oregon Chapter of the Mars Society said:

> "When the initial settlements are set up, there will most likely be a few clusters of small settlements. As time goes on, they should spread out. The more spread out the developing townships are, the more likely they will develop their own culture. In the beginning, townships will be dependant [*sic*] upon each other for shared resources, such as food, water, fuel, and air. Once a more stable infrastructure is set up on Mars, then people should be encouraged to set up more isolated townships. In any area w[h]ere colonization or expansion has occurred, one important item that cannot be ignored is the law. Some form of law will be needed on Mars. Looking at the system that was used in the old west, we can see that whoever enforces the law can have difficulty completing his job. The 'sheriffs' on Mars must be trustworthy individuals that the majority of people agree on. They should not be selected by the current form of politically interested members of society; this only encourages corruption. Instead, some sort of lottery system of volunteers should be allowed. As for the law itself, it should be set in place to guarantee all of the basic rights of everyone, from speech to privacy."

While these zealots are already concerned with establishing law and order on Mars, and spend time laying out townships for the Mars surface, this humble writer is merely concerned with getting there and back safely and affordably.

ISRU visionaries know no bounds. Imaginative proposals abound for all sorts of futuristic systems. One example is a sort of Zamboni vehicle that rolls along the surface of the Moon or Mars, imbibing silica-rich regolith, and processing it into silicon in real time, leaving in its wake a roadway covered by a carpet of silicon solar cells that stretches out for miles behind the Zamboni.

NASA is not a monolithic organization. Imbedded within NASA is a small cadre of ISRU enthusiasts who are constantly seeking support from the greater NASA for further development of ISRU. Since the 1990s, the enthusiasts have developed elaborate plans for development of ISRU technology that include the more mundane elements (propellant production, life support) as well as more ambitious elements (e.g., "in-situ manufacturing and assembly of complex parts and equipment", "in-situ fabrication and repair").

The NASA ISRU enthusiasts' approach seems to be based on the belief that if a process utilizes extraterrestrial resources rather than resources brought from Earth, it must by its very nature be worthwhile. While they have published many dozens of reports, advocacy documents, and program plans, I am unable to find any detailed economic analyses comparing the cost of developing and implementing ISRU and prospecting for resources vs. the cost savings attributable to ISRU. As a result, they have contemplated use of processes that in many cases seem to me to be impractical to implement and have little payoff compared with the cost of implementing them.

In fairness to the NASA ISRU managers, it must be pointed out that higher NASA management has provided highly vacillating leadership over the years, with programs and initiatives starting with great fanfare and ending abruptly without warning.[1] Budgets rise and fall, and continuity from year to year is difficult to achieve. The greater NASA technology theme has evolved from *unprecedented*, to *world shaking*, to *revolutionary*, to *disruptive*, to *game changing*.[2] The focus has always been on seeking incredible breakthroughs, and therefore funding to do the engineering necessary to make evolutionary systems practical has not been forthcoming. This in turn has forced the visionaries to look beyond the best near-term prospects. It is noteworthy that project managers tend to look with a wary eye at these shenanigans and, as a result, project plans tend to denigrate ISRU to secondary priority. In this environment, at each juncture when a new technology opportunity arises, the tendency is for NASA ISRU managers to ask NASA HQ for far more funding than can reasonably be expected, and hope to get some fraction of what was asked for. Inevitably, the long-range plan is so over-bloated with ambitions that the divergence between actuality and the plan becomes embarrassing. In 2005, when the NASA Vision for Space Exploration was announced, the ISRU enthusiasts wrote plans for extensive robotic and human precursors to validate ISRU on the Moon and Mars, none of which were ever funded, nor was there any serious reason to believe they would be funded. The entire exercise, like all such planning activities for ISRU, was basically fiction and fantasy. When the whole NASA enterprise was diverted to lunar mission planning, the small amount of work attributable to Mars ISRU was cancelled and new funds were allocated solely for lunar ISRU research.

Unfortunately, lunar ISRU in any form does not seem to make much economic sense. Furthermore, the technical challenges involved in implementing lunar ISRU are immense. None of the lunar ISRU schemes have a practical financial advantage and it is better, cheaper, and simpler to bring resources from Earth—at least in the short run. By comparison, some forms of Mars ISRU have the potential for logistic and financial benefit for human missions to Mars. Yet there has never been more than a bare minimum of funding for Mars ISRU technology, and funding for Mars ISRU has essentially been zero for the past seven years while funds poured in for lunar ISRU.

In this book, I review the resources available for ISRU on the Moon and Mars, and the technologies that have been proposed for implementation. I also discuss how ISRU would be implemented within human mission scenarios, and I compare the

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[1] This brings to mind the six stages in a NASA project: (1) wild enthusiasm, (2) great expectations, (3) massive disillusionment, (4) search for the guilty, (5) punish the innocent, and (6) promotion for the non-participants.

[2] As a result, the NASA technology programs have often been disrupted because the game has changed so frequently.

missions with and without ISRU as well as can be done considering the limited available data. As one might expect, the most likely possibility for ISRU to become a viable benefit to a human mission is in providing ascent propellants for the return trip to Earth. Unfortunately, there are great difficulties in this regard on the Moon. None of the processes for producing oxygen from lunar regolith are economically viable. The process for retrieving water ice from shaded lunar craters is unworkable. In addition, the cost of prospecting for water ice from shaded lunar craters is excessive. In addition to these impediments, mission plans call for use of space-storable ascent propellants on the Moon, thus eliminating any demand for oxygen (produced by ISRU) as an ascent propellant. If that were not enough, safety considerations require that the Moon Lander retain ascent propellants to allow for "abort to orbit" during descent in case of abnormal conditions. Yet, NASA has spent tens of millions of dollars over the past several years developing prototypes of arcane processes for lunar ISRU that produce oxygen that has no use. These processes do not appear to be cost-effective.

Use of ISRU to produce ascent propellants on Mars might become viable and cost-effective, but there are significant hurdles to be overcome. Unlike the Moon, it appears certain that oxygen (and probably methane as well) will be used for ascent from Mars. This assures that propellants produced by ISRU on Mars are applicable to missions. There are two potential resources on Mars: CO_2 in the atmosphere and H_2O in the near-surface regolith. Two processes have been proposed for utilization of only the CO_2 in the atmosphere to produce oxygen. Solid state electrolysis is appealing on paper but appears to have insuperable technical challenges. Alternatively, the so-called reverse water–gas shift (RWGS) process may be worthwhile. Unfortunately, after funding an initial innovative breadboard study by Zubrin and co-workers that generated some optimistic results in 1997, NASA turned a cold shoulder on this technology and did not fund it for the next 15 years while they spent millions on impractical schemes for lunar ISRU.

A well-studied, practical Sabatier–Electrolysis process exists for producing CH_4 and O_2 from CO_2 and H_2. The problem for this process on Mars is obtaining hydrogen. Early NASA mission plans hypothesized bringing the hydrogen from Earth, but they seem to have underestimated the technical difficulty in doing this. Even more important is the fact that storing hydrogen on Mars is very difficult. There are indications of widespread near-surface H_2O on Mars, even in some near-equatorial regions. If this were accessible, it would provide an extensive source of hydrogen. Thus, the main problem for this form of ISRU on Mars is not process development but, rather, prospecting for near-surface H_2O.[3] What is needed is long-range, near-surface observations with a neutron spectrometer in the regions of Mars identified from orbit as endowed with near-surface H_2O. This might involve balloons, airplanes or gliders, network landers, or possibly an orbiter that dips down to low altitudes for brief periods. None of these technologies seem to be high on NASA's priority list.

[3] We use the term H_2O rather than water here because it is not known whether the H_2O exists as water ice or mineral hydration.

Hence we have concluded the following:

- None of the lunar ISRU technologies are economically viable.
- The Mars RWGS process might be a viable option, but NASA's non-funding of this technology after an initial somewhat successful study leaves a great deal of uncertainty.
- The Sabatier–Electrolysis process for Mars ISRU is technically and economically viable if a source of hydrogen can be provided. Bringing hydrogen from Earth and storing it on Mars is problematic, and prospecting for near-surface H_2O on Mars requires a costly campaign.
- Nevertheless, prospecting for near-surface H_2O on Mars appears to be the most cost-effective and technically practical way to utilize ISRU to enhance human missions in space.
- Visionaries at NASA Centers seem to operate under the assumption that if it is ISRU, it must be worthwhile. Thus, they continue to pursue processes that have academic value but appear to have little practical value.

About the author

Donald Rapp received his B.Sc. degree in Chemical Engineering from Cooper Union, his M.Sc. degree in Chemical Engineering from Princeton in 1956, and his Ph.D. in Chemical Physics at Berkeley in January 1960. He worked as a researcher in chemical physics for a number of years, amassing a considerable number of publications. He was on the faculty of the University of Texas and was promoted to full professor in 1973 at the age of 39. While at the University of Texas, he published textbooks on quantum mechanics, statistical mechanics, and solar energy. He came to JPL/Caltech in 1979 to take a position as the Division Chief Technologist (senior technical person) in the Mechanical and Chemical Systems Division (staff of 700 including 100 Ph.Ds). At JPL, he was a pioneer in pointing the institution toward new technologies. He was Proposal Manager on the Genesis Discovery Project to return samples of the solar wind to Earth. His proposal won in a field of about 25 competitors, being funded at ~\$220 million in the Discovery 5 competition. Genesis carried out its mission in space from 2001 to 2004. After that, he played a major role in putting together the OMEGA MIDEX proposal (\$139 million) in 1998. Subsequently, he acted as Proposal Manager for the Deep Impact Discovery proposal to hit a comet with a projectile to allow examination of the interior, which won, bringing in about \$320 million to JPL. Deep Impact was a spectacular success in 2005. He was manager of the Mars Exploration Technology Program for a period, and he was manager of the *In Situ* Propellant Production (ISPP) task in this Program. He wrote a landmark report on converting Mars resources into usable propellants for return to Earth. He wrote the *Mars Technology Program Plan* in 2001.

During the period 2001–2002, he played an important role in NASA assessments of technology for radioisotope power conversion, energy storage, and photovoltaic power conversion. He also led JPL efforts in developing concepts for utilization of extraterrestrial resources in Mars missions. In 2002 he wrote the *NASA Office of Space Science Technology Blueprint for Harley Thronson, NASA Technology*

Director, a 100-page assessment of technology needs and capabilities for future missions.

In the period 2003–2006, he prepared a revised and expanded version of the *Technology Blueprint for Harley Thronson* at NASA HQ.

In 2004, he was Proposal Manager for a ground-penetrating radar experiment for the Mars Science Laboratory.

In the period 2004–2006, he concentrated on mission design for Mars and lunar human missions. This work led to his writing the book *Human Missions to Mars*, which was published by Springer/Praxis in 2007. This is a major work, comprising 520 pages with over 200 figures.

He was the lead person at JPL for ISRU technology for several decades. In this role, he carried out research and analysis leading to a number of reports and publications through the 1980s, 1990s, and into the 2000s. The work done in this regard provided the basis for the present book.

Honors

- Two articles with over 500 citations are citation classics
- Referee for the *Journal of Chemical Physics*, the *Physical Review*, the *American Journal of Physics*, the *Journal of Physical Chemistry*, and other journals on over 300 occasions
- Book reviewer for *Physics Today* and other journals
- An article was chosen as a "Citation Classic" by *Citation Abstracts* with over 370 citations
- Listed in *Who's Who in the West*
- Listed in *Who's Who in Frontiers of Science and Technology*
- Listed in *Who's Who in America*
- Listed in *Men of Achievement*
- Listed in *International Who's Who of Contemporary Achievement*
- Listed in *International Who's Who of Professionals*
- Listed in *Personalities of the Americas*
- Listed in *Who's Who in Technology Today*
- Listed in *Who's Who in Technology*
- Listed in *Who's Who in California*
- Listed in *Who's Who of Professionals*
- Listed in *Two Thousand Notable Americans*
- Listed in *Dictionary of International Biography*
- Listed in *Strathmore's Who's Who*
- Received Exceptional Service Award from NASA October, 2002
- Associate Editor of the *Mars Journal* 2006–present

Published Books

- *Quantum Mechanics*, 672 pp., published 1971 by Holt, Rinehart, & Winston
- *Statistical Mechanics*, 330 pp., published in 1972 by Holt, Rinehart, & Winston;

translated into Japanese 1977. *Statistical Mechanics* was reissued as a new updated book in 2012 and is available on amazon.com.

- *Solar Energy*, 516 pp., published in 1981 by Prentice-Hall
- *Human Missions to Mars: Enabling Technologies for Exploring the Red Planet*, Hardback, October 2007, 552 pp., two 8-page color sections
- *Assessing Climate Change: Temperatures, Solar Radiation and Heat Balance*, Series: Springer Praxis Books in Environmental Sciences, 410 pp., 130 illus., Hardcover, January 2008; Second Edition 2010
- *The Climate Debate*, available on amazon.com
- *Ice Ages and Interglacials*, Series: Springer Praxis Books in Environmental Sciences, 263 pp., Hardcover, 2009, Second Edition 2012

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