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Planetary In Situ Resource Utilization: 2000-2004

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A Custom Bibliography From the
NASA Scientific and Technical Information Program

October 2004

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OCTOBER 2004

20040086714 NASA Glenn Research Center, Cleveland, OH, USA
The Use of Nuclear Propulsion, Power and ‘In-Situ’ Resources for Routine Lunar Space Transportation and Commercial Base Development
Borowski, Stanley K.; [2003]; In English, 16-22 Nov. 2003, Waikoloa, HI, USA
Contract(s)/Grant(s): 22-319-30-C2; No Copyright; Avail: CASI; A03, Hardcopy

This viewgraph presentation illustrates possible future strategies for solar system exploration supported by Nuclear Thermal Rocket (NTR) Propulsion. Topics addressed in the presentation include: lunar mining, Liquid Oxygen (LOX) augmented NTR (LANTR), ‘Shuttle-Derived’ Heavy Lift Vehicle (SDHLV) options for future human Lunar missions, and lunar-produced oxygen (LUNOX).
CASI
Nuclear Propulsion; Space Transportation; Lunar Mining; In Situ Resource Utilization; Space Industrialization

20040084178 Vanderbilt Univ., Nashville, TN, USA
Separation of Carbon Monoxide and Carbon Dioxide for Mars ISRU
Walton, Krista S.; LeVan, M. Douglas; Strategic Research to Enable NASA’s Exploration Missions Conference; June 2004, 183-184; In English; No Copyright; Avail: CASI; A01, Hardcopy

The atmosphere of Mars has many resources that can be processed to produce things such as oxygen, fuel, buffer gas, and water for support of human exploration missions. Successful manipulation of these resources is crucial for safe, cost-effective, and self-sufficient long-term human exploration of Mars. In our research, we are developing enabling technologies that require fundamental knowledge of adsorptive gas storage and separation processes. In particular, we are designing and constructing an innovative, low mass, low power separation device to recover carbon dioxide and carbon monoxide for Mars ISRU (in-situ resource utilization). The technology has broad implications for gas storage and separations for gas-solid systems that are ideally suited for reduced gravitational environments. This paper describes our separation process design and experimental procedures and reports results for the separation of CO2 and CO by a four-step adsorption cycle.
Author
Mars Atmosphere; Carbon Dioxide; Carbon Monoxide; Adsorption

20040081136 NASA Ames Research Center, Moffett Field, CA, USA
Explanation Constraint Programming for Model-based Diagnosis of Engineered Systems
Narasimhan, Sriram; Brownston, Lee; Burrows, Daniel; 2004; In English, 6-13 Mar. 2003, Big Sky, MT, USA; Original contains black and white illustrations
Report No.(s): IEEE-AC-Paper 1139; No Copyright; Avail: CASI; A02, Hardcopy

We can expect to see an increase in the deployment of unmanned air and land vehicles for autonomous exploration of space. In order to maintain autonomous control of such systems, it is essential to track the current state of the system. When the system includes safety-critical components, failures or faults in the system must be diagnosed as quickly as possible, and their effects compensated for so that control and safety are maintained under a variety of fault conditions. The Livingstone fault diagnosis and recovery kernel and its temporal extension L2 are examples of model-based reasoning engines for health management. Livingstone has been shown to be effective, it is in demand, and it is being further developed. It was part of the successful Remote Agent demonstration on Deep Space One in 1999. It has been and is being utilized by several projects involving groups from various NASA centers, including the In Situ Propellant Production (ISPP) simulation at Kennedy Space Center, the X-34 and X-37 experimental reusable launch vehicle missions, Techsat-21, and advanced life support projects. Model-based and consistency-based diagnostic systems like Livingstone work only with discrete and finite domain models. When quantitative and continuous behaviors are involved, these are abstracted to discrete form using some mapping. This

mapping from the quantitative domain to the qualitative domain is sometimes very involved and requires the design of highly sophisticated and complex monitors. We propose a diagnostic methodology that deals directly with quantitative models and behaviors, thereby mitigating the need for these sophisticated mappings. Our work brings together ideas from model-based diagnosis systems like Livingstone and concurrent constraint programming concepts. The system uses explanations derived from the propagation of quantitative constraints to generate conflicts. Fast conflict generation algorithms are used to generate and maintain multiple candidates whose consistency can be tracked across multiple time steps.
Author
Automatic Control; Algorithms; Error Analysis; Computer Programs

20040077174 NASA Ames Research Center, Moffett Field, CA, USA
A Liquifier for Mars Surface Applications
Salerno, Louis J.; Helvensteijn, Ben; Kittel, Peter; Research and Technology 1999; December 2000, 62-63; In English; No Copyright; Avail: CASI; A01, Hardcopy

NASA is planning an extensive set of robotic and human exploration missions that will make extensive use of cryogenic propellants. In-situ-consumable production (ISCP) will reduce the mass launched from Earth by manufacturing propellant gases on the Mars surface. NASA's Exploration programs will benefit significantly from ISCP, providing that low cost, lightweight methods of propellant gas liquefaction are available to make exploration financially feasible. The objective was to demonstrate that the planned 2003 Mars surface oxygen gas liquefaction requirement could be met with an existing, off-the-shelf tactical cryogenic cooler and a simple heat exchanger. The requirement is that oxygen gas produced during the daytime on the Mars surface (typical temperature environment of 240 K) be liquefied at a rate of 12.6 grams per hour (g/hr) and stored at a pressure of 0.2 atmospheres (atm) (0.2 megapascals (MPa)).
Author
In Situ Resource Utilization; Mars Surface; Cryogenic Rocket Propellants; Coolers

20040077165 NASA Ames Research Center, Moffett Field, CA, USA
Solid-State Compressors for Mars ISRU
Finn, John; Mulloth, Lila; Borchers, Bruce; Research and Technology 1999; December 2000, 150-151; In English; No Copyright; Avail: CASI; A01, Hardcopy

One important way to extend the science and exploration capabilities of Mars surface missions is to use the readily available Mars atmosphere as a resource to provide critical supplies that would otherwise limit the mission or make it too expensive. Compressed and purified gases, oxygen, important chemicals, and even rover and rocket fuel can be manufactured largely from Martian atmospheric gases, saving the costs of their transport from Earth and ensuring that a mission doesn't end when it runs out of gas. These techniques are examples of a popular mission strategy that is generally termed in situ resource utilization, or ISRU. The Mars atmosphere consists mostly of carbon dioxide, with relatively small amounts of nitrogen and other gases. At about 0.7 kiloPascals (0.1 pounds per square inch) total pressure, the mixed gases are too thin to be useful directly, so the atmospheric constituents must be separated from each other and compressed. Ames Research Center (ARC) is developing solid-state adsorption compression and separation technology to acquire the Mars atmospheric constituents and make them available for downstream processing or direct use.
Derived from text
Compressors; In Situ Resource Utilization; Mars Surface; Solid State

20040073513 NASA Marshall Space Flight Center, Huntsville, AL, USA
Materials Science
Biological and Physical Space Research Laboratory 2002 Science Review; December 2003, 13; In English; No Copyright; Abstract Only; Available from CASI only as part of the entire parent document

The Materials Science Program is structured so that NASA s headquarters is responsible for the program content and selection, through the Enterprise Scientist, and MSFC provides for implementation of ground and flight programs with a Discipline Scientist and Discipline Manager. The Discipline Working Group of eminent scientists from outside of NASA acts in an advisory capacity and writes the Discipline Document from which the NRA content is derived. The program is reviewed approximately every three years by groups such as the Committee on Microgravity Research, the National Materials Advisory Board, and the OBPR Maximization and Prioritization (ReMaP) Task Force. The flight program has had as many as twenty-six principal investigators (PIs) in flight or flight definition stage, with the numbers of PIs in the future dependent on the results of the ReMaP Task Force and internal reviews. Each project has a NASA-appointed Project Scientist, considered a half-time

job, who assists the PI in understanding and preparing for internal reviews such as the Science Concept Review and Requirements Definition Review. The Project Scientist also insures that the PI gets the maximum science support from MSFC, represents the PI to the MSFC community, and collaborates with the Project Manager to insure the project is well-supported and remains vital. Currently available flight equipment includes the Materials Science Research Rack (MSRR-1) and Microgravity Science Glovebox. Ground based projects fall into one or more of several categories. Intellectual Underpinning of Flight Program projects include theoretical studies backed by modeling and computer simulations; bring to maturity new research, often by young researchers, and may include preliminary short duration low gravity experiments in the KC-135 aircraft or drop tube; enable characterization of data sets from previous flights; and provide thermophysical property determinations to aid PIs. Radiation Shielding and preliminary In Situ Resource Utilization (ISRU) studies work towards future long duration missions. Biomaterials support materials issues affecting crew health. Nanostructured Materials are currently considered to be maturing new research, and Advanced Materials for Space Transportation has as yet no PIs. PIs are assigned a NASA Technical Monitor to maintain contact, a position considered to be a 5 percent per PI effort. Currently 33 PIs are supported on the 1996 NRA, which is about to expire, and 59 on the 1998 NRA. Two new NRAs, one for Radiation Shielding and one for Materials Science for Advanced Space Propulsion are due to be announced by the 2003 fiscal year. MSFC has a number of facilities supporting materials science. These include the Microgravity Development Laboratory/ SD43; Electrostatic Levitator Facility; SCN Purification Facility; Electron Microscope/Microprobe Facility; Static and Rotating Magnetic Field Facility; X-Ray Diffraction Facility; and the Furnace Development Laboratory.
Author
Microgravity; Materials

20040073504 NASA Marshall Space Flight Center, Huntsville, AL, USA
Development of Aerogel Molds for Metal Casting Using Lunar and Martian Regolith
Biological and Physical Space Research Laboratory 2002 Science Review; December 2003, 7; In English; No Copyright; Abstract Only; Available from CASI only as part of the entire parent document

In the last few years NASA has set new priorities for research and development of technologies necessary to enable long-term presence on the Moon and Mars. Among these key technologies is what is known as in situ resource utilization, which defines all conceivable usage of mineral, liquid, gaseous, or biological resources on a visited planet. In response to this challenge, we have been focusing on developing and demonstrating the manufacturing of a specific product using Lunar and Martian soil simulants (i.e., a mold for the casting of metal and alloy parts) which will be an indispensable tool for the survival of outposts on the Moon and Mars. In addition, our purpose is to demonstrate the feasibility of using mesoporous materials such as aerogels to serve as efficient casting molds for high quality components in propulsion and other aerospace applications. The first part of the project consists of producing aerogels from the in situ resources available in Martian and Lunar soil. The approach we are investigating is to use chemical processes to solubilize silicates using organic reagents at low temperatures and then use these as precursors in the formation of aerogels for the fabrication of metal casting molds. One set of experiments consists of dissolving silica sources in basic ethylene glycol solution to form silicon glycolates. When ground silica aerogel was used as source material, a clear solution of silicon glycolate was obtained and reacted to form a gel thus proving the feasibility of this approach. The application of this process to Lunar and Martian simulants did not result in the formation of a gel; further study is in progress. In the second method acidified alcohol is reacted with the simulants to form silicate esters. Preliminary results indicate the presence of silicon alkoxide in the product distillation. However, no gel has been obtained so further characterization is ongoing. In the second part of the project, the focus has been on developing a series of aerogel plates suitable for thin plate metal casting and ingot metal castings. The influence of aerogels on thin wall metal castings was studied by placing aerogel plates into the cavities of thin sections of resin bonded sand molds. An 1 based commercial alloy (356) containing 7 percent Si was poured into these molds. Post-solidification studies provide evidence that aerogel inserts significantly reduce the cooling rate during solidification. The advantage of a lower rate using aerogel inserts was reflected in the reduction of casting defects such as shrinkage porosity. Quantitative results support the hypothesis that using aerogels as a mold material can offer definite advantages when used as casting thin sections. As a separate effort, silica aerogel with cylindrical cavities have been prepared and will be evaluated for casting commercial alloys.
Author
Aerogels; Aerospace Engineering; Chemical Reactions; Casting; In Situ Resource Utilization; Minerals

20040053563 Orbital Technologies Corp., Madison, WI, USA
Mars ISRU Co/O2 Rocket Engine Development And Testing
Rice, E. E.; Gramer, D. J.; SaintClair, C. P.; Chiaverini, M. J.; Seventh International Workshop on Microgravity Combustion and Chemically Reacting Systems; August 2003, 101-104; In English; No Copyright; Avail: CASI; A01, Hardcopy

This article addresses the current status of a research and development effort in which ORBITEC has undertaken to test new types of ISRU-based propulsion systems for use on Mars. The Martian atmosphere (about 95.5% CO_2) provides a readily available supply of carbon dioxide (CO_2) to produce both CO and O_2, which can be used for rocket engine applications. Hybrid propulsion systems have several safety and operational features that make them attractive for space systems. For Mars ISRU applications, CO gas can be frozen directly to form a solid fuel grain, then burned with liquid oxygen. Alternatively, both CO and O_2 gas can be liquefied and burned in a liquid propellant combustion chamber. This article presents the results of a hybrid rocket test program that used storable propellants to simulate SCO/LOX combustion, as well as a discussion of future tests with a vortex combustion, liquid bipropellant CO/O_2 thrust chamber.
Author
Rocket Engines; Thrust Chambers; Propulsion System Performance; Propellant Combustion; Liquid Rocket Propellants; Liquid Oxygen

20040047179 NASA Marshall Space Flight Center, Huntsville, AL, USA
Microgravity Materials Research and Code U ISRU
Curreri, Peter A.; Sibille, Laurent; [2004]; In English, 8-11 Feb. 2004, Albuquerque, NM, USA; No Copyright; Avail: Other Sources; Abstract Only

The NASA microgravity research program, simply put, has the goal of doing science (which is essentially finding out something previously unknown about nature) utilizing the unique long-term microgravity environment in Earth orbit. Since 1997 Code U has in addition funded scientific basic research that enables safe and economical capabilities to enable humans to live, work and do science beyond Earth orbit. This research has been integrated with the larger NASA missions (Code M and S). These new exploration research focus areas include Radiation Shielding Materials, Macromolecular Research on Bone and Muscle Loss, In Space Fabrication and Repair, and Low Gravity ISRU. The latter two focus on enabling materials processing in space for use in space. The goal of this program is to provide scientific and technical research resulting in proof-of-concept experiments feeding into the larger NASA program to provide humans in space with an energy rich, resource rich, self sustaining infrastructure at the earliest possible time and with minimum risk, launch mass and program cost. President Bush's Exploration Vision (1/14/04) gives a new urgency for the development of ISRU concepts into the exploration architecture. This will require an accelerated One NASA approach utilizing NASA's partners in academia, and industry.
Author
Microgravity; NASA Programs; Materials Science; Research and Development

20040045217 NASA Langley Research Center, Hampton, VA, USA
Recovery and Utilization of Extraterrestrial Resources
January 2004; In English; No Copyright; Avail: CASI; A10, Hardcopy

This special bibliography includes the extraction, processing, and utilization of lunar, planetary, and asteroid resources; mining and excavation equipment, oxygen and propellant production; and in situ resource utilization.
Author
Extraterrestrial Resources; Lunar Mining; Oxygen Production; Materials Recovery; Minerals; Asteroids; Bibliographies

20040034804 NASA, Washington, DC, USA
Human Support Technology Research to Enable Exploration
Joshi, Jitendra; Results of the Workshop on Two-Phase Flow, Fluid Stability and Dynamics: Issues in Power, Propulsion, and Advanced Life Support Systems; December 2003, 91-121; In English; Original contains color illustrations; No Copyright; Avail: CASI; A03, Hardcopy

Contents include the following: Advanced life support. System integration, modeling, and analysis. Progressive capabilities. Water processing. Air revitalization systems. Why advanced CO_2 removal technology? Solid waste resource recovery systems: lyophilization. ISRU technologies for Mars life support. Atmospheric resources of Mars. N_2 consumable/ make-up for Mars life. Integrated test beds. Monitoring and controlling the environment. Ground-based commercial technology. Optimizing size vs capability. Water recovery systems. Flight verification topics.
CASI
Air Conditioning Equipment; Carbon Dioxide Removal; Life Support Systems; Solid Wastes; Water Reclamation

20040020252

Benzene Production on Mars

Muscatello, Anthony C.; Berggren, Mark H.; Strott, David K.; Zubrin, Robert M.; AIP Conference Proceedings; February 04, 2004; ISSN 0094-243X; Volume 699, Issue no. 1, 1052-1059; In English; SPACE TECHNOLOGY and APPLICATIONS INTERNAT. FORUM-STAIF 2004: Conf.on Thermophys.in Microgravity; Commercial/Civil Next Gen.Space Transp.; 21st Symp.Space Nuclear Power & Propulsion; Human Space Explor.; Space Colonization; New Frontiers & Future Concepts, 8-11 February 2004, Albuquerque, New Mexico, USA; Copyright

The Methane to Aromatics on Mars (METAMARS) system is an in situ resource utilization (ISRU) technique that converts methane produced from the carbon dioxide in the martian atmosphere to low hydrogen content liquid aromatic fuels for an Earth Return Vehicle, thus greatly increasing the leverage of the hydrogen imported from the Earth. More importantly, the METAMARS system reduces the amount of hydrogen imported from Earth by a factor of four, leading to dramatic reductions in mission cost. This project involves design and construction of two fully functional oxygen/aromatic hydrocarbon production facilities (brassboard and protoflight) sized to produce 1 kg of bipropellant per day. Because aromatic fuels contain only about one hydrogen atom per carbon atom, the METAMARS system gives extremely high leverages on the order of 53 in the production of fuel and oxidizer for a Mars Sample Return (MSR) mission and human Mars missions. In addition, there are extensive potential commercial applications for the technology in converting trillions of cubic feet of stranded natural gas into easily transportable liquid aromatic products. [copyright] 2004 American Institute of Physics

Author (AIP)

Carbon Dioxide; Catalysts; Chemical Reactions; Hydrogen; Hydrogen Fuels; In Situ Resource Utilization; Liquid Fuels; Mars (Planet); Mars Atmosphere; Organic Compounds

20030107829 NASA Ames Research Center, Moffett Field, CA, USA

ISRU Technologies for Mars Life Support

Finn, John E.; Kliss, Mark; Sridhar, K. R.; Iacomini, Christie; [2001]; In English, 7 Nov. 2001, Alexandria, VA, USA

Contract(s)/Grant(s): 131-20-10; No Copyright; Avail: Other Sources; Abstract Only

Life support systems can take advantage of elements in the atmosphere of Mars to provide for necessary consumables such as oxygen and buffer gas for makeup of leakage. In situ consumables production (ISCP) can be performed effectively in conjunction with in situ propellant production, in which oxygen and methane are manufactured for rocket fuel. This project considers ways of achieving the optimal system objectives from the two sometimes competing objectives of ISPP and ISCP. In previous years we worked on production of a nitrogen-argon buffer gas as a by- product of the CO2 acquisition and compression system. Recently we have been focusing on combined electrolysis of water vapor and carbon dioxide. Combined electrolysis of water vapor and carbon dioxide is essential for reducin,o the complexity of a combined ISPP/ISCP plant. Using a solid oxide electrolysis cell (SOEC) for this combined process would be most advantageous for it allows mainly gas phase reactions, O2 gas delivered from the electrolyzer is free of any H2O vapor, and SOE is already a proven technology for pure CO2 electrolysis. Combined SOEC testing is conducted at The University of Arizona in the Space Technologies Laboratory (STL) of the Aerospace and Mechanical Engineering Department.

Author

In Situ Resource Utilization; Mars Atmosphere; Life Support Systems; Electrolysis

20030093623 Alabama Univ., Huntsville, AL, USA

Potential of Sintered Regolith Materials for Derivation of In-Situ Resource Utilization

Schwarz, Lois G.; The 2002 NASA Faculty Fellowship Program Research Reports; April 2003, 1-5; In English; No Copyright; Avail: CASI; C01, CD-ROM; A01, Hardcopy

Practical interplanetary exploration leading to sustained human habitation on Mars will need to rely on in-situ resource utilization (ISRU). Material processing and fabrication using indigenous resources to produce metal alloys and ceramics would be economically beneficial rather than transporting necessary materials from Earth. ISRU is constrained, however, by resource availability, mining, and processing methods. Desirable materials will be dependent on manufacturing and construction processes, as well as, performance in uniquely hostile environments. A specifically developed Martian soil simulant, JSC Mars-1, that is spectrally similar to the ubiquitous Martian regolith, is used in research since only a limited amount of Martian soil has been retrieved from the planet. Sintering involves shrinkage of a body as particles pull closer together and porosity decreases. Dominant in the sintering process is atomic motion, governed by diffusion mechanics, occurring at a rate that increases as temperature increases as described by the Arrhenius equation. Distinct stages of densification are defined by solid state atomic diffusion, the formation of a liquid (oftentimes glassy) phase between the particles, and by reactions at the grain boundaries. The transport of thermal energy by sintering can be categorized into the

mechanisms of conduction, convection, and radiation; the latter is usually dominant from the furnace heating elements. The most influential parameter in sintering is temperature, other variables include time held at peak temperature or soak period, rates of heating and cooling, atmosphere type, particle surface area, compaction or density, and additives to increase particle bonding, softening, and flexibility. The objectives of are to investigate the potential of using a sintering process method on JSC Mars-1 to (a) isolate raw metals and/or compounds and (b) develop a material suitable for structural products that may manifest enhanced engineering properties. These materials could be used for construction purposes of storage facilities, habitat facilities, launch platforms, shielding, etc.
Derived from text
In Situ Resource Utilization; Regolith; Sintering; Soil Science; Manufacturing; Planetary Geology

20030067889 Lockheed Martin Space Systems Co., Denver, CO, USA
CO2 Acquisition Membrane (CAM) Project
Mason, Larry W.; [2003]; In English
Contract(s)/Grant(s): NAS8-00126
Report No.(s): MCR-00-509; No Copyright; Avail: CASI; A05, Hardcopy

The CO2 Acquisition Membrane (CAM) project was performed to develop, test, and analyze thin film membrane materials for separation and purification of carbon dioxide (CO2) from mixtures of gases, such as those found in the Martian atmosphere. The membranes developed in this project are targeted toward In Situ Resource Utilization (ISRU) applications, such as In Situ Propellant Production (ISPP) and In Situ Consumables Production (ISCP). These membrane materials may be used in a variety of ISRU systems, for example as the atmospheric inlet filter for an ISPP process to enhance the concentration of CO2 for use as a reactant gas, to passively separate argon and nitrogen trace gases from CO2 for habitat pressurization, to provide a system for removal of CO2 from breathing gases in a closed environment, or within a process stream to selectively separate CO2 from other gaseous components. The membranes identified and developed for CAM were evaluated for use in candidate ISRU processes and other gas separation applications, and will help to lay the foundation for future unmanned sample return and human space missions. CAM is a cooperative project split among three institutions: Lockheed Martin Astronautics (LMA), the Colorado School of Mines (CSM), and Marshall Space Flight Center (MSFC).
Author
Membrane Structures; Carbon Dioxide; In Situ Resource Utilization; Purification

20030060573 Massachusetts Inst. of Tech., MA, USA
From Oxygen Generation to Metals Production: In Situ Resource Utilization by Molten Oxide Electrolysis
Khetpal, Deepak; Ducret, Andrew C.; Sadoway, Donald R.; 2002 Microgravity Materials Science Conference; February 2003, 548-555; In English; Original contains color and black and white illustrations; No Copyright; Avail: CASI; A02, Hardcopy

For the exploration of other bodies in the solar system, electrochemical processing is arguably the most versatile technology for conversion of local resources into usable commodities: by electrolysis one can, in principle, produce (1) breathable oxygen, (2) silicon for the fabrication of solar cells, (3) various reactive metals for use as electrodes in advanced storage batteries, and (4) structural metals such as steel and aluminum. Even so, to date there has been no sustained effort to develop such processes, in part due to the inadequacy of the database. The objective here is to identify chemistries capable of sustaining molten oxide electrolysis in the cited applications and to examine the behavior of laboratory-scale cells designed to generate oxygen and to produce metal. The basic research includes the study of the underlying high-temperature physical chemistry of oxide melts representative of lunar regolith and of Martian soil. To move beyond empirical approaches to process development, the thermodynamic and transport properties of oxide melts are being studied to help set the limits of composition and temperature for the processing trials conducted in laboratory-scale electrolysis cells. The goal of this investigation is to deliver a working prototype cell that can use lunar regolith and Martian soil to produce breathable oxygen along with metal by-product. Additionally, the process can be generalized to permit adaptation to accommodate different feedstock chemistries, such as those that will be encountered on other bodies in the solar system. The expected results of this research include: (1) the identification of appropriate electrolyte chemistries; (2) the selection of candidate anode and cathode materials compatible with electrolytes named above; and (3) performance data from a laboratory-scale cell producing oxygen and metal. On the strength of these results it should be possible to assess the technical viability of molten oxide electrolysis for in situ resource utilization on the Moon and Mars. In parallel, there may be commercial applications here on earth, such as new green technologies for metals extraction and for treatment of hazardous waste, e.g., fixing heavy metals.
Author
In Situ Resource Utilization; Electrolysis; Heavy Metals; Melts (Crystal Growth); Oxygen; Molten Salts

20030053430 NASA Kennedy Space Center, Cocoa Beach, FL, USA

An Introduction to Mars ISPP Technologies

Lueck, Dale E.; Research Needs in Fire Safety for the Human Exploration and Utilization of Space: Proceedings and Research Plan; April 2003, 65-77; In English; Original contains black and white illustrations; No Copyright; Avail: CASI; A03, Hardcopy

This viewgraph presentation provides information on potential In Situ Propellant Production (ISPP) technologies for Mars. The presentation discusses Sabatier reactors, water electrolysis, the advantages of methane fuel, oxygen production, PEM cell electrolyzers, zirconia solid electrolyte cells, reverse water gas shift (RWGS), molten carbonate electrolysis, liquid CO2, and ionic liquids.

CASI

In Situ Resource Utilization; Oxygen Production; Hydrocarbon Fuel Production; Hydrogen Production; Methane; Mars (Planet); Water Splitting; Electrolysis

20030045487

A portable ultrahigh vacuum apparatus for the production and in situ characterization of clusters and cluster-assembled materials

Barborini, E.; Siviero, F.; Vinati, S.; Lenardi, C.; Piseri, P.; Milani, P.; Review of Scientific Instruments; May 2002; ISSN 0034-6748; Volume 73, Issue no. 5, 2060-2066; In English; Copyright

We present and discuss the design and operation of a compact ultrahigh vacuum compatible apparatus for the production and deposition of supersonic cluster beams. The apparatus is equipped with a pulsed microplasma cluster source capable of providing supersonic beams of high stability and intensity. The cluster mass distribution can be analyzed by a two-stage time-of-flight mass spectrometer. The transportability and versatility of the apparatus make the system well suited to perform in situ studies on both gas phase clusters and cluster assembled materials using different characterization facilities. The performances of the system have been tested by scanning tunneling microscopy and photoemission spectroscopy experiments on cluster-assembled carbon films. [copyright] 2002 American Institute of Physics.

Author (AIP)

Carbon; Deposition; In Situ Resource Utilization; Mass Spectrometers; Mass Spectroscopy; Nanostructure (Characteristics); Photoelectrons; Scanning Tunneling Microscopy; Spectroscopic Analysis; Thin Films; Time of Flight Spectrometers; Ultrahigh Vacuum; Ultraviolet Spectra; Vacuum Apparatus; Vacuum Chambers; X Ray Spectra

20030006908

A View of Future Human Colonies on Mars

Gustafson, Robert J.; Rice, Eric E.; Gramer, Daniel J.; White, Brant C.; AIP Conference Proceedings; January 28, 2003; ISSN 0094-243X; Volume 654, Issue no. 1, 1250-1257; In English; SPACE TECHNOLOGY and APPLICATIONS INT.FORUM-STAIF 2003: Conf.on Thermophysics in Microgravity; Commercial/Civil Next Generation Space Transportation; Human Space Exploration, 2-5 February 2003, Albuquerque, New Mexico, USA

Contract(s)/Grant(s): 07600-041; Copyright

In a recent feasibility study, ORBITEC conceptualized systems and an evolving architecture for producing and utilizing Mars-based in-situ resources utilization (ISRU) propellant combinations. The propellants will be used to support the propulsion and power systems for ground and flight vehicles that would be part of Mars exploration and colonization. The key aspect of the study was to show the benefits of ISRU, develop an analysis methodology, as well as provide some guidance to future propellant system choices based upon what is known today about Mars. The study time frame included an early unmanned and manned exploration period (now to 2040) and a colonization period that occurs from 2040 to 2090. As part of this feasibility study, ORBITEC developed two different Mars colonization scenarios, namely a low case that ends with a 100-person colony and a high case that ends with a 10.000-person colony. A population growth model, mission traffic model, and infrastructure model was developed for each scenario to better understand the requirements of future Mars colonies. This paper outlines the characteristics of the Mars colonies that ORBITEC envisions under both colonization scenarios. This includes a discussion of the flow of people and materials between the Earth and Mars, the infrastructure requirements of the colonies, potential colony configurations, and the mission requirements of the colonies. [copyright] 2003 American Institute of Physics

Author (AIP)

Mars (Planet); Spacecraft; Spacecraft Propulsion

20030006898

Optimized ISRU Propellants for Propulsion and Power Needs for Future Mars Colonization

Rice, Eric E.; Gustafson, Robert J.; Gramer, Daniel J.; Chiaverini, Martin J.; Teeter, Ronald R.; White, Brant C.; AIP Conference Proceedings; January 28, 2003; ISSN 0094-243X; Volume 654, Issue no. 1, 1163-1170; In English; SPACE TECHNOLOGY and APPLICATIONS INT.FORUM-STAIF 2003: Conf.on Thermophysics in Microgravity; Commercial/Civil Next Generation Space Transportation; Human Space Exploration, 2-5 February 2003, Albuquerque, New Mexico, USA
Contract(s)/Grant(s): 07600-041; Copyright

In recent studies (Rice, 2000, 2002) conducted by ORBITEC for the NASA Institute for Advanced Concepts (NIAC), we conceptualized systems and an evolving optimized architecture for producing and utilizing Mars-based in-situ space resources utilization (ISRU) propellant combinations for future Mars colonization. The propellants are to be used to support the propulsion and power systems for ground and flight vehicles. The key aspect of the study was to show the benefits of ISRU, develop an analysis methodology, as well as provide guidance to propellant system choices in the future based upon what is known today about Mars. The study time frame included an early unmanned and manned exploration period (through 2040) and two colonization scenarios that are postulated to occur from 2040 to 2090. As part of this feasibility study, ORBITEC developed two different Mars colonization scenarios: a low case that ends with a 100-person colony (an Antarctica analogy) and a high case that ends with a 10,000-person colony (a Mars terraforming scenario). A population growth model, mission traffic model, and infrastructure model were developed for each scenario to better understand the requirements of future Mars colonies. Additionally, propellant and propulsion systems design concepts were developed. Cost models were also developed to allow comparison of the different ISRU propellant approaches. This paper summarizes the overall results of the study. ISRU proved to be a key enabler for these colonization missions. Carbon monoxide and oxygen, proved to be the most cost-effective ISRU propellant combination. The entire final reports Phase I and II) and all the details can be found at the NIAC website www.niac.usra.edu. [copyright] 2003 American Institute of Physics

Author (AIP)

Carbon Compounds; Extraterrestrial Resources; Mars (Planet); Oxygen; Spacecraft; Spacecraft Propulsion

20030006897

ISRU Reactant, Fuel Cell Based Power Plant for Robotic and Human Mobile Exploration Applications

Baird, Russell S.; Sanders, Gerald; Simon, Thomas; McCurdy, Kerri; AIP Conference Proceedings; January 28, 2003; ISSN 0094-243X; Volume 654, Issue no. 1, 1157-1162; In English; SPACE TECHNOLOGY and APPLICATIONS INT.FORUM-STAIF 2003: Conf.on Thermophysics in Microgravity; Commercial/Civil Next Generation Space Transportation; Human Space Exploration, 2-5 February 2003, Albuquerque, New Mexico, USA; Copyright

Three basic power generation system concepts are generally considered for lander, rover, and Extra-Vehicular Activity (EVA) assistant applications for robotic and human Moon and Mars exploration missions. The most common power system considered is the solar array and battery system. While relatively simple and successful, solar array/battery systems have some serious limitations for mobile applications. For typical rover applications, these limitations include relatively low total energy storage capabilities, daylight only operating times (6 to 8 hours on Mars), relatively short operating lives depending on the operating environment, and rover/lander size and surface use constraints. Radioisotope power systems are being reconsidered for long-range science missions. Unfortunately, the high cost, political controversy, and launch difficulties that are associated with nuclear-based power systems suggests that the use of radioisotope powered landers, rovers, and EVA assistants will be limited. The third power system concept now being considered are fuel cell based systems. Fuel cell power systems overcome many of the performance and surface exploration limitations of solar array/battery power systems and the prohibitive cost and other difficulties associated with nuclear power systems for mobile applications. In an effort to better understand the capabilities and limitations of fuel cell power systems for Moon and Mars exploration applications. NASA is investigating the use of In-Situ Resource Utilization (ISRU) produced reactant, fuel cell based power plants to power robotic outpost rovers, science equipment, and future human spacecraft, surface-excursion rovers, and EVA assistant rovers. This paper will briefly compare the capabilities and limitations of fuel cell power systems relative to solar array/battery and nuclear systems, discuss the unique and enhanced missions that fuel cell power systems enable, and discuss the common technology and system attributes possible for robotic and human exploration to maximize scientific return and minimize cost and risk to both. Progress made to date at the Johnson Space Center on an ISRU producible reactant. Proton Exchange Membrane (PEM) fuel cell based power plant project for use in the first demonstration of this concept in conjunction with rover applications will be presented in detail. [copyright] 2003 American Institute of Physics

Author (AIP)

Extravehicular Activity; Fuel Cell Power Plants; Fuel Cells; Mars (Planet); Mars Exploration; Membranes; Moon; Protons; Robot Dynamics; Robotics; Roving Vehicles

20030006896

The Development of ISRU and ISSE Technologies Leveraging Canadian Mining Expertise

Boucher, Dale S.; Richard, Jim; Dupuis, Erick; AIP Conference Proceedings; January 28, 2003; ISSN 0094-243X; Volume 654, Issue no. 1, 1150-1156; In English; SPACE TECHNOLOGY and APPLICATIONS INT.FORUM-STAIF 2003: Conf.on Thermophysics in Microgravity; Commercial/Civil Next Generation Space Transportation; Human Space Exploration, 2-5 February 2003, Albuquerque, New Mexico, USA; Copyright

F uture space missions to planetary bodies, both manned and robotic, will require the efficient utilization of in-situ resources to ensure longevity and success. In Situ Resources Utilization (ISRU) and In Situ Support Equipment (ISSE), while requiring the development of new technologies and methods for commodity extraction, will still rely upon some method of mining technology for the harvesting and pre-beneficiation of the raw materials prior to processing. The Northern Centre for Advanced Technologies Inc., in partnership with Electric Vehicle Controllers Ltd., is presently engaged in the development and adaptation of existing mining technologies and methodologies for use extra-terrestrially as pre cursor and enabling technologies for ISRU and for use as ISSE in support of longer term missions. More specifically, NORCAT and EVC, in partnership with MD Robotics and under contract to the Canadian Space Agency, are developing a drill and sample handler system for sub surface sampling of planetary bodies, specifically Mars. The partnership brings to the table some formidable world leading expertise in space robotics coupled with world leading expertise in mining technologies. [copyright] 2003 American Institute of Physics

Author (AIP)

Mining; Robot Dynamics; Robotics; Space Missions; Spacecraft

20030006893

Operation, Modeling and Analysis of the Reverse Water Gas Shift Process

Whitlow, Jonathan E.; Parrish, Clyde F.; AIP Conference Proceedings; January 28, 2003; ISSN 0094-243X; Volume 654, Issue no. 1, 1116-1123; In English; SPACE TECHNOLOGY and APPLICATIONS INT.FORUM-STAIF 2003: Conf.on Thermophysics in Microgravity; Commercial/Civil Next Generation Space Transportation; Human Space Exploration, 2-5 February 2003, Albuquerque, New Mexico, USA; Copyright

The Reverse Water Gas Shift (RWGS) process is a candidate technology for water and oxygen production on Mars as part of the In-Situ Space Resource Utilization (ISRU) initiative. This paper focuses on the operation and analysis of the RWGS process, which has been constructed and operated at Kennedy Space Center. While the investigation of the RWGS process is on-going, a summary of results obtained from the operation to date is presented. In addition, simulation models of the RWGS process have been developed and description of the models is also included. [copyright] 2003 American Institute of Physics

Author (AIP)

Mars (Planet); Oxygen; Oxygen Production; Water

20030006890

ISRU Development Strategy and Recent Activities to Support Near and Far Term Missions

Baird, Russell S.; Sanders, Gerald B.; Simon, Thomas M.; AIP Conference Proceedings; January 28, 2003; ISSN 0094-243X; Volume 654, Issue no. 1, 1087-1094; In English; SPACE TECHNOLOGY and APPLICATIONS INT.FORUM-STAIF 2003: Conf.on Thermophysics in Microgravity; Commercial/Civil Next Generation Space Transportation; Human Space Exploration, 2-5 February 2003, Albuquerque, New Mexico, USA; Copyright

The practical expansion of humans beyond low Earth orbit into near-Earth space and out into the solar system for exploration, commercialization, tourism, and colonization will require the effective utilization of whatever indigenous resources are available to make these endeavors economically feasible and capable of extended operations. This concept of ‘living off the land’ is called In-Situ Resource Utilization (ISRU). The resources available for ISRU applications vary widely, depending upon the location. However, there are resources, technologies, and processes that are common to multiple destinations and ISRU-related applications. These resources range from carbon dioxide (CO2) and water vapor found in human habitats (surface & spacecraft) and in the Martian atmosphere, to water (ice and hydrated minerals) and various oxygen, carbon, and metal-bearing resources found on comets and asteroids, and in planetary surface materials at numerous destinations of interest (Moon, Mars, Titan, and Europa). Many parties are investigating the common technologies and processes to effectively extract and use these resources. This paper will discuss how ISRU is enabling for both near and far term human exploration missions, and present a summary of recent and on-going ISRU work sponsored by the NASA/Johnson Space Center. Technology development activities that will be described in detail include an advanced CO2 freezer acquisition system, a multi-fluid common bulkhead cryogenic storage tank, and a variety of microchannel chemical reactor concepts. Recent advanced Sabatier reactor concept development activities in preparation for later, end-to-end system testing will be

described as well. This paper will also discuss an ISRU-based strategy to enable extensive robotic and human surface exploration operations and a related on-going demonstration program for a fuel cell based power plant for rover applications. Technology commonalities between ISRU, life support systems, and Extra Vehicular Activity (EVA), applications will also be presented. [copyright] 2003 American Institute of Physics
Author (AIP)
Electric Generators; In Situ Resource Utilization; Low Earth Orbits; Robot Dynamics; Robotics; Roving Vehicles; Solar System; Space Exploration; Spacecraft; Spacecraft Power Supplies

20030005546 Battelle Memorial Inst., Richland, WA USA
Microchannel Phase Separation and Partial Condensation in Normal and Reduced Gravity Environments
TeGrotenhuis, Ward E.; Stenkamp, Victoria S.; Sixth Microgravity Fluid Physics and Transport Phenomena Conference: Exposition Topical Areas 1-6; November 2002; Volume 2, 122-123; In English; Original contains color illustrations; No Copyright; Avail: CASI; A01, Hardcopy

Microtechnology was conceived as a means of shrinking the length scales of heat and mass transfer to 100 microns or less so that orders of magnitude increases in throughput can be realized in chemical processes. The subsequent reduction in size and mass lends itself well to space applications. Using proprietary sheet architecture, Battelle has created such devices with micro chemical and thermal systems (MicroCATS) for gas phase reactions, heat transfer and solvent extraction. In this work, Battelle has extended the technology to include phase separation and partial condensation with phase separation in channels between 100 microns and a few millimeters at the smallest dimension. These length scale channels are advantageous for all reduced gravity applications involving two-phase flow since hydrodynamic, interfacial and capillary forces dominate over gravitational forces. By controlling the wettability and porosity of the materials within the device, separation occurs spontaneously thus allowing high throughputs and easy recovery from process upsets. Enhanced heat transfer in the case of condensation is obtained through reduction of the narrowest channel dimension. Scale up is achieved by simply increasing the number of layers. Potential space applications for phase separation and condensation include water management in environmental control and life support and thermal systems involving phase change (heat pipes, vapor compression cycles). These devices are also well suited for in-situ resource utilization or 'living off the land' since they are compact and efficient. Applications include phase separation and condensation of water during in-situ propellant production.
Author
Two Phase Flow; Microgravity; Phase Separation (Materials); Phase Transformations; Nanotechnology; Condensing; Fluid Dynamics

20030003654 NASA Ames Research Center, Moffett Field, CA USA
Separation of Carbon Monoxide and Carbon Dioxide for Mars ISRU
LeVan, M. Douglas; Walton, Krista S.; Finn, John E.; Sridhar, K. R.; Sixth Microgravity Fluid Physics and Transport Phenomena Conference; November 2002; Volume 1, 620-635; In English; No Copyright; Avail: CASI; A03, Hardcopy

Human Exploration and Development of Space will require the use of fundamental process technologies for gas storage and separation. These are enabling technologies. In our research, we are designing, constructing, and testing an innovative, robust, low mass, low power separation device that can recover carbon dioxide and carbon monoxide for Mars ISRU (in-situ resource utilization). The work has broad implications for gas storage and separations for gas-solid systems; these are ideally suited for reduced gravitational environments. The work is also important for robotic sample return missions using ISRU and in lunar oxygen production from regolith using carbothermal reduction. This paper describes our overall effort and highlights our results on adsorption equilibrium determination and process design. A second paper will provide details on adsorption equilibrium measurement and adsorbent selection.
Author
In Situ Resource Utilization; Mars Exploration; Carbon Dioxide Removal; Carbon Monoxide

20020094311 Search for Extraterrestrial Intelligence Inst., Mountain View, CA USA
Physics of Granular Materials: Investigations in Support of Astrobiology
Marshall, John R.; Nov. 25, 2002; In English
Contract(s)/Grant(s): NCC2-1120; No Copyright; Avail: CASI; A01, Hardcopy

This publication list is submitted as a summary of the work conducted under Cooperative Agreement 1120. The goal of the 1120 research was to study granular materials within a planetary, astrophysical, and astrobiological context. This involved research on the physical, mechanical and electrostatic properties of granular systems, as well as the examination of these

materials with atomic force microscopy and x-ray analysis. Instruments for analyzing said materials in planetary environments were developed, including the MECA (Mars Environment Compatibility Assessment) experiment for the MSP ‘01 lander, the ECHOS/MATADOR experiment for the MSP ‘03 lander, an ISRU experiment for the ‘03 lander, and MiniLEAP technology. Flight experiments for microgravity (Space Station and Shuttle) have also been developed for the study of granular materials. As expressed in the publications, work on 1120 encompassed laboratory research, theoretical modeling, field experiments, and flight experiments: a series of successful new models were developed for understanding the behavior of triboelectrostatically charged granular masses, and 4 separate instruments were selected for space flight. No inventions or patents were generated by the research under this Agreement.
Author
Mars Environment; Mars Missions; Granular Materials

20020074713 Hawaii Univ., Honolulu, HI USA
Lunar Prospecting
Taylor, G. Jeffrey; Martel, Linda; The Moon Beyond 2002: Next Steps in Lunar Science and Exploration; 2002, 60; In English; No Copyright; Avail: CASI; A01, Hardcopy

Space resources are essential for space settlement: Large space settlements on the Moon or Mars will require use of indigenous resources to build and maintain the infrastructure and generate products for export. Prospecting for these resources on the Moon is a crucial step in human migration to space and needs to begin before the establishment of industrial complexes. We are devising a multi-faceted approach to prospect for resources that involves planetary research, technology development, human workforce training, and education. Our work builds on previous studies.
Author
Lunar Resources; Lunar Mining; Lunar Geology

20020074706 NASA Ames Research Center, Moffett Field, CA USA
A Miniature Mineralogical Instrument for In-Situ Characterization of Ices and Hydrous Minerals at the Lunar Poles
Sarrazin, P.; Blake, D.; Vaniman, D.; Bish, D.; Chipera, S.; Collins, S. A.; The Moon Beyond 2002: Next Steps in Lunar Science and Exploration; 2002, 53; In English; No Copyright; Avail: CASI; A01, Hardcopy

Lunar missions over the past few years have provided new evidence that water may be present at the lunar poles in the form of cold-trapped ice deposits, thereby rekindling interest in sampling the polar regions. Robotic landers fitted with mineralogical instrumentation for in-situ analyses could provide unequivocal answers on the presence of crystalline water ice and/or hydrous minerals at the lunar poles. Data from Lunar Prospector suggest that any surface exploration of the lunar poles should include the capability to drill to depths of more than 40 cm. Limited data on the lunar geotherm indicate temperatures of approximately 245-255 K at regolith depths of 40 cm, within a range where water may exist in the liquid state as brine. A relevant terrestrial analog occurs in Antarctica, where the zeolite mineral chabazite has been found at the boundary between ice-free and ice-cemented regolith horizons, and precipitation from a regolith brine is indicated. Soluble halogens and sulfur in the lunar regolith could provide comparable brine chemistry in an analogous setting. Regolith samples collected by a drilling device could be readily analyzed by CheMin, a mineralogical instrument that combines X-ray diffraction (XRD) and X-ray fluorescence (XRF) techniques to simultaneously characterize the chemical and mineralogical compositions of granular or powdered samples. CheMin can unambiguously determine not only the presence of hydrous alteration phases such as clays or zeolites, but it can also identify the structural variants or types of clay or zeolite present (e.g., well-ordered versus poorly ordered smectite; chabazite versus phillipsite). In addition, CheMin can readily measure the abundances of key elements that may occur in lunar minerals (Na, Mg, Al, Si, K, Ca, Fe) as well as the likely constituents of lunar brines (F, Cl, S). Finally, if coring and analysis are done during the lunar night or in permanent shadow, CheMin can provide information on the chemistry and structure of any crystalline ices that might occur in the regolith samples.
Author
Lunar Surface; Lunar Resources; Ice; Robotics; Sampling; Mineralogy; Samplers

20020074702 Los Alamos National Lab., NM USA
Classification of Regolith Materials from Lunar Prospector Data Reveals a Magnesium-Rich Highland Province
Prettyman, T. H.; Lawrence, D. J.; Vaniman, D. T.; Elphic, R. C.; Feldman, W. C.; The Moon Beyond 2002: Next Steps in Lunar Science and Exploration; 2002, 49; In English; No Copyright; Avail: CASI; A01, Hardcopy

The Lunar Prospector (LP) mission returned the first global elemental maps of major elements O, Si, Al, Ti, Fe, Mg, and Ca. The maps were submitted to the Planetary Data System (PDS) archive in June of 2002. Maps are provided for all of the

elements at 5 spatial resolution, corresponding to 1790 equal area pixels. This resolution is sufficient to investigate large-scale compositional variations within major lunar terranes. Further work is underway to develop 2 and 0.5 maps for a subset of these elements, which will reduce the effects of instrumental mixing and will enable more meaningful comparisons to the sample collection. We believe that we have discovered a highland province that may contain an abundance of Mg-rich troctolitic or noritic materials. We are investigating several possibilities for the origin of this province, one of which is the exceptional abundance of late-stage Mgsuite intrusions at a high level in the lunar crust. We will use the entire Lunar Prospector elemental data set to investigate candidate hypotheses.
Author
Lunar Maps; Mineralogy; Magnesium; Lunar Geology; Lunar Resources; Lunar Crust; Lunar Rocks

20020074657 Colorado School of Mines, Golden, CO USA
Sensitivity of Lunar Resource Economic Model to Lunar Ice Concentration
Blair, Brad; Diaz, Javier; The Moon Beyond 2002: Next Steps in Lunar Science and Exploration; 2002, 4; In English
Contract(s)/Grant(s): JPL-1237006; No Copyright; Avail: CASI; A01, Hardcopy

Lunar Prospector mission data indicates sufficient concentration of hydrogen (presumed to be in the form of water ice) to form the basis for lunar in-situ mining activities to provide a source of propellant for near-Earth and solar system transport missions. A model being developed by JPL, Colorado School of Mines, and CSP, Inc. generates the necessary conditions under which a commercial enterprise could earn a sufficient rate of return to develop and operate a LEO propellant service for government and commercial customers. A combination of Lunar-derived propellants, L-1 staging, and orbital fuel depots could make commercial LEO/GEO development, inter-planetary missions and the human exploration and development of space more energy, cost, and mass efficient.
Author
Hydrogen; Lunar Mining; Ice; Propellants; Space Commercialization

20020051396 NASA Kennedy Space Center, Cocoa Beach, FL USA
Models of an In-Situ Propellant Production Plant for Mars Exploration
Goodrich, Charlie; Kurien, James; Millar, Bill; Sweet, Adam; Waterman, Sue; Clancy, Daniel, Technical Monitor; [2001]
Contract(s)/Grant(s): NASA Order H-6309-MD; RTOP 632-37-00; No Copyright; Avail: Other Sources; Abstract Only

An in-situ propellant production system (ISPP) is designed to make rocket fuel from chemicals in the Martian atmosphere in order to reduce the amount of materials that would need to be brought from Earth to support Mars missions. We have developed a description of a hypothetical ISPP system that we would like to make available to researchers who are interested in the problem of automatically diagnosing failures in complex NASA systems. This problem description will help researchers to investigate problems of interest to NASA. We would like to make the following material publicly available: (1) a ‘common sense’ model of an ISPP system; (2) low- and medium-fidelity simulations of the ISPP system written in Microsoft Excel and HCC; and (3) previously published data and diagrams concerning ISPP components. We do not believe there are any export considerations on these materials for the following reasons: (1) These models are not useful for guidance and real time control of vehicles, encrpytion, or any other software purpose categorized under the Export Control Classification Numbers; and (2) The models are very high level and would not by themselves enable real-time control of a real hardware system. The models are at the level of common sense. They capture, for example, that if a heater is turned on an increase in temperature should result(see the attached excerpt). We do not believe there is any commercial value to this material, given the low commercial demand for propellant plants on mars. We have spoken to acting Code IC Division Chief Dan Clancy, and he concurs with our desire to make these materials publicly available via a technical report.
Author
Propellants; In Situ Resource Utilization; Mars Missions

20020051224 NASA Ames Research Center, Moffett Field, CA USA
Continuous Measurements and Quantitative Constraints: Challenge Problems for Discrete Modeling Techniques
Goodrich, Charles H.; Kurien, James; Clancy, Daniel, Technical Monitor; [2001]; In English; ISAIRAS Conference, Jun. 2001, Montreal, Canada
Contract(s)/Grant(s): NASA Order H-6309-MD; RTOP 632-37-00; No Copyright; Avail: CASI; A01, Hardcopy

We present some diagnosis and control problems that are difficult to solve with discrete or purely qualitative techniques. We analyze the nature of the problems, classify them and explain why they are frequently encountered in systems with closed loop control. This paper illustrates the problem with several examples drawn from industrial and aerospace applications and

presents detailed information on one important application: In-Situ Resource Utilization (ISRU) on Mars. The model for an ISRU plant is analyzed showing where qualitative techniques are inadequate to identify certain failure modes and to maintain control of the system in degraded environments. We show why the solution to the problem will result in significantly more robust and reliable control systems. Finally, we illustrate requirements for a solution to the problem by means of examples.
Author
Control Systems Design; Systems Health Monitoring; Fault Detection; Aerospace Engineering

20020050928 Louisiana Tech Univ., Ruston, LA USA
Thermal Design of a Collapsible Cryogenic Vessel
Hegab, Hisham E.; NASA/ASEE Summer Faculty Fellowship Program; October 2001, 85-94; In English
Contract(s)/Grant(s): NAG10-299; No Copyright; Avail: CASI; A02, Hardcopy

Strategic planning for human exploration missions to Mars has conclusively identified in-situ resource utilization (ISRU) as an enabling technology. Most mission scenarios include an ISRU plant to produce propellants for ascent from Mars as well as the production of backup reserves of water, oxygen, and process gases. Current mission scenarios call for an ISRU plant to be deployed and then produce and store the required propellants and life support reserves before the arrival of the first human mission. Reliable cryogenic propellant liquefaction and storage technologies for extended period missions are especially critical. This report examines the cryogenic storage problem for liquid oxygen produced by an ISRU plant for a human mission scenario. The analysis examines various hardware configurations including insulation types, packaging techniques, and required cryocoolers to minimize the initial launch mass to low Earth orbit. Results of the analyses indicate that high vacuum insulation systems requiring vacuum pressures below one millitorr will be required to minimize the ‘initial launch mass into low Earth orbit even though the temperature on the surface of Mars is much lower than Earth.
Author
Life Support Systems; Collapse; Cryogenics; Mars Missions; Propellant Storage; Cryogenic Cooling

20020050609 Florida Inst. of Tech., FL USA
Operation, Modeling and Analysis of the Reverse Water Gas Shift Process
Whitlow, Jonathan E.; NASA/ASEE Summer Faculty Fellowship Program; October 2001, 189-198; In English
Contract(s)/Grant(s): NAG10-299; No Copyright; Avail: CASI; A02, Hardcopy

The Reverse Water Gas Shift process is a candidate technology for water and oxygen production on Mars under the In-Situ Propellant Production project. This report focuses on the operation and analysis of the Reverse Water Gas Shift (RWGS) process, which has been constructed at Kennedy Space Center. A summary of results from the initial operation of the RWGS, process along with an analysis of these results is included in this report. In addition an evaluation of a material balance model developed from the work performed previously under the summer program is included along with recommendations for further experimental work.
Author
Material Balance; Oxygen Production; Propellants

20020050545 Florida Inst. of Tech., FL USA
Evaluation of Design Concepts for Collapsible Cryogenic Storage Vessels
Fleming, David C.; NASA/ASEE Summer Faculty Fellowship Program; October 2001, 53-62; In English
Contract(s)/Grant(s): NAG10-299; No Copyright; Avail: CASI; A02, Hardcopy

Future long-duration missions to Mars using in situ resource production to obtain oxygen from the Martian atmosphere for use as a propellant or for life support will require long term oxygen storage facilities. This report describes preliminary analysis of design concepts for lightweight, collapsible liquid oxygen storage tanks to be used on the surface of Mars. With storage at relatively low pressures, an inflatable tank concept in which the cryogen is stored within a fiber-reinforced Teflon FEP bladder is an efficient approach. The technology required for such a tank is well-developed through similar previous applications in positive expulsion bladders for zero-g liquid fuel rocket tanks and inflatable space habitat technology, though the liquid oxygen environment presents unique challenges. The weight of the proposed structure is largely dominated by the support structure needed to hold the tank off the ground and permit a vacuum insulation space to be maintained around the tank. In addition to the inflatable tank concept, telescoping tank concepts are studied. For a telescoping tank, the greatest difficulty is in making effective joints and seals. The use of shape memory alloy to produce a passive clamping ring is

evaluated. Although the telescoping tank concepts are a viable option, it appears that inflatable tank concepts will be more efficient and are recommended.
Author
Aerospace Engineering; Expandable Structures; Oxygen; Life Support Systems; Cryogenics; Fiber Composites; In Situ Resource Utilization

20020039615 NASA Kennedy Space Center, Cocoa Beach, FL USA
Membrane Separation Processes at Low Temperatures
Parrish, Clyde; [2002]; In English, 14-17 Jan. 2002, Reno, NV, USA
Report No.(s): NASA/TP-2002-210266; NAS 1.60:210266; AIAA Paper 2002-0461; Copyright; Avail: CASI; A03, Hardcopy

The primary focus of Kennedy Space Center's gas separation activities has been for carbon dioxide, nitrogen, and argon used in oxygen production technologies for Martian in-situ resource utilization (ISRU) projects. Recently, these studies were expanded to include oxygen for regenerative life support systems. Since commercial membrane systems have been developed for separation of carbon dioxide, nitrogen, and oxygen, initially the studies focused on these membrane systems, but at lower operating temperatures and pressures. Current investigations art examining immobilized liquids and solid sorbents that have the potential for higher selectivity and lower operating temperatures. The gas separation studies reported here use hollow fiber membranes to separate carbon dioxide, nitrogen, and argon in the temperature range from 230 to 300 K. Four commercial membrane materials were used to obtain data at low feed and permeate pressures. These data were used with a commercial solution-diffusion modeling tool to design a system to prepare a buffer gas from the byproduct of a process to capture Martian carbon dioxide. The system was designed to operate, at 230 K with a production rate 0.1 sLpm; Feed composition 30% CO2, 44% N2, and 26% Ar; Feed pressure 104 kPa (780); and Permeate pressure 1 kPa (6 torr); Product concentration 600 ppm CO2. This new system was compared with a similar system designed to operate at ambient temperatures (298 K). The systems described above, along with data, test apparatus, and models are presented.
Author
Low Temperature; Gas Mixtures; Membranes; Systems Engineering; Permeability; Gas Chromatography; Mars (Planet)

20020039172 Research Inst. for Advanced Computer Science, Moffett Field, CA USA
Verification and Validation of Model-Based Autonomous Systems
Pecheur, Charles; Koga, Dennis, Technical Monitor; [2001]; In English; 1st Annual NASA Office of Safety and Mission Assurance Software Assurance Symposium, 5-7 Sep. 2001, Morgantown, WV, USA; No Copyright; Avail: CASI; A03, Hardcopy

This paper presents a three year project (FY99 to FY01) on the verification and validation of model based autonomous systems. The topics include: 1) Project Profile; 2) Model-Based Autonomy; 3) The Livingstone MIR; 4) MPL2SMV; 5) Livingstone to SMV Translation; 6) Symbolic Model Checking; 7) From Livingstone Models to SMV Models; 8) Application In-Situ Propellant Production; 9) Closed-Loop Verification Principle; 10) Livingstone PathFinder (LPF); 11) Publications and Presentations; and 12) Future Directions. This paper is presented in viewgraph form.
CASI
Autonomy; Program Verification (Computers); Systems Engineering; Models

20020016967 NASA Marshall Space Flight Center, Huntsville, AL USA
Space Resource Requirements for Future In-Space Propellant Production Depots
Smitherman, David; Fikes, John; Roy, Stephanie; Henley, Mark W.; Potter, Seth D.; Howell, Joe T., Technical Monitor; [2001]; In English; Space Resources Utilization Roundtable III, 24-26 Oct. 2001, Golden, CO, USA
Contract(s)/Grant(s): RTOP 905-22-00; No Copyright; Avail: CASI; A03, Hardcopy

In 2000 and 2001 studies were conducted at the NASA Marshall Space Flight Center on the technical requirements and commercial potential for propellant production depots in low Earth orbit (LEO) to support future commercial, NASA, and other Agency missions. Results indicate that propellant production depots appear to be technically feasible given continued technology development, and there is a substantial growing market that depots could support. Systems studies showed that the most expensive part of transferring payloads to geosynchronous orbit (GEO) is the fuel. A cryogenic propellant production and storage depot stationed in LEO could lower the cost of missions to GEO and beyond. Propellant production separates water into hydrogen and oxygen through electrolysis. This process utilizes large amounts of power, therefore a depot derived from advanced space solar power technology was defined. Results indicate that in the coming decades there could be a significant demand for water-based propellants from Earth, moon, or asteroid resources if in-space transfer vehicles (upper stages)

transitioned to reusable systems using water based propellants. This type of strategic planning move could create a substantial commercial market for space resources development, and ultimately lead toward significant commercial infrastructure development within the Earth-Moon system.
Derived from text
Low Earth Orbits; Propellant Storage; Geosynchronous Orbits

20010125132 NASA Kennedy Space Center, Cocoa Beach, FL USA
Technology Development for Human Exploration Beyond LEO in the New Millennium IAA-13-3 Strategies and Plans for Human Mars Missions
Larson, William E.; Lueck, Dale E.; Parrish, Clyde F.; Sanders, Gerald B.; Trevathan, Joseph R.; Baird, R. Scott; Simon, Tom; Peters, T.; Delgado, H., Technical Monitor; [2001]; In English; 51st International Astronautical Federation, 1-5 Oct. 2001, Toulouse, France; No Copyright; Avail: CASI; A03, Hardcopy

As we look forward into the new millennium, the extension of human presence beyond Low-Earth Orbit (LEO) looms large in the plans of NASA. The Agency's Strategic Plan specifically calls out the need to identify and develop technologies for 100 and 1000-day class missions beyond LEO. To meet the challenge of these extended duration missions, it is important that we learn how to utilize the indigenous resources available to us on extraterrestrial bodies. This concept, known as In-Situ Resource Utilization (ISRU) can greatly reduce the launch mass & cost of human missions while reducing the risk. These technologies may also pave the way for the commercial development of space. While no specific target beyond LEO is identified in NASA's Strategic Plan, mission architecture studies have been on-going for the Moon, Mars, Near-Earth Asteroids and Earth/Moon & Earth/Sun Libration Points. As a result of these studies, the NASA Office of Space Flight (Code M) through the Johnson and Kennedy Space Centers, is leading the effort to develop ISRU technologies and systems to meet the current and future needs of human missions beyond LEO and on to Mars. This effort also receives support from the NASA Office of Biological and Physical Research (Code U), the Office of Space Science (Code S), and the Office of Aerospace Technology (Code R). This paper will present unique developments in the area of fuel and oxidizer production, breathing air production, water production, C02 collection, separation of atmospheric gases, and gas liquefaction and storage. A technology overview will be provided for each topic along with the results achieved to date, future development plans, and the mission architectures that these technologies support.
Author
Long Duration Space Flight; In Situ Resource Utilization; Materials Recovery

20010110410 Colorado Univ., Boulder, CO USA
Combustion of Metals in Reduced-Gravity and Extraterrestrial Environments
Branch, M. C.; Abbud-Madrid, A.; Daily, J. W.; Oct. 10, 2001; In English; No Copyright; Avail: CASI; A03, Hardcopy

As a result of the ongoing exploration of Mars and the several unmanned and possibly manned missions planned for the near future, increased attention has been given to the use of the natural resources of the planet for rocket propellant production and energy generation. Since the atmosphere of Mars consists of approximately 95% carbon dioxide (CO2), this gas is the resource of choice to be employed for these purposes. Since many metals burn vigorously with CO2, these may be used as an energy source or as propellants for a research vehicle on the surface of Mars. Shafirovich and Goldshleger conducted experiments with spherical particles up to 2.5 mm in diameter and found that the burning process was controlled by diffusion and that the particles exhibited pulsating combustion due to superheating of the Mg vapor trapped inside a protective oxide shell. They also proposed a reaction mechanism based on the gas-phase reaction, Mg + CO2 yields MgO + CO and the heterogeneous reaction Mg + CO yields MgO + C occurring on the sample surface. In all the above studies with large Mg particles, the burning process is invariably influenced by strong convective currents that accelerate the combustion reaction and shorten the burning times. Although these currents are nearly absent in the burning of small particles, the high emissivity of the flames, rapid reaction, and small length scales make the gathering of any useful information on burning rates and flame structure very difficult. The goal of this investigation is to provide a detailed study of flame structure by taking advantage of large, free-floating spherical metal samples and their corresponding long burning times available in a weightless environment. The use of reduced gravity is essential to eliminate the intrusive buoyant flows that plague high temperature metal reactions, to remove the destructive effect of gravity on the shape of molten metal samples, and to study the combustion behavior of metals in the presence of solid oxides undisturbed by natural convection. This work presents the most complete modeling of metal particle burning to date for Mg with CO2 and O2.
Author
Metal Combustion; Metals; Rocket Propellants; Spacecraft Power Supplies; Mars Surface; Magnesium Oxides; Flames

20010089407 MDS Research, Washington, DC USA

Terrestrial Methane Hydrate: A Potentially Universal Planetary Attribute. Is Hydrate a Key to Human Habitation of Other Planetary Bodies?

Max, M. D.; Conference on the Geophysical Detection of Subsurface Water on Mars; August 2001, 70-71; In English; No Copyright; Abstract Only; Available from CASI only as part of the entire parent document

Terrestrial gas hydrates comprise ice-like crystalline compounds of gas (mainly methane) and water which are stable both at very low temperatures in permafrost regions, and in the low temperature - high pressure regimes present in the deep oceans on Earth. Methane and other gases are thermodynamically stabilized within gas hydrates by hydrogen bonding in a crystalline lattice of water molecules. Hydrate forms in both primary and secondary pore space and fractures in sediments as a diagenetic mineral. The presence of hydrate, which replaces water in pore space, strongly alters the physical properties of the sediments in which it occurs. Although hydrate is generally referred to as an 'ice-like' material and some of the physical properties of hydrate are similar to water-ice, they are different in some respects. Additional information is contained in the original extended abstract.

Author

Methane; Hydrates; Planetary Composition; Extraterrestrial Resources

20010089403 MDS Research, Washington, DC USA

Methane and Carbon Dioxide Hydrates on Mars: Are There Sufficient Natural Resources on Mars to Sustain Human Habitation?

Pellenbarg, R. E.; Max, M. D.; Clifford, S. M.; Conference on the Geophysical Detection of Subsurface Water on Mars; August 2001, 80-81; In English; No Copyright; Abstract Only; Available from CASI only as part of the entire parent document

The crust of Mars has been stable for enough time for methane formed by magmatic processes and/or as a by-product of anaerobic deep biosphere activity to have risen toward the planet's surface. This methane would have been captured and stored as methane hydrate, which concentrates methane and water. Both CH4 and carbon dioxide (CO2, the predominant gas in the Martian atmosphere) are stable as gases on the Martian surface but could collect within the hydrate stability field in surface-parallel zones that reach close to the Martian surface. In order for humankind to establish itself on Mars, colonies should be self-sustaining there as soon as possible. With hydrates of both carbon dioxide (CO2) and methane (CH4), Mars would contain the basic elements for human habitation: fuel, potable water, and industrial feedstock in a near-surface situation suitable for controlled extraction by drilling. The presence of methane hydrate may prove to be the key to human habitation of Mars. Instead of transporting to Mars the return-journey fuel and all the items needed for human habitation of the planet, optimized standard industrial chemical plants can be designed for operation on Mars in order to manufacture a variety of plastic objects, such as shelter, ecohabitats, vehicles and other apparatus, in addition to synthetic liquid high-energy-density fuels. Additional information is contained in the original extended abstract.

Author

Carbon Dioxide; Hydrates; Mars Surface; Methane; Extraterrestrial Resources

20010076879 Shimizu Corp., Japan

Study on the Utilization of Lunar Resources

Kanamori, Hiroshi; Proceedings of Advanced Space Technology Workshop; September 2000, 269-271; In English; Also available within the Conference Proceedings with 4 other reports on CD-ROM. See 20010068892.; Copyright; Avail: CASI; A01, Hardcopy; US Distribution and Sales Only

This conference paper outlines resource utilization technology and the kind of technology that will be necessary in the future. The starting point is data on the lunar environment and resources obtained by the Apollo project. Based on this data, there have been many plans to produce a variety of materials from lunar resources. The approaches used in such studies basically fall into two groups. The first generally entails finding out how to use these resources in future space development scenario. For example, there is a study on what economic effects the oxygen and helium-3 on the Moon will have on future space development. The other approach is technical, and focuses on how to actually make these materials from the resources available.

Derived from text

Lunar Resources; Lunar Bases; Lunar Environment

20010076876 National Aerospace Lab., Tokyo, Japan

Future Works on Space Energy Utilization Technology

Eguchi, Kunihisa; Proceedings of Advanced Space Technology Workshop; September 2000, 245-249; In English; Also available within the Conference Proceedings with 4 other reports on CD-ROM. See 20010068892.; Copyright; Avail: CASI; A02, Hardcopy; US Distribution and Sales Only

What is the best way to efficiently use energy in the future? How should we develop space power technologies? And finally, what role should such energy technologies play in space activities? I would mainly like to speak about what has been accomplished by people doing in house energy studies at NAL. In what direction are future studies on space energy headed? In Japan, the question was answered by a long-term vision for space development conceived in 1994. Therefore, this vision will serve as a foundation for our future evolution. Mankind will step up from an age of the International Space Station to that of lunar utilization, and talk today will basically be about applications to the space station, as well as about how we should develop space activities on Moon and other planets.

Derived from text

Energy Technology; International Space Station; Extraterrestrial Resources; Space Station Power Supplies

20010074041 Orbital Technologies Corp., Madison, WI USA

Status Report on Mars ISRU CO/O2 Hybrid Engine Development and Testing

Rice, E. E.; Chiaverini, M. J.; Malecki, M. M.; St. Clair, C. P.; Knuth, W. H.; Gustafson, R. J.; Gramer, D. J.; Sixth International Microgravity Combustion Workshop; May 2001, 189-192; In English; No Copyright; Avail: CASI; A01, Hardcopy

This article addresses the current status of a research and development effort in which ORBITEC has undertaken to test a new type of fuel/oxidizer system for In-situ Resource Utilization (ISRU)-based propulsion systems on Mars. The Martian atmosphere (about 95.5% CO_2) provides a readily available supply of carbon dioxide (CO_2) to produce both CO and O_2, which can be used for hybrid rocket engine applications. Hybrid propulsion systems have several safety and operational features that make them attractive for space systems. For Mars ISRU applications, CO gas can be frozen directly to form a solid fuel grain, then burned with liquid oxygen. The objectives of the program are to investigate the ignition, combustion, and fuel regression rate characteristics of SCO burning with oxygen in a hybrid engine, to demonstrate an end-to-end benchtop system of the total propellant manufacturing, grain freezing, and hot firing system, and to develop preliminary space system designs. This article presents recent results of the SCO combustion characterization efforts.

Author

Extraterrestrial Resources; Hybrid Propellant Rocket Engines; Cryogenic Rocket Propellants

20010068380 Florida Inst. of Tech., Melbourne, FL USA

Modeling and Analysis of the Reverse Water Gas Shift Process for In-Situ Propellant Production

Whitlow, Jonathan E.; 1999 Research Reports: NASA/ASEE Summer Faculty Fellowship Program; November 2000, 197-206; In English; No Copyright; Avail: CASI; A02, Hardcopy

This report focuses on the development of mathematical models and simulation tools developed for the Reverse Water Gas Shift (RWGS) process. This process is a candidate technology for oxygen production on Mars under the In-Situ Propellant Production (ISPP) project. An analysis of the RWGS process was performed using a material balance for the system. The material balance is very complex due to the downstream separations and subsequent recycle inherent with the process. A numerical simulation was developed for the RWGS process to provide a tool for analysis and optimization of experimental hardware, which will be constructed later this year at Kennedy Space Center (KSC). Attempts to solve the material balance for the system, which can be defined by 27 nonlinear equations, initially failed. A convergence scheme was developed which led to successful solution of the material balance, however the simplified equations used for the gas separation membrane were found insufficient. Additional more rigorous models were successfully developed and solved for the membrane separation. Sample results from these models are included in this report, with recommendations for experimental work needed for model validation.

Author

Material Balance; Software Development Tools

20010057302 NASA Marshall Space Flight Center, Huntsville, AL USA, Universities Space Research Association, Huntsville, AL USA

Microgravity Materials Science Conference 2000, Volume 3

Ramachandran, Narayanan; Bennett, Nancy; McCauley, Dannah; Murphy, Karen; Poindexter, Samantha; Microgravity Materials Science Conference 2000; March 2001; In English; 4th Microgravity Materials Science Conference 2000, 6-8 June 2000, Huntsville, AL, USA; CD-ROM conatins the entire conference proceedings presented in PDF format

Report No.(s): NASA/CP-2001-210827/VOL3; M-1003/VOL3; NONP-NASA-CD-2001082995; NAS 1.55:210827/VOL3; No Copyright; Avail: CASI; C01, CD-ROM; A11, Hardcopy

This is Volume 3 of 3 of the 2000 Microgravity Materials Science Conference that was held June 6-8 at the Von Braun Center, Huntsville, Alabama. It was organized by the Microgravity Materials Science Discipline Working Group, sponsored by the Microgravity Research Division (MRD) at NASA Headquarters, and hosted by NASA Marshall Space Flight Center and the Alliance for Microgravity Materials Science and Applications (AMMSA). It was the fourth NASA conference of this type in the Microgravity materials science discipline. The microgravity science program sponsored ~200 investigators, all of whom made oral or poster presentations at this conference- In addition, posters and exhibits covering NASA microgravity facilities, advanced technology development projects sponsored by the NASA Microgravity Research Division at NASA Headquarters, and commercial interests were exhibited. The purpose of the conference was to inform the materials science community of research opportunities in reduced gravity and to highlight the Spring 2001 release of the NASA Research Announcement (NRA) to solicit proposals for future investigations. It also served to review the current research and activities in material,, science, to discuss the envisioned long-term goals. and to highlight new crosscutting research areas of particular interest to MRD. The conference was aimed at materials science researchers from academia, industry, and government. A workshop on in situ resource utilization (ISRU) was held in conjunction with the conference with the goal of evaluating and prioritizing processing issues in Lunar and Martian type environments. The workshop participation included invited speakers and investigators currently funded in the material science program under the Human Exploration and Development of Space (HEDS) initiative. The conference featured a plenary session every day with an invited speaker that was followed by three parallel breakout sessions in subdisciplines. Attendance was close to 350 people, Posters were available for viewing during the conference and a dedicated poster session was held on the second day. Nanotechnology, radiation shielding materials, Space Station science opportunities, biomaterials research, and outreach and educational aspects of the program were featured in the plenary talks. This volume, the first to be released on CD-ROM for materials science, is comprised of the research reports submitted by the Principal Investigators at the conference.

Author

Conferences; Microgravity Applications; Crystal Growth; Microgravity; Gravitational Effects; Directional Solidification (Crystals)

20010057262 Stanford Univ., Stanford, CA USA

Solid State Electrochemical Oxygen Conversion for Martian and Lunar Environments

Alemozafar, Ali Reza; Guer, Turgut M.; Homsy, George M.; Microgravity Materials Science Conference 2000; March 2001; Volume 2, 310-315; In English; CD-ROM contains the entire Conference Proceedings presented in PDF format; No Copyright; Avail: CASI; A02, Hardcopy

This work involves an innovative solid state electrochemical approach to address the need for on-site generation and recovery of oxygen for resource utilization and life-support systems for Martian and Lunar landing missions, and is concerned with the investigation of heterogeneous kinetics, materials and fluid dynamic issues presented by this electrochemical system in achieving this goal.

Author

Electrochemistry; Oxygen Supply Equipment; Extraterrestrial Resources; Life Support Systems

20010057256 NASA Marshall Space Flight Center, Huntsville, AL USA, Universities Space Research Association, Huntsville, AL USA

Microgravity Materials Science Conference 2000, Volume 2

Narayanan, Ramachandran, Editor; Bennett, Nancy, Editor; McCauley, Dannah, Editor; Murphy, Karen, Editor; Poindexter, Samantha, Editor; Microgravity Materials Science Conference 2000; March 2001; In English; 4th Microgravity Materials Science Conference 2000, 6-8 June 2000, Huntsville, AL, USA; CD-ROM contains the entire Conference Proceedings presented in PDF format

Report No.(s): NASA/CP-2000-210827/VOL2; M-1003/VOL2; NONP-NASA-CD-2001082994; NAS 1.55:210827/VOL2; No Copyright; Avail: CASI; C01, CD-ROM; A12, Hardcopy

This is Volume 2 of 3 of the 2000 Microgravity Materials Science Conference that was held June 6-8 at the Von Braun Center, Huntsville, Alabama. It was organized by the Microgravity Materials Science Discipline Working Group, sponsored by the Microgravity Research Division (MRD) at NASA Headquarters, and hosted by NASA Marshall Space Flight Center and the Alliance for Microgravity Materials Science and Applications (AMMSA). It was the fourth NASA conference of this type in the Microgravity materials science discipline. The microgravity science program sponsored approx. 200 investigators, all of whom made oral or poster presentations at this conference- In addition, posters and exhibits covering NASA microgravity facilities, advanced technology development projects sponsored by the NASA Microgravity Research Division at NASA Headquarters, and commercial interests were exhibited. The purpose of the conference %%,its to inform the materials science community of research opportunities in reduced gravity and to highlight the Spring 2001 release of the NASA Research Announcement (NRA) to solicit proposals for future investigations. It also served to review the current research and activities in material,, science, to discuss the envisioned long-term goals. and to highlight new crosscutting research areas of particular interest to MRD. The conference was aimed at materials science researchers from academia, industry, and government. A workshop on in situ resource utilization (ISRU) was held in conjunction with the conference with the goal of evaluating and prioritizing processing issues in Lunar and Martian type environments. The workshop participation included invited speakers and investigators currently funded in the material science program under the Human Exploration and Development of Space (HEDS) initiative. The conference featured a plenary session every day with an invited speaker that was followed by three parallel breakout sessions in subdisciplines. Attendance was close to 350 people, Posters were available for viewing during the conference and a dedicated poster session was held on the second day. Nanotechnology, radiation shielding materials, Space Station science opportunities, biomaterials research, and outreach and educational aspects of the program were featured in the plenary talks. This volume, the first to be released on CD-ROM for materials science, is comprised of the research reports submitted by the Principal Investigators at the conference.
Author

Conferences; Crystal Growth; Microgravity; Microgravity Applications; Gravitational Effects; Directional Solidification (Crystals)

20010057199 NASA Marshall Space Flight Center, Huntsville, AL USA, Universities Space Research Association, Huntsville, AL USA

Microgravity Materials Science Conference 2000, Volume 1

Ramachandran, Narayanan, Editor; Bennett, Nancy, Editor; McCauley, Dannah, Editor; Murphy, Karen, Editor; Poindexter, Samantha, Editor; Microgravity Materials Science Conference 2000; March 2001; In English; 4th Microgravity Materials Science Conference 2000, 6-8 June 2000, Huntsville, AL, USA; CD-ROM contains the entire Conference Proceedings presented in PDF format

Report No.(s): NASA/CP-2001-210827/VOL1; M-1003/VOL1; NONP-NASA-CD-2001082963; NAS 1.55:210827/VOL1; No Copyright; Avail: CASI; C01, CD-ROM; A15, Hardcopy

This is Volume 1 of 3 of the 2000 Microgravity Material Science Conference that was held June 6-8 at the Von Braun Center, Huntsville, Alabama. It was organized by the Microgravity Materials Science Discipline Working Group, sponsored by the Microgravity Research Division (MRD) at NASA Headquarters, and hosted by NASA Marshall Space Flight Center and the Alliance for Microgravity Materials Science and Applications (AMMSA). It was the fourth NASA conference of this type in the microgravity materials science discipline. The microgravity science program sponsored approx. 200 investigators, all of whom made oral or poster presentations at this conference. In addition, posters and exhibits covering NASA microgravity facilities, advanced technology development projects sponsored by the NASA Microgravity Research Division at NASA Headquarters, and commercial interests were exhibited. The purpose of the conference was to inform the materials science community of research opportunities in reduced gravity and to highlight the Spring 2001 release of the NASA Research Announcement (NRA) to solicit proposals for future investigations. It also served to review the current research and activities in materials science, to discuss the envisioned long-term goals. and to highlight new crosscutting research areas of particular interest to MRD. The conference was aimed at materials science researchers from academia, industry, and government. A workshop on in situ resource utilization (ISRU) was held in conjunction with the conference with the goal of evaluating and prioritizing processing issues in Lunar and Martian type environments. The workshop participation included invited speakers and investigators currently funded in the material science program under the Human Exploration and Development of Space (HEDS) initiative. The conference featured a plenary session every day with an invited speaker that was followed by three parallel breakout sessions in subdisciplines. Attendance was close to 350 people. Posters were available for viewing during the conference and a dedicated poster session was held on the second day. Nanotechnology radiation shielding materials, Space Station science opportunities, biomaterials research, and outreach and educational aspects of the program were featured in the plenary talks. This volume, the first to be released on CD-ROM for materials science, is

comprised of the research reports submitted by the Principal Investigators at the conference.
Author
Conferences; Microgravity Applications; Crystal Growth; Microgravity; Gravitational Effects; Directional Solidification (Crystals)

20010039031 Boeing Co., Huntington Beach, CA USA, NASA Marshall Space Flight Center, Huntsville, AL USA
A Cryogenic Propellant Production Depot for Low Earth Orbit
Potter, Seth D.; Henley, Mark; Guitierrez, Sonia; Fikes, John; Carrington, Connie; Smitherman, David; Gerry, Mark; Sutherlin, Steve; Beason, Phil; Howell, Joe, Technical Monitor; [2001]; In English; International Space Development Conference, 24-28 May 2001, Albuquerque, NM, USA; No Copyright; Avail: CASI; A03, Hardcopy

The cost of access to space beyond low Earth orbit can be lowered if vehicles can refuel in orbit. The power requirements for a propellant depot that electrolyzes water and stores cryogenic oxygen and hydrogen can be met using technology developed for space solar power. A propellant depot is described that will be deployed in a 400 km circular equatorial orbit, receive tanks of water launched into a lower orbit from Earth by gun launch or reusable launch vehicle, convert the water to liquid hydrogen and oxygen, and store Lip to 500 metric tonnes of cryogenic propellants. The propellant stored in the depot can support transportation from low Earth orbit to geostationary Earth orbit, the Moon, LaGrange points, Mars, etc. The tanks are configured in an inline gravity-gradient configuration to minimize drag and settle the propellant. Temperatures can be maintained by body-mounted radiators; these will also provide some shielding against orbital debris. Power is supplied by a pair of solar arrays mounted perpendicular to the orbital plane, which rotate once per orbit to track the Sun. In the longer term, cryogenic propellant production technology can be applied to a larger LEO depot, as well as to the use of lunar water resources at a similar depot elsewhere.
Author
Cryogenic Rocket Propellants; Low Earth Orbits; Refueling

20010027421 NASA Kennedy Space Center, Cocoa Beach, FL USA
Buffer Gas Acquisition and Storage
Parrish, Clyde F.; Lueck, Dale E.; Jennings, Paul A.; Callahan, Richard A.; Delgado, H., Technical Monitor; [2001]; In English; Space Technology, 11-14 Feb. 2001, Albuquerque, NM, USA; No Copyright; Avail: CASI; A02, Hardcopy

The acquisition and storage of buffer gases (primarily argon and nitrogen) from the Mars atmosphere provides a valuable resource for blanketing and pressurizing fuel tanks and as a buffer gas for breathing air for manned missions. During the acquisition of carbon dioxide (CO2), whether by sorption bed or cryo-freezer, the accompanying buffer gases build up in the carbon dioxide acquisition system, reduce the flow of CO2 to the bed, and lower system efficiency. It is this build up of buffer gases that provide a convenient source, which must be removed, for efficient capture Of CO2 Removal of this buffer gas barrier greatly improves the charging rate of the CO2 acquisition bed and, thereby, maintains the fuel production rates required for a successful mission. Consequently, the acquisition, purification, and storage of these buffer gases are important goals of ISRU plans. Purity of the buffer gases is a concern e.g., if the CO, freezer operates at 140 K, the composition of the inert gas would be approximately 21 percent CO2, 50 percent nitrogen, and 29 percent argon. Although there are several approaches that could be used, this effort focused on a hollow-fiber membrane (HFM) separation method. This study measured the permeation rates of CO2, nitrogen (ND, and argon (Ar) through a multiple-membrane system and the individual membranes from room temperature to 193K and 10 kpa to 300 kPa. Concentrations were measured with a gas chromatograph that used a thermoconductivity (TCD) detector with helium (He) as the carrier gas. The general trend as the temperature was lowered was for the membranes to become more selective, In addition, the relative permeation rates between the three gases changed with temperature. The end result was to provide design parameters that could be used to separate CO2 from N2 and Ar.
Author
Buffer Storage; Acquisition; Mars Atmosphere; Argon; Nitrogen

20010024956 NASA Ames Research Center, Moffett Field, CA USA
Separation of Carbon Monoxide and Carbon Dioxide for Mars ISRU-Concepts
LeVan, M. Douglas; Finn, John E.; Sridhar, K. R.; Proceedings of the Fifth Microgravity Fluid Physics and Transport Phenomena Conference; December 2000, 1204-1216; In English; No Copyright; Avail: CASI; A03, Hardcopy

Solid oxide electrolyzers, such as electrolysis cells utilizing yttria-stabilized zirconia, can produce oxygen from Mars atmospheric carbon dioxide and reject carbon monoxide and unreacted carbon dioxide in a separate stream. The oxygen-production process has been shown to be far more efficient if the high-pressure, unreacted carbon dioxide can be

separated and recycled back into the feed stream. Additionally, the mass of the adsorption compressor can be reduced. Also, the carbon monoxide by-product is a valuable fuel for space exploration and habitation, with applications from fuel cells to production of hydrocarbons and plastics. In our research, we will design, construct, and test an innovative, robust, low mass, low power separation device that can recover carbon dioxide and carbon monoxide for Mars ISRU. Such fundamental process technology, involving gas-solid phase separation in a reduced gravitational environment, will help to enable Human Exploration and Development of Space. The separation device will be scaled to operate with a CO2 sorption compressor and a zirconia electrolysis device built at the NASA Ames Research Center and the University of Arizona, respectively. In our research, we will design, construct, and test an innovative, robust, low mass, low power separation device that can recover carbon dioxide and carbon monoxide for Mars ISRU, Such fundamental process technology, involving gas-solid phase separation in a reduced gravitational environment, will help to enable Human Exploration and Development of Space. The separation device will be scaled to operate with a CO2 sorption compressor and a zirconia electrolysis device built at the NASA Ames Research Center and the University of Arizona, The separation device will be scaled to operate with a CO2 sorption compressor and a zirconia electrolysis device built at the NASA Ames Research Center and the University of Arizona, Research needs for the design shown are as follows: (1) The best adsorbent for the process must be determined. (2) Adsorption isotherms must be measured, both for pure components and mixtures. (3) Mathematical modeling must be performed to provide a solid framework for design. (4) The separation system must be constructed and tested. (5) System integration must be studied.
Author (revised)
Mars Atmosphere; Carbon Dioxide; Carbon Monoxide; Electrolysis; Oxygen Production

20010024908 Arizona Univ., Tucson, AZ USA
Modeling of Transport Processes in a Solid Oxide Electrolyzer Generating Oxygen
Tao, G.; Sridhar, K. R.; Chan, C. L.; Proceedings of the Fifth Microgravity Fluid Physics and Transport Phenomena Conference; December 2000, 426-461; In English; No Copyright; Avail: CASI; A03, Hardcopy

Carbon dioxide, the predominant atmospheric constituent on Mars, can be used to produce oxygen using Solid Oxide Electrolyzer Cells (SOEC). The extracted oxygen is of interest for propulsion and life support needs. Several studies have shown that using local resources, ISRU (in-situ resource utilization), can reduce both the launch mass from earth and the landed mass on Mars, thereby providing significant cost savings and reduced risks for future human missions to Mars. SOEC works on the principle of oxygen ion transport in certain ceramic oxides. The electrochemical cell is made of a solid nonporous oxygen ion conducting electrolyte, such as fully stabilized Zirconia doped with Yttrium(YSZ), that is sandwiched between two porous electrodes. An external DC power supply is applied to the electrodes. The porous electrodes help to form the triple phase boundary (TPB) or electrochemical reaction sites (ERS) that facilitate oxygen transport. TPB or ERS is a location of an interface where an oxygen bearing gas such as carbon dioxide, an electron conductor such as the electrode, and the electrolyte with oxygen ion vacancies intersect. There are several transport processes occurring in a SOEC generating oxygen from carbon dioxide. At cathode side, for example, CO2 gas impinges on the electrode surface from the bulk flow and then diffuses through the porous electrode. A CO2 molecule dissociates into oxygen atom and CO. The oxygen atom picks up two electrons from the electrode to become a doubly charged oxygen ion. The oxygen ion, forced by external applied voltage, transports through the vacancies in the crystal lattice of the electrolyte to anode side. The whole process consists of gas diffusion, adsorptive dissociation, electrochemical reaction, and ion migration. Associated with these irreversible processes are three kinds of overpotentials which contribute to the degree of deviation of the cell voltage from its thermodynamic open circuit voltage. The three overpotentials are concentration, activation, and ohmic. Quantification of the different overpotentials is essential to understand the reaction mechanism and to develop efficient SOEC for space applications. The ohmic overpotential and activation overpotential can be measured by the current interruption method in conjunction with a recording oscilloscope. As the current cut off, the potential differences begin to drop. The voltage drop curve consists of linear and nonlinear parts. The initial linear drop within couple of microseconds corresponds to ohmic losses followed the nonlinear drop which lasts couple seconds account for activation overpotential. The typical performance characteristics of a SOEC at 800 C is shown. In the beginning, the current density increases with the CO2 electrode (cathode) potential. Then the current saturates, reaching a plateau for a range of cathode potentials. After the CO2 electrode voltage exceeds a threshold value, the current density increases sharply. While the CO2 electrode potential is increased, the anode and cathode activation overpotentials also change. The measured overpotential is the sum of the activation overpotential and ohmic losses. By using the current interruption method at high voltage, we can measure the characteristic resistance of anode and cathode electrodes and thereby the ohmic overpotential. From these two measurements, the activation overpotential can be calculated. From the characteristic shapes of the curves shown, we can classify a cell's typical performance into three regions, namely small current region, constant current region, and high current region. In region I, the current increases gradually from negative to positive as the

CO_2 electrode voltage potential increases in magnitude. The activation overpotential also increases on both sides. The current is caused by the impurity content (O_2, 0.107%) in CO_2 gas source. In region II, the cell's current stays at a nearly constant level although the CO_2 electrode potential increases in magnitude. The anodic activation overpotential at the oxygen side remains unchanged, while the cathodic overpotential increased sharply. At this point, all O_2 taking part in electrochemical reaction comes from O_2 impurity of CO_2. There is no CO_2 dissociating into CO and O. Because of limited O_2 source, the cell is in a mass limited flow condition. All the increase in applied potential is utilized at the cathode, while the activation overpotential on anode side remains unchanged. The overpotential at the cathode side is still not sufficient to provide the free energy required to crack CO_2. In region III, the cell's current increases with applied voltage, after the CO_2 electrode voltage reaches a certain threshold value. The activation overpotential at CO_2 side drops sharply, while activation overpotential on the anode side increases. The magnitude of the threshold is a function of temperature. It can be determined by the CO_2 energy of formation and is termed the Nernst potential. In region III the activation overpotentials fit the Tafel plot well. The data on exchange current density and charge transfer coefficients obtained from the Tafel plots can be used to fit the well known Butler Volmer equation. SOECs have been used in a CO_2 environment to produce O_2. The current-voltage characteristics and overpotentials associated with the process have been measured. Three distinct regions are observed, and been analyzed.
Author (revised)
Solid Oxide Fuel Cells; Ceramics; Electric Potential; Electrolytic Cells; Electrolytes; Ionic Mobility; Ion Motion

20010023137 NASA Johnson Space Center, Houston, TX USA
In-Situ Resource Utilization: Laying the Foundation for 'Living off the Land'
Kaplan, D. I.; Concepts and Approaches for Mars Exploration; July 2000, Issue Part 1, 170-171; In English; No Copyright; Avail: CASI; A01, Hardcopy

The technology to manufacture rocket propellants, breathing and life-support gases, fuel cell reagents, and other consumables on Mars using indigenous Martian resources as feedstock in the production process is known as In-Situ Resource Utilization (ISRU). Several studies of the long-term, committed exploration of Mars by humans show that ISRU is essential ... an enabling technology. The recognized value of ISRU to human exploration is reflected in the NASA Strategic Plan. In the description of the 'Strategies and Outcomes' of the Human Exploration and Development of Space (HEDS) Enterprise, the NASA Strategic Plan states: The [HEDS] Enterprise relies on the robotic missions of the Space Science Enterprise to provide extensive knowledge of the geology, environment, and resources of planetary bodies. The Space Science Enterprise missions will also demonstrate the feasibility of utilizing local resources to 'live off the land.'
Derived from text
Mars Missions; Mars Exploration; Extraterrestrial Resources; Resources Management

20010023129 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA
Robotic Precursor Missions for Mars Habitats
Huntsberger, Terry; Pirjanian, Paolo; Schenker, Paul S.; Trebi-Ollennu, Ashitey; Das, Hari; Joshi, Sajay; Concepts and Approaches for Mars Exploration; July 2000, Issue Part 1, 154-155; In English; No Copyright; Avail: CASI; A01, Hardcopy

Infrastructure support for robotic colonies, manned Mars habitat, and/or robotic exploration of planetary surfaces will need to rely on the field deployment of multiple robust robots. This support includes such tasks as the deployment and servicing of power systems and ISRU generators, construction of beaconed roadways, and the site preparation and deployment of manned habitat modules. The current level of autonomy of planetary rovers such as Sojourner will need to be greatly enhanced for these types of operations. In addition, single robotic platforms will not be capable of complicated construction scenarios. Precursor robotic missions to Mars that involve teams of multiple cooperating robots to accomplish some of these tasks is a cost effective solution to the possible long timeline necessary for the deployment of a manned habitat. Ongoing work at JPL under the Mars Outpost Program in the area of robot colonies is investigating many of the technology developments necessary for such an ambitious undertaking. Some of the issues that are being addressed include behavior-based control systems for multiple cooperating robots (CAMPOUT), development of autonomous robotic systems for the rescue/repair of trapped or disabled robots, and the design and development of robotic platforms for construction tasks such as material transport and surface clearing.
Derived from text
Robotics; Mars Missions; Mars Exploration; Robots

20010023096 Colorado School of Mines, Golden, CO USA

Extraction of Water from the Martian Regolith

Duke, M. B.; Baldwin, R. M.; King, R. H.; Knecht, R. D.; Muff, T.; Holland, B.; Concepts and Approaches for Mars Exploration; July 2000, Issue Part 1, 99-100; In English; No Copyright; Avail: CASI; A01, Hardcopy

Access to usable water on Mars is important for human missions. Water would be used for life support and as a source of rocket propellant. Among the potential sources of water that have been discussed are extraction from the atmosphere, permafrost, and subsurface liquid water. The most ubiquitous and widespread source of water is likely to be bound water in the regolith, which would have to be obtained by heating the regolith to 500 C. Whereas this may seem complicated and energy-intensive, we are studying small (-20kg each) robotic systems for regolith excavation and thermal extraction capable of producing an amount of water per year approximately 30 times the combined mass of equipment required, including the power supply for the extraction system. At this production capacity an integrated system could produce in one year an amount of water equivalent to about 3 times the mass of hydrogen that would have to be transported to produce the same amount of water. In practice, this would be approximately 6 times better than bringing hydrogen from Earth, when the mass of the tanks needed to transport the hydrogen is also considered.

Derived from text

Mars Surface; Regolith; Water Resources; Extraterrestrial Resources

20010023066 NASA Ames Research Center, Moffett Field, CA USA

Mars Exploration 2003 to 2013 - An Integrated Perspective: Time Sequencing the Missions

Briggs, G.; McKay, C.; Concepts and Approaches for Mars Exploration; July 2000, Issue Part 1, 47; In English; No Copyright; Abstract Only; Available from CASI only as part of the entire parent document

The science goals for the Mars exploration program, together with the HEDS precursor environmental and technology needs, serve as a solid starting point for re-planning the program in an orderly way. Most recently, the community has recognized the significance of subsurface sampling as a key component in 'following the water'. Accessing samples from hundreds and even thousands of meters beneath the surface is a challenge that will call for technology development and for one or more demonstration missions. Recent mission failures and concerns about the complexity of the previously planned MSR missions indicate that, before we are ready to undertake sample return and deep sampling, the Mars exploration program needs to include: 1) technology development missions; and 2) basic landing site assessment missions. These precursor missions should demonstrate the capability for reliable & accurate soft landing and in situ propellant production. The precursor missions will need to carry out close-up site observations, ground-penetrating radar mapping from orbit and conduct seismic surveys. Clearly the programs should be planned as a single, continuous exploration effort. A prudent minimum list of missions, including surface rovers with ranges of more than 10 km, can be derived from the numerous goals and requirements; they can be sequenced in an orderly way to ensure that time is available to feed forward the results of the precursor missions. One such sequence of missions is proposed for the decade beginning in 2003.

Author

Mars Exploration; Mars Missions; Mission Planning

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In Situ Resource Utilization Technologies for Enhancing and Expanding Mars Scientific and Exploration Missions

Sridhar, K. R.; Finn, J. E.; Concepts and Approaches for Mars Exploration; July 2000, Issue Part 2, 291; In English; No Copyright; Avail: CASI; A01, Hardcopy

The primary objectives of the Mars exploration program are to collect data for planetary science in a quest to answer questions related to Origins, to search for evidence of extinct and extant life, and to expand the human presence in the solar system. The public and political engagement that is critical for support of a Mars exploration program is based on all of these objectives. In order to retain and to build public and political support, it is important for NASA to have an integrated Mars exploration plan, not separate robotic and human plans that exist in parallel or in sequence. The resolutions stemming from the current architectural review and prioritization of payloads may be pivotal in determining whether NASA will have such a unified plan and retain public support. There are several potential scientific and technological links between the robotic-only missions that have been flown and planned to date, and the combined robotic and human missions that will come in the future. Taking advantage of and leveraging those links are central to the idea of a unified Mars exploration plan. One such link is in situ resource utilization (ISRU) as an enabling technology to provide consumables such as fuels, oxygen, sweep and utility gases from the Mars atmosphere.

Author

Mars Exploration; Mars Missions; Mission Planning; Robotics; Manned Mars Missions

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Common In-Situ Consumable Production Plant for Robotic Mars Exploration

Sanders, G. B.; Trevathan, J. R.; Peters, T. A.; Baird, R. S.; Concepts and Approaches for Mars Exploration; July 2000, Issue Part 2, 273-274; In English; No Copyright; Avail: CASI; A01, Hardcopy

Utilization of extraterrestrial resources, or In-Situ Resource Utilization (ISRU), is viewed by the Human Exploration and Development of Space (HEDS) Enterprise as an enabling technology for the exploration and commercial development of space. A key subset of ISRU which has significant cost, mass, and risk reduction benefits for robotic and human exploration, and which requires a minimum of infrastructure, is In-Situ Consumable Production (ISCP). ISCP involves acquiring, manufacturing, and storing mission consumables from in situ resources, such as propellants, fuel cell reagents, and gases for crew and life support, inflation, science and pneumatic equipment. One of the four long-term goals for the Space Science Enterprise (SSE) is to 'pursue space science programs that enable and are enabled by future human exploration beyond low-Earth orbit - a goal exploiting the synergy with the human exploration of space'. Adequate power and propulsion capabilities are critical for both robotic and human exploration missions. Minimizing the mass and volume of these systems can reduce mission cost or enhance the mission by enabling the incorporation of new science or mission-relevant equipment. Studies have shown that in-situ production of oxygen and methane propellants can enhance sample return missions by enabling larger samples to be returned to Earth or by performing Direct Earth Return (DER) sample return missions instead of requiring a Mars Orbit Rendezvous (MOR). Recent NASA and Department of Energy (DOE) work on oxygen and hydrocarbon-based fuel cell power systems shows the potential of using fuel cell power systems instead of solar arrays and batteries for future rovers and science equipment. The development and use of a common oxygen/methane ISCP plant for propulsion and power generation can extend and enhance the scientific exploration of Mars while supporting the development and demonstration of critical technologies and systems for the human exploration of Mars.

Author

Mars Sample Return Missions; Mission Planning; Mars (Planet); Mars Exploration; Robotics

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Mars Mobile Lander Systems for 2005 and 2007 Launch Opportunities

Sabahi, D.; Graf, J. E.; Concepts and Approaches for Mars Exploration; July 2000, 271-272; In English; No Copyright; Avail: CASI; A01, Hardcopy

A series of Mars missions are proposed for the August 2005 launch opportunity on a medium class Evolved Expendable Launch Vehicle (EELV) with a injected mass capability of 2600 to 2750 kg. Known as the Ranger class, the primary objective of these Mars mission concepts are: (1) Deliver a mobile platform to Mars surface with large payload capability of 150 to 450 kg (depending on launch opportunity of 2005 or 2007); (2) Develop a robust, safe, and reliable workhorse entry, descent, and landing (EDL) capability for landed mass exceeding 750 kg; (3) Provide feed forward capability for the 2007 opportunity and beyond; and (4) Provide an option for a long life telecom relay orbiter. A number of future Mars mission concepts desire landers with large payload capability. Among these concepts are Mars sample return (MSR) which requires 300 to 450 kg landed payload capability to accommodate sampling, sample transfer equipment and a Mars ascent vehicle (MAV). In addition to MSR, large in situ payloads of 150 kg provide a significant step up from the Mars Pathfinder (MPF) and Mars Polar Lander (MPL) class payloads of 20 to 30 kg. This capability enables numerous and physically large science instruments as well as human exploration development payloads. The payload may consist of drills, scoops, rock corers, imagers, spectrometers, and in situ propellant production experiment, and dust and environmental monitoring.

Author

Mars Sample Return Missions; Mars Missions; Payloads; Mission Planning; Equipment Specifications; Mars (Planet)

20010020485 Utah State Univ., Logan, UT USA

Designing a Mars Mission that Will Generate Public Excitement and Support: Sample Return Using In Situ Propellant Production

Mueller, P. J.; Concepts and Approaches for Mars Exploration; July 2000, Issue Part 2, 228a; In English; No Copyright; Avail: CASI; A01, Hardcopy

Publicly funded space missions (e.g. all NASA missions) must be perceived by the public as worthwhile in order to retain broad support for NASA and a sustainable space program. In addition, if the public finds the missions exciting and even entertaining, then the level of support will be even greater. 'Good Science' alone is not enough to keep the public interested in space. Examples of missions that generated great public enthusiasm and those which were hardly noticed are given. A Mars

sample return mission architecture is proposed which will generate much public interest and also provide solid scientific research.
Author
Mars Sample Return Missions; Public Relations; Mars Missions; Mission Planning

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Mars Exploration with a Self-Refueling Hopper
Landis, Geoffrey A.; Linne, Diane; Concepts and Approaches for Mars Exploration; July 2000, Issue Part 2, 187-188; In English; No Copyright; Avail: CASI; A01, Hardcopy

A small reusable 'hopper' vehicle, the Mars In-situ Propellants Rocket (MIPR), is proposed to fly autonomously on Mars, using in-situ propellant production to manufacture rocket propellant directly out of the Martian atmosphere. The MIPR explores the Martian surface under rocket power and can repeatedly takeoff and land, carrying a suite of science instruments over a range of hundreds of meters per hop. The flight demonstration will accomplish a range of technology objectives important to both unmanned probes and to future human missions, including: (1) demonstration of a sub-orbital Mars launch vehicle, (2) demonstration of a pressure-fed small propulsion system for Mars ascent vehicles, (3) demonstration of a lightweight space engine, and (4) use for the first time of propellants manufactured in-situ on another planetary body. In addition to these technology objectives, the MIPR vehicle can carry a science payload that will advance our understanding of the surface and atmosphere of Mars.
Author
Mars Exploration; Flight Tests; Hoppers; Launch Vehicles; Mars Atmosphere; Mars Missions

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Utilization of Resources from NEAs
Lewis, J. S.; Near-Earth Asteroid Sample Return Workshop; 2000, 25; In English; No Copyright; Abstract Only; Available from CASI only as part of the entire parent document

Materials extracted from Near-Earth Asteroids may find use in future space-based activities as propellants, life-support fluids, or structures. The utility of any space resource is governed by several factors, including energetic accessibility from Low Earth Orbit (LEO), resource concentration, availability of appropriate microgravity extraction and processing techniques, process energy efficiency, process independence of consumables from Earth, and the energetic accessibility of the intended site of use from the asteroid being processed. Additional information is contained in the original extended abstract.
Author
Asteroids; Resources Management; Extraterrestrial Resources

20010019449 NASA Johnson Space Center, Houston, TX USA
Regolith Evolved Gas Analyzer
Hoffman, John H.; Hedgecock, Jud; Nienaber, Terry; Cooper, Bonnie; Allen, Carlton; Ming, Doug; Near-Earth Asteroid Sample Return Workshop; 2000, 19-20; In English; No Copyright; Abstract Only; Available from CASI only as part of the entire parent document

The Regolith Evolved Gas Analyzer (REGA) is a high-temperature furnace and mass spectrometer instrument for determining the mineralogical composition and reactivity of soil samples. REGA provides key mineralogical and reactivity data that is needed to understand the soil chemistry of an asteroid, which then aids in determining in-situ which materials should be selected for return to earth. REGA is capable of conducting a number of direct soil measurements that are unique to this instrument. These experimental measurements include: (1) Mass spectrum analysis of evolved gases from soil samples as they are heated from ambient temperature to 900 C; and (2) Identification of liberated chemicals, e.g., water, oxygen, sulfur, chlorine, and fluorine. REGA would be placed on the surface of a near earth asteroid. It is an autonomous instrument that is controlled from earth but does the analysis of regolith materials automatically. The REGA instrument consists of four primary components: (1) a flight-proven mass spectrometer, (2) a high-temperature furnace, (3) a soil handling system, and (4) a microcontroller. An external arm containing a scoop or drill gathers regolith samples. A sample is placed in the inlet orifice where the finest-grained particles are sifted into a metering volume and subsequently moved into a crucible. A movable arm then places the crucible in the furnace. The furnace is closed, thereby sealing the inner volume to collect the evolved gases for analysis. Owing to the very low g forces on an asteroid compared to Mars or the moon, the sample must be moved from inlet to crucible by mechanical means rather than by gravity. As the soil sample is heated through a programmed pattern, the gases evolved at each temperature are passed through a transfer tube to the mass spectrometer for analysis and identification.

Return data from the instrument will lead to new insights and discoveries including: (1) Identification of the molecular masses of all of the gases liberated from heated soil samples; (2) Identification of the asteroid soil mineralogy to aid in the selection process for returned samples; (3) Existence of oxygen in the asteroid soil and the potential for in-situ resource utilization (ISRU); and (4) Existence of water and other volatiles in the asteroid soil. Additional information is contained in the original extended abstract.
Author
Asteroids; Soil Sampling; Regolith; Spacecraft Instruments; In Situ Measurement

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Considerations on Use of Lunar Regolith in Lunar Constructions
Toklu, Y. C.; Space Resources Roundtable II; [2000], 73; In English; No Copyright; Avail: Other Sources; Abstract Only

Lunar regolith has a primordial place among in-situ lunar resources for lunar constructions. It can be used as toutvenant material (screened or not), or after being processed at some level. Completely nonprocessed, even without screening, lunar regolith can be used for shielding, just by piling or damping. In a more elaborate way, it can be used after being packed in cages or sacks made of special plastics and fibers, like gabions and sandbags, This form can be used for protection purposes, or for constructing wall type structures. Other levels of processing may lead to bricks, cement, mortar, concrete and materials involving more chemical decomposition and synthesis. It would of course be possible to produce reinforced-concrete or prestresses-concrete elements, but this will involve the use of tendons different than steel, which is so widely used on The Earth.
Derived from text
Regolith; Lunar Resources; Lunar Rocks; Bricks; Construction

20010001690 Arizona Univ., Tucson, AZ USA
A New Concept in Planetary Exploration: ISRU With Power Bursts
Streibech, Douglas; Urdaneta, Mario; Chapman, Patricia; Furfaro, Roberto; Ramohalli, Kumar; Space Resources Roundtable II; [2000], 65; In English; No Copyright; Avail: Other Sources; Abstract Only

The concept of generating power bursts upon demand in space exploration is presented. As acknowledged by two NASA Novel Technology Report (NTR) awards, the concept is new and innovative. As a general background, it must be recalled that power has always been a major limiting factor in exploration, especially in the exploration of far off sites like Mars (contrasted with LEO or GEO). Without the high power ability, no amount of energy (that can only be expended at a low rate, i.e., low power) can accomplish such simple operations as: crushing a rock, hopping over an obstacle, drilling deep, and eventually ascent from the planet to an orbiting craft above, or even the return journey to Earth. The concept presented here is an advance over the much studied In-Situ Resource Utilization (ISRU); we use ISRU for the extraction of the needed fuel and oxidizer from the local resources, store these gases, and expend them rapidly when needed. In the martian scenario, these gases will be carbon monoxide (fuel) and oxygen (oxidizer) extracted from the atmospheric carbon dioxide; subsequently, higher chemistry is possible after the discovery, and utilization of water which enables the production of an entire spectrum of hydrocarbons and carbohydrates. If nitrogen can also be added at a still later date, many more chemicals in the ammonia based family are possible. At SERC (University of Arizona) we have pioneered all of these chemical productions. In another award-winning innovation, an ultra-light weight material, popularly known as muscle wires, is used in a biology-inspired robot called BiRoD. The expenditure of energy in these materials produces power that results in mechanical motion. The short term power generation is thousands of times the average power that was used to harness the local resource in the first place. At the time of this abstract, BiRoD has been designed, assembled, and shown to work in a primitive way, in its component form; new media have carried the high-profile story all over the nation. At the time of the Congress, we expect to no only have many more pieces of quantitative, engineering data from BiRoD but we still also attempt to bring that robot to the session for an actual demonstration.
Author
Ammonia; Atmospheric Composition; Carbon Dioxide Concentration; Hydrocarbons; Nitrogen; Oxidizers; Space Exploration; Water; Bursts

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Space Resources Development: The Link Between Human Exploration and the Long-Term Commercialization of Space

Sanders, Gerald B.; Space Resources Roundtable 2; [2000], 59-60; In English; No Copyright; Avail: Other Sources; Abstract Only

In a letter to the NASA Administrator, Dan Goldin, in January of 1999, the Office of Management and Budget (OMB) stated the following . OMB recommends that NASA consider commercialization in a broader context than the more focused efforts to date on space station and space shuttle commercialization. We suggest that NASA examine architectures that take advantage of a potentially robust future commercial infrastructure that could dramatically lower the cost of future human exploration.' In response to this letter, the NASA Human Exploration and Development of Space (HEDS) Enterprise launched the BEDS Technology & Commercialization Initiative (HTCI) to link technology and system development for human exploration with the commercial development of space to emphasize the 'D' (Development) in BEDS. The development of technologies and capabilities to utilize space resources is the first of six primary focus areas in this program. It is clear that Space Resources Development (SRD) is key for both long-term human exploration of our solar system and to the long-term commercialization of space since: a) it provides the technologies, products, and raw materials to support efficient space transportation and in-space construction and manufacturing, and b) it provides the capabilities and infrastructure to allow outpost growth, self-sufficiency, and commercial space service and utility industry activities.

Author

Space Commercialization; Technology Utilization; Extraterrestrial Resources

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Lunar Mineral Resources: Extraction and Application

Rowland, S.; Space Resources Roundtable II; [2000], 57; In English; No Copyright; Avail: Other Sources; Abstract Only

A discussion of the various uses and extraction techniques for useful but seldom-discussed lunar mineral resources. This talk comes both from the perspective of finding uses for materials and finding materials for an anticipated application. Includes indigenous propellants for chemical and electrical propulsion (beyond the obvious), metal extraction, leveraging imports, chemical extraction processes, things to do with lunar ceramics and glass fibres -- how to extract and use many materials on the Moon.

Author

Lunar Resources; Minerals; Extraction

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Lorpex for Power Surges: Drilling, Rock Crushing

Ramohalli, Kumar; Urdaneta, Mario; Marcozzi, Massimilliano; Duke, Vanessa; Space Resources Roundtable II; [2000], 45; In English; No Copyright; Avail: Other Sources; Abstract Only

This paper presents a new concept in space power: the ability to generate high levels of power (power surges) for short durations, even when the average power level is quite low. This power surge is generated through In-Situ Resource Utilization (ISRU), where the low average power is used to extract and store fuel/oxidizer combinations that can be rapidly expended when needed. It should be recalled that power surges have always been the main limiting factors in space exploration, planetary rovers; without the high power, no duration (no matter how long in duration) of low power can do such simple operations as crushing a rock, drilling deep, hopping over an obstacle, or ascent to a waiting mother craft. While the basic concept is straightforward, this paper presents results from an actual project that designed, built, and demonstrated (at Planetfest97, in Pasadena, California) the first robot. Called, LORPEX (for Locally Refueled Planetary Explorer) this 20 kg robot uses an array of silicon photovoltaic cells to harness solar energy through traditional means. Carbon dioxide (either from the atmosphere, or from a storage container) is dissociated into carbon monoxide and oxygen. These two gases are stored separately in two containers. When needed, these two gases are burned in a simple engine to generate a rapid power surge that is mechanical, but can be easily converted into electrical power (if needed) through a generator. As a simple variation, we have also explored carrying a high-density solid fuel on board and burning it with the ISRU produced oxidizer (i.e., a hybrid rocket for propulsion). The photovoltaic array was thoroughly tested in our Mars chamber (simulating temperature, composition, and pressure in the martian atmosphere) including the day-night cycling. At the time of the meeting, we expect to have more data on the power surge numbers. We have also developed (in cooperation with Jet Propulsion Laboratory) a novel ISRU unit that promises significant improvement over the much studied solid oxide electrolyzer cells. From various media produced segments, we will show a brief video tape.

Author

Robots; Solar Arrays; Simulation; Oxygen; Outer Planets Explorers; Mars Atmosphere

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Drilling and Logging in Space: An Oil-Well Perspective

Peeters, Max; Kovats, James; Space Resources Roundtable II; [2000], 43; In English, 27 Feb. - 2 Mar. 2000, Albuquerque, NM, USA; No Copyright; Avail: Other Sources; Abstract Only

Growing interest in extraterrestrial subsurface exploration has prompted an examination of advanced technologies for drilling slim holes and obtaining geophysical data in these holes. The borehole surveys with geophysical measurements called 'logging', complement, and under favorable conditions, replace soil sampling. Very shallow drilling systems were used extensively during the Apollo lunar missions, and are in the planning stages for use on Mars, The prime objective is to gather scientific data, but these data could eventually provide a basis for the commercial use of space mineral resources. Given the strong scientific interest in water on Mars and the Moon, subsurface characterization with geophysical methods is attractive, because these methods can cover a much larger volume than soil sampling. Space technology has boosted the development of borehole geophysical instruments because both in space and in boreholes the instruments have to function in hostile environments, in confined spaces, and to be able to withstand large g-forces.

Author

Boreholes; Confinement; Drilling; Extraterrestrial Resources; Geophysics; Mars Surface; Soil Sampling; Surveys

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The Registration of Space-Based Property

O'Donnell (Declan J.); Space Resources Roundtable II; [2000], 39; In English; No Copyright; Avail: Other Sources; Abstract Only

Any form of property interest to be held in outer space will need to be registered in order to provide notice and for the purpose of protecting it from appropriation by others. Some such property may include space resources, such as orbits and land on the Moon and Mars. Condition Law Estates have been recommended as legitimate possessory property interests in space resources. However, the public registration of those interests, (however acquired), has never been defined. The legal estate is separate from the resource affected and it is a man made space object as a matter of law and fact. As such there is both an opportunity and a duty to register same with the State and with the United Nations under Article II of the Convention on Registration of Objects Launched into Outer Space, January 4, 1975. This paper will detail how that works and what alternatives are available. A conclusion is suggested that the Treaty on Registration may be available for this purpose, but that other registration procedures should be utilized prior to Treaty Registration for qualification and definition purposes. The Participating States need to work out a fair set of qualifications and standards lest they abuse this treaty which has no provision for arbitration, mediation, or other conflict resolution. The entire history of property rights and registration at common law is offered as an analogy.

Author

Appropriations; Conventions; Extraterrestrial Resources; Properties; Law (Jurisprudence)

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New Strategy for Exploration Technology Development: The Human Exploration and Development of Space (HEDS) Exploration/Commercialization Technology Initiative

Mankins, John C.; Space Resources Roundtable II; [2000], 31; In English; No Copyright; Avail: Other Sources; Abstract Only

In FY 2001, NASA will undertake a new research and technology program supporting the goals of human exploration: the Human Exploration and Development of Space (HEDS) Exploration/Commercialization Technology Initiative (HTCI). The HTCI represents a new strategic approach to exploration technology, in which an emphasis will be placed on identifying and developing technologies for systems and infrastructures that may be common among exploration and commercial development of space objectives. A family of preliminary strategic research and technology (R&T) road maps have been formulated that address 'technology for human exploration and development of space (THREADS). These road maps frame and bound the likely content of the HTCL Notional technology themes for the initiative include: (1) space resources development, (2) space utilities and power, (3) habitation and bioastronautics, (4) space assembly, inspection and maintenance, (5) exploration and expeditions, and (6) space transportation. This paper will summarize the results of the THREADS road mapping process and describe the current status and content of the HTCI within that framework. The paper will highlight the space resources development theme within the Initiative and will summarize plans for the coming year.

Author

Space Exploration; Space Commercialization; Maintenance; Extraterrestrial Resources; Bioastronautics

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A Costing Strategy for Manufacturing in Orbit Using Extraterrestrial Resources

Ganesh, B.; Matos, C. A.; Coker, A.; Hausaman, J.; Komerath, N. M.; Space Resources Roundtable II; [2000], 17-18; In English; No Copyright; Avail: Other Sources; Abstract Only

At the First Space Resource Utilization Roundtable we presented abstracts discussing the technology of Acoustic Shaping, and its relevance to the development of a Space-based economy. This paper extends the work to study the impact of lunar-based materials on the construction of orbital infrastructure needed for longterm missions. It suggests ways of dealing at a rudimentary level with the uncertainties in cost estimation encountered in considering such endeavors.

Derived from text

Manufacturing; Extraterrestrial Resources; Aerospace Engineering

20010001658 Houston Univ., TX USA

Space Resources Roundtable 2

Ignatiev, A.; Space Resources Roundtable II; [2000]; In English, 8-10 Nov. 2000, Golden, CO, USA

Contract(s)/Grant(s): NASW-4574

Report No.(s): LPI-Contrib-1070; No Copyright; Avail: CASI; A05, Hardcopy

Contents include following: Developing Technologies for Space Resource Utilization - Concept for a Planetary Engineering Research Institute. Results of a Conceptual Systems Analysis of Systems for 200 m Deep Sampling of the Martian Subsurface. The Role of Near-Earth Asteroids in Long-Term Platinum Supply. Core Drilling for Extra-Terrestrial Mining. Recommendations by the 'LSP and Manufacturing' Group to the NSF-NASA Workshop on Autonomous Construction and Manufacturing for Space Electrical Power Systems. Plasma Processing of Lunar and Planetary Materials. Percussive Force Magnitude in Permafrost. Summary of the Issues Regarding the Martian Subsurface Explorer. A Costing Strategy for Manufacturing in Orbit Using Extraterrestrial Resources. Mine Planning for Asteroid Orebodies. Organic-based Dissolution of Silicates: A New Approach to Element Extraction from LunarRegohth. Historic Frontier Processes Active in Future Space-based Mineral Extraction. The Near-Earth Space Surveillance (NIESS) Mission: Discovery, Tracking, and Characterization of Asteroids, Comets, and Artificial Satellites with a microsatellite. Privatized Space Resource Property Ownership. The Fabrication of Silicon Solar Cells on the Moon Using In-Situ Resources. A New Strategy for Exploration Technology Development: The Human Exploration and Development of Space (HEDS) Exploratiori/Commercialization Technology Initiative. Space Resources for Space Tourism. Recovery of Volatiles from the Moon and Associated Issues. Preliminary Analysis of a Small Robot for Martian Regolith Excavation. The Registration of Space-based Property. Continuous Processing with Mars Gases. Drilling and Logging in Space; An Oil-Well Perspective. LORPEX for Power Surges: Drilling, Rock Crushing. An End-To-End Near-Earth Asteroid Resource Exploitation Plan. An Engineering and Cost Model for Human Space Settlement Architectures: Focus on Space Hotels and Moon/Mars Exploration. The Development and Realization of a Silicon-60-based Economy in CisLunar Space. Our Lunar Destiny: Creating a Lunar Economy. Cost-Effective Approaches to Lunar Passenger Transportation. Lunar Mineral Resources: Extraction and Application. Space Resources Development - The Link Between Human Exploration and the Long-term Commercialization of Space. Toward a More Comprehensive Evaluation of Space Information. Development of Metal Casting Molds by Sol-Gel Technology Using Planetary Resources. A New Concept in Planetary Exploration: ISRU with Power Bursts. Bold Space Ventures Require Fervent Public Support. Hot-pressed Iron from Lunar Soil. The Lunar Dust Problem: A Possible Remedy. Considerations on Use of Lunar Regolith in Lunar Constructions. Experimental Study on Water Production by Hydrogen Reduction of Lunar Soil Simulant in a Fixed Bed Reactor.

CASI

Conferences; Artificial Satellites; Cost Analysis; Crushing; Extraterrestrial Resources; Fabrication; Lunar Dust; Mars (Planet); Mars Exploration; Mars Surface

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Performance of Adsorption - Based CO2 Acquisition Hardware for Mars ISRU

Finn, John E.; Mulloth, Lila M.; Borchers, Bruce A.; Luna, Bernadette, Technical Monitor; [2000]; In English; Environmental Systems, 10-13 Jul. 2000, Toulouse, France

Contract(s)/Grant(s): RTOP 131-20-10; No Copyright; Avail: Other Sources; Abstract Only

Chemical processing of the dusty, low-pressure Martian atmosphere typically requires conditioning and compression of the gases as first steps. A temperature-swing adsorption process can perform these tasks using nearly solid-state hardware and with relatively low power consumption compared to alternative processes. In addition, the process can separate the atmospheric constituents, producing both pressurized CO2 and a buffer gas mixture of nitrogen and argon. To date we have developed and tested adsorption compressors at scales appropriate for the near-term robotic missions that will lead the way to ISRU-based human exploration missions. In this talk we describe the characteristics, testing, and performance of these devices. We also discuss scale-up issues associated with meeting the processing demands of sample return and human missions.

Author

Adsorption; Carbon Dioxide; Mars Atmosphere; Life Support Systems

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Microreactor System Design for a NASA In Situ Propellant Production Plant on Mars

TeGrotenhuis, W. E.; Wegeng, R. S.; Vanderwiel, D. P.; Whyatt, G. A.; Viswanathan, V. V.; Schielke, K. P.; Sanders, G. B.; Peters, T. A.; Nicholson, Leonard S., Technical Monitor; [2000]; In English; 4th 4th International Conferenc eon Microreaction Technology, 5-9 Mar. 2000, Atlanta, GA, USA

Contract(s)/Grant(s): RTOP 953-20-632-70; No Copyright; Avail: Other Sources; Abstract Only

The NASA In Situ Resource Utilization (ISRU) program is planning near-term missions to Mars that will include chemical processes for converting the carbon dioxide (CO2) and possibly water from the Martian environment to propellants, oxygen, and other useful chemicals. The use of indigenous resources reduces the size and weight of the payloads from Earth significantly, representing enormous cost savings that make human exploration of Mars affordable. Extraterrestrial chemical processing plants will need to be compact, lightweight, highly efficient under reduced gravity, and extraordinarily reliable for long periods. Microchemical and thermal systems represent capability for dramatic reduction in size and weight, while offering high reliability through massive parallelization. In situ propellant production (ISPP), one aspect of the ISRU program, involves collecting and pressurizing atmospheric CO2, conversion reactions, chemical separations, heat exchangers, and cryogenic storage. A preliminary system design of an ISPP plant based on microtechnology has demonstrated significant size, weight, and energy efficiency gains over the current NASA baseline. Energy management is a strong driver for Mars-based processes, not only because energy is a scarce resource, but because heat rejection is problematic; the low pressure environment makes convective heat transfer ineffective. Energy efficiency gains are largely achieved in the microchemical plant through extensive heat recuperation and energy cascading, which has a small size and weight penalty because the added micro heat exchangers are small. This leads to additional size and weight gains by reducing the required area of waste heat radiators. The microtechnology-based ISPP plant is described in detail, including aspects of pinch analysis for optimizing the heat exchanger network. Three options for thermochemical compression Of CO2 from the Martian atmosphere, adsorption, absorption, and cryogenic freezing, are presented, as well as three options for water decomposition, low temperature electrolysis, high temperature electrolysis, and thermochemical decomposition. Other elements of the plant include Sabatier and reverse water gas shift reactors, water recovery, chemical separations, and cryogenic storage. Data are presented supporting preliminary sizing of components, and results of the system design are compared to the existing NASA baseline that is based on conventional technologies.

Author

Propellants; Industrial Plants; Mars (Planet); Systems Engineering; Chemical Reactions; Reactor Technology

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ISRU: An Overview of NASA'S Current Development Activities and Long-Term Goals

Sanders, Gerald B.; Nicholson, Leonard S., Technical Monitor; [2000]; In English; 38th Aerospace Sciences, 10-13 Jan. 2000, Reno, NV, USA

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The concept of 'living off the land' by utilizing the indigenous resources of the Moon, Mars, or other potential sites of robotic and human exploration has been termed In-Situ Resource Utilization (ISRU). It is fundamental to any program of extended human presence and operation on other extraterrestrial bodies that we learn how to utilize the indigenous resources. The chief benefits of ISRU are that it can reduce the mass, cost, and risk of robotic and human exploration while providing capabilities that enable the commercial development of space. In January 1997, the American Institute of Aeronautics and Astronautics (AIAA) Space Processing Technical Committee released a position paper entitled, 'Need for A NASA Indigenous Space Resource Utilization (ISRU) Program'. Besides outlining some of the potential advantages of incorporating ISRU into Lunar and Mars human mission plans and providing an overview of technologies and processes of interest, the position paper concluded with a list of seven recommendations to NASA. This paper will examine the seven recommendations proposed and provide an overview of NASA's current ISRU development activities and possible long term goals with respect to these recommendations.

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Mars Bases; Space Habitats; Lunar Bases; Resources; Space Colonies; Lunar Resources

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Moon-Based Advanced Reusable Transportation Architecture: The MARTA Project

Alexander, Roger; Bechtel, Ryan; Chen, Ted; Cormier, Tim; Kalaver, Sachin; Kirtas, Mehmet; Lewe, Jung-Ho; Marcus, Leland; Marshall, Dave; Medlin, Matt, et al.; Third Annual HEDS-UP Forum; 2000, 206-224; In English; No Copyright; Avail: CASI; A03, Hardcopy

The Moon-based Advanced Reusable Transportation Architecture (MARTA) Project conducted an in-depth investigation of possible Low Earth Orbit (LEO) to lunar surface transportation systems capable of sending both astronauts and large masses of cargo to the Moon and back. This investigation was conducted from the perspective of a private company operating the transportation system for a profit. The goal of this company was to provide an Internal Rate of Return (IRR) of 25% to its shareholders. The technical aspect of the study began with a wide open design space that included nuclear rockets and tether systems as possible propulsion systems. Based on technical, political, and business considerations, the architecture was quickly narrowed down to a traditional chemical rocket using liquid oxygen and liquid hydrogen. However, three additional technologies were identified for further investigation: aerobraking, in-situ resource utilization (ISRU), and a mass driver on the lunar surface. These three technologies were identified because they reduce the mass of propellant used. Operational costs are the largest expense with propellant cost the largest contributor. ISRU, the production of materials using resources on the Moon, was considered because an Earth to Orbit (ETO) launch cost of $1600 per kilogram made taking propellant from the Earth's surface an expensive proposition. The use of an aerobrake to circularize the orbit of a vehicle coming from the Moon towards Earth eliminated 3, 100 meters per second of velocity change (Delta V), eliminating almost 30% of the 11,200 m/s required for one complete round trip. The use of a mass driver on the lunar surface, in conjunction with an ISRU production facility, would reduce the amount of propellant required by eliminating using propellant to take additional propellant from the lunar surface to Low Lunar Orbit (LLO). However, developing and operating such a system required further study to identify if it was cost effective. The vehicle was modeled using the Simulated Probabilistic Parametric Lunar Architecture Tool (SPPLAT), which incorporated the disciplines of Weights and Sizing, Trajectories, and Cost. This tool used ISRU propellant cost, Technology Reduction Factor (a dry weight reduction due to improved technology), and vehicle engine specific impulse as inputs. Outputs were vehicle dry weight, total propellant used per trip, and cost to charge the customer in order to guarantee an IRR of 25%. SPPLAT also incorporated cost estimation error, weight estimation error, market growth, and ETO launch cost as uncertainty variables. Based on the stipulation that the venture be profitable, the price to charge the customer was highly dependent on ISRU propellant cost and relatively insensitive to the other inputs. The best estimate of ISRU cost is $1000/kg, and results in a price to charge the customer of $2600/kg of payload. If ISRU cost can be reduced to $160/kg, the price to the customer is reduced to just $800/kg of payload. Additionally, the mass driver was only cost effective at an ISRU propellant cost greater than $250/kg, although it reduced total propellant used by 35%. In conclusion, this mission is achievable with current technology, but is only profitable with greater research into the enabling technology of ISRU propellant production.

Author

Commerce; Cost Effectiveness; Lunar Surface; Propellants; Propulsion System Configurations; Lunar Resources; Space Logistics

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Mars SCHEME: The Mars Society of Caltech Human Exploration of Mars Endeavor

Hirata, Christopher; Brown, Nathan; Shannon, Derek; Third Annual HEDS-UP Forum; 2000, 96-115; In English; No Copyright; Avail: CASI; A03, Hardcopy

The Mars Society of Caltech Human Exploration of Mars Endeavor (Mars SCHEME) is a detailed description of robotic and human missions necessary to establish a permanent human presence on the surface of Mars. The sequence begins in 2009 with a robotic Mars sample return mission on a larger scale than that currently planned. This is followed in 2011 by a pair of HEDS landers designed to test in-situ propellant production and other necessary technologies. Cargo for the human crews is sent in 2016 and in 2018, with the first five-member crew traveling to Mars during the 2020 opportunity. The Mars SCHEME features design redundancy; for example, the capsules for Earth ascent, Mars ascent, and Earth arrival are based upon a common design. Systems redundancy is also included to provide multiple habitats on Mars and in interplanetary space. The plan uses only chemical propulsion, starting with the Z-5 launch vehicle that can deliver up to 112,000 kg to low Earth orbit. Costs of human missions are comparable with those of the NASA Design Reference Mission 3.0. Human missions have low recurring costs, high reliability, and high scientific return. Extensive computer simulations were used to develop launch vehicles and trajectories. Further details are available at http://mars.caltech.edu/.

Author

Mars (Planet); Mars Exploration; Mars Bases; Mission Planning; Manned Mars Missions; NASA Space Programs

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Automated Construction of a Martian Base

Braun, Angela Nicole; Butler, Dan Bordeaux Burk; Kirk, Benjamin Shelton; White, Scott William; Third Annual HEDS-UP Forum; 2000, 44-56; In English; No Copyright; Avail: CASI; A03, Hardcopy

This document describes the construction of a Martian base that will support human exploration. The base will be constructed without a human presence in order to minimize the risk to the crew. The base will be verified remotely before the crew leaves Earth to ensure that all systems are performing as expected. Life support is the most obvious function the base will have to perform. The crew will require consumables such as food and water. They must also be provided with a controlled atmosphere. The base will use in-situ resource generation (ISRG) as the primary means to provide these services. The ISRG system will extract chemicals from the Martian atmosphere and convert them to usable resources. Power is a key resource for the base. The primary power needs will be met by an SP-100 nuclear reactor and three Stirling engines. This primary power source can provide 375 kW of power under nominal conditions, which is sufficient to support all base operations. Backup systems are present that can sustain critical functions such as life support and communications in the case of primary system failure. The base will provide a substantial communications infrastructure. Both Earth to Mars and surface communications are supported. A satellite constellation will be used to provide this capability. Backup systems are also provided that can be used in the event of primary system failure. Surface operations and science capability is an important aspect of the base design. The base includes two primary laboratories. One laboratory is contained in a lab module that is stationary, and the other is part of a pressurized rover. This mobile science unit (MSU) gives the exploration team the capability of collecting samples and exploring geologic features up to 500 km away. The MSU can operate autonomously from the base for periods up to two weeks with a crew, or it can function robotically for longer periods of time. A transportation and delivery scheme has also been developed. This scheme requires 4 cargo and assembly missions. The cargo modules will transfer from Earth to Mars on a low energy, near-Hohmann trajectory and then aerocapture into Martian orbit. The cargo modules will then descend to the Martian surface and land within 1km of the chosen landing site. Each cargo module can land up to 15 metric tons on the surface.Construction will begin as soon as the cargo modules land. The first launch opportunity will send the power and resource generation systems for the base as well as the surface communications infrastructure and two unpressurized rovers in a single launch package. Resource generation will begin as soon as possible. The second launch package will contain the water extraction system, an ascent vehicle, and scientific equipment and instruments. The remainder of the base will be arrive with the second launch opportunity. The first cargo mission in this opportunity will transport the science and utility modules and a pressurized science rover to the surface. The final launch will contain the habitation module, crew consumables, and a supplemental life support system. Base assembly is accomplished through component movement and integration. This work is accomplished primarily with the two unpressurized rovers. The assembly procedure is controlled from the surface with the help of artificial intelligence. The final base is comprised of a central hub, three inflatable utility modules, the power system, and the ascent module. The base is validated using telemetry from each subsystem. The validation must be successfully completed before sending a crew to Mars.

Author

Construction; Life Support Systems; Mars (Planet); Mars Surface; Mars Bases; Extraterrestrial Environments; Space Habitats; Extraterrestrial Resources; Space Logistics

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Micro Thermal and Chemical Systems for In Situ Resource Utilization on Mars

Wegeng, Robert S.; Sanders, Gerald; [2000]; In English; No Copyright; Avail: Other Sources; Abstract Only

Robotic sample return missions and postulated human missions to Mars can be greatly aided through the development and utilization of compact chemical processing systems that process atmospheric gases and other indigenous resources to produce hydrocarbon propellants/fuels, oxygen, and other needed chemicals. When used to reduce earth launch mass, substantial cost savings can result. Process Intensification and Process Miniaturization can simultaneously be achieved through the application of microfabricated chemical process systems, based on the rapid heat and mass transport in engineered microchannels. Researchers at NASA's Johnson Space Center (JSC) and the Department of Energy's Pacific Northwest National Laboratory (PNNL) are collaboratively developing micro thermal and chemical systems for NASA's Mission to Mars program. Preliminary results show that many standard chemical process components (e.g., heat exchangers, chemical reactors and chemical separations units) can be reduced in hardware volume without a corresponding reduction in chemical production rates. Low pressure drops are also achievable when appropriate scaling rules are applied. This paper will discuss current progress in the development of engineered microchemical systems for space and terrestrial applications, including fabrication

methods, expected operating characteristics, and specific experimental results.
Author
Mars Sample Return Missions; Miniaturization; Extraterrestrial Resources; Space Logistics; Chemical Engineering

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Two-Phase Flow in Packed Columns and Generation of Bubbly Suspensions for Chemical Processing in Space
Motil, Brian J.; Green, R. D.; Nahra, H. K.; Sridhar, K. R.; July 2000; In English; 30th, 10-13 Jul. 2000, Toulouse, France
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Report No.(s): NASA/TM-2000-210212; E-12331; NAS 1.15:210212; SAE Paper 2000-01-2239; No Copyright; Avail: CASI; A03, Hardcopy

For long-duration space missions, the life support and In-Situ Resource Utilization (ISRU) systems necessary to lower the mass and volume of consumables carried from Earth will require more sophisticated chemical processing technologies involving gas-liquid two-phase flows. This paper discusses some preliminary two-phase flow work in packed columns and generation of bubbly suspensions, two types of flow systems that can exist in a number of chemical processing devices. The experimental hardware for a co-current flow, packed column operated in two ground-based low gravity facilities (two-second drop tower and KC- 135 low-gravity aircraft) is described. The preliminary results of this experimental work are discussed. The flow regimes observed and the conditions under which these flow regimes occur are compared with the available co-current packed column experimental work performed in normal gravity. For bubbly suspensions, the experimental hardware for generation of uniformly sized bubbles in Couette flow in microgravity conditions is described. Experimental work was performed on a number of bubbler designs, and the capillary bubble tube was found to produce the most consistent size bubbles. Low air flow rates and low Couette flow produce consistent 2-3 mm bubbles, the size of interest for the 'Behavior of Rapidly Sheared Bubbly Suspension' flight experiment. Finally the mass transfer implications of these two-phase flows is qualitatively discussed.
Author
Flow Velocity; Two Phase Flow; Bubbles; Air Flow; Liquid-Gas Mixtures; Life Support Systems

20000080919 Lunar Industries, Inc., Houston, TX USA
Fluorination of Lunar Ilmenite for In-Situ Production of Lunar Oxygen, Iron, and Titanium
Agosto, B.; Lunar and Planetary Science XXXI; March 2000; In English; CD-ROM: CD-ROM contains the entire conference proceedings presented in PDF format; No Copyright; Available from CASI only as part of the entire parent document

Oxygen can be quantitatively extracted in-situ by fluorination of lunar ilmenite. The resulting metal fluoride separates can be reduced to Fe and Ti metal by reduction with Na derived from electrolysis of fused alkali fluorides transported from Earth as the fluorine source.
Author
Fluorination; Ilmenite; Oxygen Production; Lunar Resources; Electrolysis

Subject Terms

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