Recovery and Utilization of Extraterrestrial Resources

A Special Bibliography From the
NASA Scientific and Technical Information Program

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.

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Recovery and Utilization of Extraterrestrial Resources

A Special Bibliography from the NASA Scientific and Technical Information Program

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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; Advanced Life Support PI Meeting, 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

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; 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

20030060555 NASA Marshall Space Flight Center, Huntsville, AL, USA
CO2 Acquisition Membrane (CAM)
Mason, Larry W.; Way, J. Douglas; Vlasse, Marcus; 2002 Microgravity Materials Science Conference; February 2003; In English; No Copyright; Abstract Only; Available from CASI only as part of the entire parent document

The objective of CAM is 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 are targeted toward In Situ Resource Utilization (ISRU) applications that will operate in extraterrestrial environments and support future unmanned and human space missions. A primary application is the Sabatier Electrolysis process that uses Mars atmosphere CO2 as raw material for producing water, oxygen, and methane for rocket fuel and habitat support. Other applications include use as an inlet filter to collect and concentrate Mars atmospheric argon and nitrogen gases for habitat pressurization, and to remove CO2 from breathing gases in Closed Environment Life Support Systems (CELSS). CAM membrane materials include crystalline faujasite (FAU) zeolite and rubbery polymers such as silicone rubber (PDMS) that have been shown in the literature and via molecular simulation to favor adsorption and permeation of CO2 over nitrogen and argon. Pure gas permeation tests using commercial PDMS membranes have shown that both CO2 permeance and the separation factor relative to other gases increase as the temperature decreases, and low (Delta)P(Sub CO2) favors higher separation factors. The ideal CO2/N2 separation factor increases from 7.5 to 17.5 as temperature decreases from 22 C to -30 C. For gas mixtures containing CO2, N2, and Ar, plasticization decreased the separation factors from 4.5 to 6 over the same temperature range. We currently synthesize and test our own Na(+) FAU zeolite membranes using standard formulations and secondary growth methods on porous alumina. Preliminary tests with a Na(+) FAU membrane at 22 C show a He/SF6 ideal separation factor of 62, exceeding the Knudsen diffusion selectivity by an order of magnitude. This shows that the membrane is relatively free from large defects and associated non-selective (viscous flow) transport mechanisms. The Membrane Test Facility (MTF) has been developed to measure membrane permeance over a wide range of temperature and pressure. The facility uses two volume compartments separated by the membrane that are instrumented to measure temperature, delta pressure across the membrane, and gas composition. A thermal shroud supports and encloses the membrane, and provides temperature control. Methods were developed to determine membrane permeance using the first order decay of the pressure difference between the sealed compartments, using the total pressure for pure gases, and partial pressure of each species in gas mixtures. The technique provides an end-to-end measurement of gas permeance that includes concentration polarization effects. Experiments have shown that in addition to membrane permeance properties, the geometry and design of associated structures play an important role in how membrane systems will function on Mars.
Author
Carbon Dioxide; Membranes; Performance Tests; Thin Films; Gas Mixtures; In Situ Resource Utilization; Purification; Zeolites; Polymers

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; 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

20030020389 NASA, Washington, DC USA

The Preliminary Design of a Universal Martian Lander

Norman, Timothy L.; Gaskin, David; Adkins, Sean; MacDonnell, David; Ross, Enoch; Hashimoto, Kouichi; Miller, Loran; Sarick, John; Hicks, Jonathan; Parlock, Andrew; Swalley, Frank, Technical Monitor, et al.; Proceedings of the Ninth Annual Summer Conference: NASA/USRA University Advanced Design Program; [1993]; In English; No Copyright; Avail: CASI; A03, Hardcopy

As part of the NASA/USRA program, nineteen West Virginia University students conducted a preliminary design of a manned Universal Martian Lander (UML). The WVU design considers descent to Mars from polar orbit, a six month surface stay, and ascent for rendezvous. The design begins with an unmanned UML landing at Elysium Mons followed by the manned UML landing nearby. During the six month surface stay, the eight modules are assembled to form a Martian base where scientific experiments are performed. The mission also incorporates hydroponic plant growth into a Controlled Ecological Life Support System (CELSS) for water recycling, food production, and to counteract psycho-logical effects of living on Mars. In situ fuel production for the Martian Ascent and Rendezvous Vehicle (MARV) is produced From gases in the Martian atmosphere. Following surface operations, the eight member crew uses the MARV to return to the Martian Transfer Vehicle (MTV) for the journey home to Earth.

Author

Maneuverable Reentry Bodies; Hydroponics; Life Support Systems; In Situ Resource Utilization; Mars Landing

20030020385 Washington Univ., Seattle, WA USA

Project Hyreus: Mars Sample Return Mission Utilizing in Situ Propellant Production

Bruckner, A. P.; Thill, Brian; Abrego, Anita; Koch, Amber; Kruse, Ross; Nicholson, Heather; Nill, Laurie; Schubert, Heidi; Schug, Eric; Smith, Brian, et al.; Proceedings of the Ninth Annual Summer Conference: NASA/USRA University Advanced Design Program; [1993]; In English; No Copyright; Avail: CASI; A03, Hardcopy

Project Hyreus is an unmanned Mars sample return mission that utilizes propellants manufactured in situ from the Martian atmosphere for the return voyage. A key goal of the mission is to demonstrate the considerable benefits of using indigenous resources and to test the viability of this approach as a precursor to manned Mars missions. The techniques, materials, and equipment used in Project Hyreus represent those that are currently available or that could be developed and readied in time for the proposed launch date in 2003. Project Hyreus includes such features as a Mars-orbiting satellite equipped with ground-penetrating radar, a large rover capable of sample gathering and detailed surface investigations, and a planetary science array to perform on-site research before samples are returned to Earth. Project Hyreus calls for the Mars Landing Vehicle to land in the Mangala Valles region of Mars, where it will remain for approximately 1.5 years. Methane and oxygen propellant for the Earth return voyage will be produced using carbon dioxide from the Martian atmosphere and a small supply of hydrogen brought from Earth. This process is key to returning a large Martian sample to Earth with a single Earth launch.

Author

Mars Sample Return Missions; In Situ Resource Utilization; Propellants; Manned Mars Missions; Mars Atmosphere

20030014643 NASA Glenn Research Center, Cleveland, OH USA

Vehicle and Mission Design Options for the Human Exploration of Mars/Phobos Using 'Bimodal' NTR and LANTR Propulsion

Borowski, Stanley K.; Dudzinski, Leonard A.; McGuire, Melissa L.; December 2002; In English; 34th Joint Propulsion Conference, 13-15 Jul. 1998, Cleveland, OH, USA; Original contains color illustrations

Contract(s)/Grant(s): NAS3-27186; RTOP 953-20-0C

Report No.(s): NASA/TM-1998-208834/REV1; NAS 1.15:208834/REV1; E-11445-1/REV1; AIAA Paper 98-3883/REV1; Copyright; Avail: CASI; A04, Hardcopy; Distribution as joint owner in the copyright

The nuclear thermal rocket (NTR) is one of the leading propulsion options for future human missions to Mars because of its high specific impulse (1sp is approximately 850-1000 s) capability and its attractive engine thrust-to-weight ratio (approximately 3-10). To stay within the available mass and payload volume limits of a 'Magnum' heavy lift vehicle, a high performance propulsion system is required for trans-Mars injection (TMI). An expendable TMI stage, powered by three 15 thousand pounds force (klbf) NTR engines is currently under consideration by NASA for its Design Reference Mission (DRM). However, because of the miniscule burnup of enriched uranium-235 during the Earth departure phase (approximately 10 grams out of 33 kilograms in each NTR core), disposal of the TMI stage and its engines after a single use is a costly and inefficient use of this high performance stage. By reconfiguring the engines for both propulsive thrust and modest power generation (referred to as 'bimodal' operation), a robust, multiple burn, 'power-rich' stage with propulsive Mars capture and reuse capability is possible. A family of modular bimodal NTR (BNTR) vehicles are described which utilize a common 'core' stage powered by three 15 klbf BNTRs that produce 50 kWe of total electrical power for crew life support, an active refrigeration / reliquification system for long term, zero-boiloff liquid hydrogen (LH2) storage, and high data rate communications. An innovative, spine-like 'saddle truss' design connects the core stage and payload element and is open underneath to allow supplemental 'in-line' propellant tanks and contingency crew consumables to be easily jettisoned to improve vehicle performance. A 'modified' DRM using BNTR transfer vehicles requires fewer transportation system elements, reduces IMLEO and mission risk, and simplifies space operations. By taking the next logical step--use of the BNTR for propulsive capture of all payload elements into Mars orbit--the power available in Mars orbit grows to 150 kWe compared to 30 kWe for the DRM. Propulsive capture also eliminates the complex, higher risk aerobraking and capture maneuver which is replaced by a simpler reentry using a standardized, lower mass 'aerodescent' shell. The attractiveness of the 'all BNTR' option is further increased by the substitution of the lightweight, inflatable 'TransHab' module in place of the heavier, hard-shell hab module. Use of TransHab introduces the potential for propulsive recovery and reuse of the BNTR / Earth return vehicle (ERV). It also allows the crew to travel to and from Mars on the same BNTR transfer vehicle thereby cutting the duration of the ERV mission in half--from approximately 4.7 to 2.5 years. Finally, for difficult Mars options, such as Phobos rendezvous and sample return missions, volume (not mass) constraints limit the performance of the 'all LH2' BNTR stage. The use of 'LOX-augmented' NTR (LANTR) engines, operating at a modest oxygen-to-hydrogen mixture ratio (MR) of 0.5, helps to increase 'bulk' propellant density and total thrust during the TMI burn. On all subsequent burns, the bimodal LANTR engines operate on LH2 only (MR=0) to maximize vehicle performance while staying within the mass limits of two Magnum launches.

Author

Nuclear Propulsion; Mars Missions; In Situ Resource Utilization; High Thrust; 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, no. 1; 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

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, no. 1; 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

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; 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

20020086598 NASA Johnson Space Center, Houston, TX USA
Space Resources
McKay, Mary Fae, Editor; McKay, David S., Editor; Duke, Michael S., Editor; 1992; In English; Original contains color illustrations
Report No.(s): NASA-SP-509; LC-92-4468; S-689; NAS 1.21:509; No Copyright; Avail: CASI; A99, Hardcopy

Space resources must be used to support life on the Moon and exploration of Mars. Just as the pioneers applied the tools they brought with them to resources they found along the way rather than trying to haul all their needs over a long supply line, so too must space travelers apply their high technology tools to local resources. The pioneers refilled their water barrels at each river they forded; moonbase inhabitants may use chemical reactors to combine hydrogen brought from Earth with oxygen found in lunar soil to make their water. The pioneers sought temporary shelter under trees or in the lee of a cliff and built sod houses as their first homes on the new land; settlers of the Moon may seek out lava tubes for their shelter or cover space station modules with lunar regolith for radiation protection. The pioneers moved further west from their first settlements, using wagons they had built from local wood and pack animals they had raised; space explorers may use propellant made at a lunar base to take them on to Mars. The concept for this report was developed at a NASA-sponsored summer study in 1984. The program was held on the Scripps campus of the University of California at San Diego (UCSD), under the auspices of the American Society for Engineering Education (ASEE). It was jointly managed under the California Space Inst. and the NASA Johnson Space Center, under the direction of the Office of Aeronautics and Space Technology (OAST) at NASA Headquarters. The study participants (listed in the addendum) included a group of 18 university teachers and researchers (faculty fellows) who were present for the entire 10-week period and a larger group of attendees from universities, Government, and industry who came for a series of four 1-week workshops. The organization of this report follows that of the summer study. Space Resources consists of a brief overview and four detailed technical volumes: (1) Scenarios; (2) Energy, Power, and Transport; (3) Materials; (4) Social Concerns. Although many of the included papers got their impetus from workshop discussions, most have been written since then, thus allowing the authors to base new applications on established information and tested technology. All these papers have been updated to include the authors' current work. This overview, drafted by faculty fellow Jim Burke, describes the findings of the summer study, as participants explored the use of space resources in the development of future space activities and defined the necessary research and development that must precede the practical utilization of these resources. Space resources considered included lunar soil, oxygen derived from lunar soil, material retrieved from near-Earth asteroids, abundant sunlight, low gravity, and high vacuum. The study participants analyzed the direct use of these resources, the potential demand for products from them, the techniques for retrieving and processing space resources, the necessary infrastructure, and the economic tradeoffs. This is certainly not the first report to urge the utilization of space resources in the development of space activities. In fact, Space Resources may be seen as the third of a trilogy of NASA Special Publications reporting such ideas arising from similar studies. It has been preceded by Space Settlements: A Design Study (NASA SP-413) and Space Resources and Space Settlements (NASA SP-428). And other, contemporaneous reports have responded to the same themes. The National Commission on Space, led by Thomas Paine, in Pioneering the Space Frontier, and the NASA task force led by astronaut Sally Ride, in Leadership and America's Future in Space, also emphasize expansion of the space Infrastructure; more detailed exploration of the Moon, Mars, and asteroids; an early start on the development of the technology necessary for using space resources; and systematic development of the skills necessary for long-term human presence in space. Our report does not represent any Government-authorized view or official NASA policy. NASA's official response to these challenging opportunities must be found in the reports of its Office of Exploration, which was established in 1987. That office's report, released in November 1989, of a 90-day study of possible plans for human exploration of the Moon and Mars is NASA's response to the new initiative proposed by President Bush on July 20, 1989, the 20th anniversary of the Apollo 11 landing on the Moon: 'First, for the coming decade, for the 1990s, Space Station Freedom, our critical next step in all our space endeavors. And next, for the new century, back to the Moon, back to the future, and this time, back to stay. And then a journey into tomorrow, a journey to another planet, a manned mission to Mars.' This report, Space Resources, offers substantiation for NASA's bid to carry out that new initiative.
Author
Extraterrestrial Resources; Space Exploration; Resources Management; Resource Allocation

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; 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

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; 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

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; 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

20020038770 NASA Ames Research Center, Moffett Field, CA USA
Information Technology and the Autonomous Control of a Mars In-Situ Propellant Production System
Gross, Anthony R.; Sridhar, K. R.; Larson, William E.; Clancy, Daniel J.; Peschur, Charles; Briggs, Geoffrey A.; Zornetzer, Steven F., Technical Monitor; [1999]; In English; 50th International Astronautical Congress, 3-7 Oct. 1999, USA; No Copyright; Avail: CASI; A03, Hardcopy

With the rapidly increasing performance of information technology, i.e., computer hardware and software systems, as well as networks and communication systems, a new capability is being developed that holds the clear promise of greatly increased exploration capability, along with dramatically reduced design, development, and operating costs. These new intelligent systems technologies, utilizing knowledge-based software and very high performance computer systems, will provide new design and development tools, scheduling mechanisms, and vehicle and system health monitoring capabilities. In addition, specific technologies such as neural nets will provide a degree of machine intelligence and associated autonomy which has previously been unavailable to the mission and spacecraft designer and to the system operator. One of the most promising applications of these new information technologies is to the area of in situ resource utilization. Useful resources such as oxygen, compressed carbon dioxide, water, methane, and buffer gases can be extracted and/or generated from planetary atmospheres, such as the Martian atmosphere. These products, when used for propulsion and life-support needs can provide significant savings in the launch mass and costs for both robotic and crewed missions. In the longer term the utilization of indigenous resources is an enabling technology that is vital to sustaining long duration human presence on Mars. This paper will present the concepts that are currently under investigation and development for mining the Martian atmosphere, such as temperature-swing adsorption, zirconia electrolysis etc., to create propellants and life-support materials. This description will be followed by an analysis of the information technology and control needs for the reliable and autonomous operation of such processing plants in a fault tolerant manner, as well as the approach being taken for the development of the controlling software. Finally, there will be a brief discussion of the verification and validation process so crucial to the implementation of mission-critical software.
Author
In Situ Resource Utilization; Mars Atmosphere; Propellants; Life Support Systems; Automatic Control; Computer Systems Design

20020023715 NASA Ames Research Center, Moffett Field, CA USA
A Liquefier for Mars Surface Propellant Production
Salerno, Lou J.; Helvensteijn, B. P. M.; Kittel, P.; Arnold, James O., Technical Monitor; [1999]; In English; 1999 Cryogenic Engineering and International Cryogenic Materials Conference, 12-16 Jul. 1999, Montreal, Canada
Contract(s)/Grant(s): RTOP 242-82-10; No Copyright; Avail: CASI; A01, Hardcopy

NASA's planned Mars exploration missions will require that cryogenic propellants be manufactured on the surface. The present scenario calls for oxygen and methane gases to he produced using the carbon dioxide atmosphere plus seed hydrogen brought from Earth. Gases will require liquefaction for both storage on the Martian surface and for use in the ascent vehicle. The planned liquefaction rates range from 12.6 g/hr of oxygen for the 2003 robotic mission to 2500 g/hr for the later human missions. This paper presents the results of a nitrogen liquefaction demonstration using a commercially available cryocooler. The experiment was set up to liquefy nitrogen gas instead of oxygen to limit laboratory safety concerns. A nitrogen gas condensor, attached to the cooler's cold tip, was sized to liquefy up to 42 gN2/hr at the intended storage pressure (0.2 MPa).

The experiment was conducted inside an atmospheric, air-filled, refrigerated chamber simulating the average Martian daytime temperature (240 K). In this demonstration a liquefaction rate of 9.1 gN2/hr was realized, which is equivalent to 13 gO2/hr.
Author
Condensers (Liquefiers); Liquefaction; Mars Surface; In Situ Resource Utilization; Cryogenic Rocket Propellants; Coolers

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

20010082934 NASA Ames Research Center, Moffett Field, CA USA
ISRU Technologies for Mars Life Support
Finn, John E.; Sridhar, K. R.; [2000]; In English; Concepts and Approaches for the Robotic Exploration of Mars, 18-20 Jul. 2000, Houston, TX, USA
Contract(s)/Grant(s): RTOP 131-20-10; No Copyright; Avail: Other Sources; Abstract Only

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 resolution 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 robotic + 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. ISRU for propellant production and for generation of life support consumables is a key element of human exploration mission plans because of the tremendous savings that can be realized in terms of launch costs and reduction in overall risk to the mission. The Human Exploration and Development of Space (HEDS) Enterprise has supported ISRU technology development for several years, and is funding the MIP and PROMISE payloads that will serve as the first demonstrations of ISRU technology for Mars. In our discussion and presentation at the workshop, we will highlight how the PROMISE ISRU experiment that has been selected by HEDS for a future Mars flight opportunity can extend and enhance the science experiments on board.
Author
In Situ Resource Utilization; Life Support Systems; Solar System; Mars Exploration

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, Part 1; 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

20010001687 NASA Johnson Space Center, Houston, TX USA

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

Sanders, Gerald B.; Space Resources Roundtable 2; [2000]; 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

20010001673 NASA, Washington, DC USA

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]; 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

20010001658 Houston Univ., TX USA

Space Resources Roundtable 2

Ignatiev, A.; Space Resources Roundtable II; [2000]; In English; Space Resources Roundtable II, 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

20000109667 NASA Johnson Space Center, Houston, TX USA

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

Contract(s)/Grant(s): RTOP 953-20-00; RTOP 632-70-00; No Copyright; Avail: Other Sources; Abstract Only

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.

Author

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

20000090517 NASA Johnson Space Center, Houston, TX USA

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

20000080804 Washington Univ., Saint Louis, MO USA

An Empirical Relation Between the Lunar Prospector Gamma-Ray and Soil Sample Th Abundances

Gillis, Jeffrey J.; Jolliff, Brad L.; Korotev, Randy L.; Lawrence, David J.; Lunar and Planetary Science XXXI; March 2000; In English; CD-ROM: CD-ROM contains the entire conference proceedings presented in PDF format

Contract(s)/Grant(s): NAG5-6784; NAG5-8609; NAG5-4172; No Copyright; Available from CASI only as part of the entire parent document

This abstract compares Th abundances for soils from Apollo 12, 14, 16, and the lunar feldspathic meteorites with Th concentrations using a theoretical calibration of the Lunar Prospector gamma-ray data.

Author

Abundance; Gamma Rays; Thorium; Lunar Composition; Lunar Soil; Lunar Crust; Spectrum Analysis; Lunar Surface; Lunar Resources; Soil Sampling

20000027399 NASA Johnson Space Center, Houston, TX USA

An Overview of NASA's current In-Situ Consumable Production (ISCP) Development Activities and Goals

Sanders, G. B.; Space Resources Utilization Roundtable; 1999; In English; No Copyright; Avail: CASI; A01, Hardcopy

Utilization of extraterrestrial resources, or In-Situ Resource Utilization (ISRU), is viewed as an enabling technology for the exploration and commercial exploitation of our solar system. 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 the enable commercial development of space. A key subset of ISRU which has significant cost 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 propellants for planetary ascent or Earth return vehicles, gases and water for crew and life support, and fuel cell reagents for power generation by using resources available at the site of exploration. Since propellant mass typically makes up 60 to 80% of the ascent or Earth return vehicle mass, In-Situ Propellant Production (ISPP) on the Lunar or Mars surface can significantly reduce the overall mass for the return vehicle needed to be brought from Earth. Systems analyses of human Mars missions have indicated that solely producing propellants on the surface of Mars by processing atmospheric carbon dioxide can reduce the initial mission mass required in low Earth orbit by approximately 20% as compared to carrying all required propellant to the Mars surface from Earth. An even greater leverage can occur for Mars missions when in-situ water can be processed.

Author

Extraterrestrial Resources; Solar System; Consumables (Spacecraft); Lunar Surface; Mars Surface

20000027389 Orbital Technologies Corp., Madison, WI USA

Lunar Polar Ice: Methods for Mining the New Resource for Exploration

Gustafson, Robert J.; Rice, Eric E.; Space Resources Utilization Roundtable; 1999; In English; No Copyright; Avail: CASI; A01, Hardcopy

The presence of ice in permanently shadowed depressions near the lunar poles and determination of its properties will significantly influence both the near- and long-term prospects for lunar exploration and development. Since data from the Lunar Prospector spacecraft indicate that water ice is likely present (the instrument measures hydrogen strongly suggests the presence of water), it is important to understand how to extract it for beneficial use, as well as how to preserve it for scientific analysis. Two types of processes can be considered for the extraction of water ice from the lunar poles. In the first case, energy is transported into the shadowed regions, ice is constrain models of impacts on the lunar surface and processed in-situ, and water is transported out of the cold trap. In the second case, ice-containing regolith can be mined in the cold trap, transported outside the cold trap, and the ice extracted in a location with abundant solar energy. A series of conceptual implementations has been examined and criteria have been developed for the selection of systems and subsystems for further study.
Author
Lunar Surface; Lunar Exploration; Ice; Moon; Lunar Mining

20000027384 Lunar and Planetary Inst., Houston, TX USA
Space Resources Utilization Roundtable
1999; In English
Contract(s)/Grant(s): NASW-4574
Report No.(s): LPI-Contrib-988; No Copyright; Avail: CASI; A04, Hardcopy
This volume contains abstracts that have been accepted for presentation at the Space Resources Utilization Roundtable, October 27-29, 1999, in Golden, Colorado. The program committee consisted of M. B. Duke (Lunar and Planetary Institute), G. Baughman (Colorado School of Mines), D. Criswell (University of Houston), C. Graham (Canadian Mining Industry Research Organization), H. H. Schmitt (Apollo Astronaut), W. Sharp (Colorado School of Mines), L. Taylor (University of Tennessee), and a space manufacturing representative. Administration and publications support for this meeting were provided by the staff of the Publications and Program Services Department at the Lunar and Planetary Institute.
Derived from text
Space Manufacturing; Extraterrestrial Resources; Lunar Exploration

20000025353 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA
In Situ Identification of Mineral Resources with an X-Ray-Optical ‘Hands-Lens’ Instrument
Marshall, J.; Koppel, L.; Bratton, C.; Metzger, E.; Hecht, M.; Studies of Mineralogical and Textural Properties of Martian Soil: An Exobiological Perspective; September 1999; In English; In Situ Research Utilization, Nov. 1997, Houston, TX, USA
Contract(s)/Grant(s): NCC2-926; No Copyright; Abstract Only; Available from CASI only as part of the entire parent document
The recognition of material resources on a planetary surface requires exploration strategies not dissimilar to those employed by early field geologists who searched for ore deposits primarily from surface clues. In order to determine the location of mineral ores or other materials, it will be necessary to characterize host terranes at regional or subregional scales. This requires geographically broad surveys in which statistically significant numbers of samples are rapidly scanned from a roving platform. To enable broad-scale, yet power-conservative planetary-surface exploration, we are developing an instrument that combines x-ray diffractometry (XRD), x-ray fluorescence spectrometry (XRF), and optical capabilities; the instrument can be deployed at the end of a rover’s robotic arm, without the need for sample capture or preparation. The instrument provides XRD data for identification of mineral species and lithological types; diffractometry of minerals is conducted by ascertaining the characteristic lattice parameters or ‘d-spacings’ of mineral compounds. D-spacings of 1.4 to 25 angstroms can be determined to include the large molecular structures of hydrated minerals such as clays. The XRF data will identify elements ranging from carbon (Atomic Number = 6) to elements as heavy as barium (Atomic Number = 56). While a sample is being x-rayed, the instrument simultaneously acquires an optical image of the sample surface at magnifications from lx to at least 50x (200x being feasible, depending on the sample surface). We believe that imaging the sample is extremely important as corroborative sample-identification data (the need for this capability having been illustrated by the experience of the Pathfinder rover). Very few geologists would rely on instrument data for sample identification without having seen the sample. Visual inspection provides critical recognition data such as texture, crystallinity, granularity, porosity, vesicularity, color, lustre, opacity, and so forth. These data can immediately distinguish sedimentary from igneous rocks, for example, and can thus eliminate geochemical or mineral ambiguities arising, say between arkose and granite. It would be important to know if the clay being analyzed was part of a uniform varve deposit laid down in a quiescent lake, or the matrix of a megabreccia diamictite deposited as a catastrophic impact ejecta blanket. The unique design of the instrument, which combines Debye-Scherrer geometry with elements of standard goniometry, negates the need for sample preparation of any kind, and thus negates the need for power-hungry and mechanically-complex sampling systems that would have to chip, crush,

sieve, and mount the sample for x-ray analysis. Instead, the instrument is simply rested on the sample surface of interest (like a hand lens); the device can interrogate rough rock surfaces, coarse granular material, or fine rock flour. A breadboard version of the instrument has been deployed from the robotic arm of the Marsokhod rover in field trials at NASA Ames, where large vesicular boulders were x-rayed to demonstrate the functionality of the instrument design, and the ability of such a device to comply with constraints imposed by a roving platform. Currently under development is a flight prototype concept of this instrument that will weigh 0.3 kg, using about 4500 J of energy per sample analysis. It requires about 5 min. for XRD analysis, and about 30 min. for XRF interrogation. Its small mass and rugged design make it ideal for deployment on small rovers of the type currently envisaged for the exploration of Mars (e.g., Sojourner-scale platforms). The design utilizes a monolithic P-N junction photodiode pixel array for XRD, a Si PIN photodiode/avalanche photodiode system for XRF, and an endoscopic imaging camera system unobtrusively embedded between the detectors and the x-ray source (the endoscope with its board-mounted camera can be adapted for IR light in addition to visible wavelenths. A rugged, miniature (7 cu cm) x-ray source for the instrument has already been breadboarded.
Author
Geological Surveys; Mineral Deposits; Mars Surface; Extraterrestrial Resources

19990114936 NASA Johnson Space Center, Houston, TX USA
An Overview of NASA's Current In-Situ Consumable Production (ISCP) Development Activities and Goals
Sanders, G. B.; Space Resources Utilization Roundtable; 1999; In English; Copyright; Avail: Other Sources; Abstract Only;

Utilization of extraterrestrial resources, or In-Situ Resource Utilization (ISRU), is viewed as an enabling technology for the exploration and commercial exploitation of our solar system. 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 the enable commercial development of space. A key subset of ISRU which has significant cost 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 propellants for planetary ascent or Earth return vehicles, gases and water for crew and life support, and fuel cell reagents for power generation by using resources available at the site of exploration. Since propellant mass typically makes up 60 to 80% of the ascent or Earth return vehicle mass, In-Situ Propellant Production (ISPP) on the Lunar or Mars surface can significantly reduce the overall mass for the return vehicle needed to be brought from Earth. Systems analyses of human Mars missions have indicated that solely producing propellants on the surface of Mars by processing atmospheric carbon dioxide can reduce the initial mission mass required in low Earth orbit by approximately 20% as compared to carrying all required propellant to the Mars surface from Earth. An even greater leverage can occur for Mars missions when in-situ water can be processed.
Derived from text
Extraterrestrial Resources; Exploitation; Solar System

19990114925 Orbital Technologies Corp., Madison, WI USA
Lunar Polar Ice: Methods for Mining the New Resource for Exploration
Gustafson, Robert J.; Rice, Eric E.; Space Resources Utilization Roundtable; 1999; In English; Copyright; Avail: Other Sources; Abstract Only;

The presence of ice in permanently shadowed depressions near the lunar poles and determination of its properties will significantly influence both the near- and long-term prospects for lunar exploration and development. Since data from the Lunar Prospector spacecraft indicate that water ice is likely present (the instrument measures hydrogen which strongly suggests the presence of water), it is important to understand how to extract it for beneficial use, as well as how to preserve it for scientific analysis. Two types of processes can be considered for the extraction of water ice from the lunar poles. In the first case, energy is transported into the shadowed regions, ice is processed in-situ, and water is transported out of the cold trap. In the second case, ice-containing regolith can be mined in the cold trap, transported outside the cold trap, and the ice extracted in a location with abundant solar energy. A series of conceptual implementations has been examined and criteria have been developed for the selection of systems and subsystems for further study.
Derived from text
Ice; Lunar Exploration; Lunar Prospector; Lunar Resources; Lunar Mining

19990114920 Lunar and Planetary Inst., Houston, TX USA
Space Resources Utilization Roundtable
1999; In English, 27-29 Oct. 1999, Golden, CO, USA
Contract(s)/Grant(s): NASW-4574
Report No.(s): LPI-Contrib-988; Copyright; Avail: Other Sources; Abstracts Only;

This volume contains abstracts on various topics. These topics include; Economics of Lunar Mineral Exploration; Lunar Solar Power System and Lunar Development; Space Resource Roundtable Rationale; Successfully Mining Asteroids and Comets; Lunar Polar Ice: Method for Mining the New Resource for Exploration; Acoustic Shaping: Enabling Technology for a Space-based Economy; Return to the Moon: A New Strategic Evaluation; Spacewatch Discovery and Study of Accessible Asteroids; Role of Mining in Space Development; A Commercial/Lunar Resources Exploration Concept; Radar Reconnaissance of Near-Earth Asteroids; Solar Energy Conversion Using In Situ Lunar Soil; The Application of Thermal Plasmas to Ore Reduction for In Situ Resource Utilization; Prospecting Near-Earth Asteroids from the Ground; Some Implications of Space Tourism for Extraterrestrial Resources; An Overview of NASA's Current In Situ Consumable Production (ISCP) Development Activities and Goals; Prospectives on Lunar Helium-3; Self-Propagating High-Temperature Synthesis for In Situ Materials Processing; Subsurface Exploration from Lander and Rover Platforms with Seismic Surface Waves; Space Weathering and the Formation of Lunar Soil: The Moon as the Model for all Airless Bodies in the Solar System; and Acoustic Shaping in Microgravity: Technology Issues.
CASI
Extraterrestrial Resources; Lunar Exploration; Lunar Resources

19990087481 NASA Johnson Space Center, Houston, TX USA
Oxygen Generator System Mars In-Situ Propellant Production Precursor Flight
Sridhar, K. R.; Gottmann, M.; Baird, R. S.; Abstracts In Situ Resource Utilization (ISRU 3) Technical Interchange Meeting: Abstracts; 1999; In English; No Copyright; Abstract Only; Available from CASI only as part of the entire parent document

The 2001 Lander to Mars will carry the first ever In situ Resource Utilization (ISRU) payload to Mars. This payload, the Mars In-situ Propellant production Precursor (MIP), will demonstrate a variety of technologies that will be required for future ISRU Mars indigenous material processing plant designs. One of those technologies is that of extracting oxygen from the predominantly carbon dioxide atmosphere of Mars, a prerequisite for future sample return and human missions to Mars. The Oxygen Generator Subsystem (OGS) portion of the MIP will demonstrate this and is the focus of this paper. The primary objective of the OGS is to demonstrate the production of oxygen from Mars atmospheric gases. Secondary objectives are to measure the performance and reliability of oxygen generation hardware in actual mission environments over an extended time. Major constraints on the OGS design came from several sources. The Lander provides power to the system from solar power that is harnessed by photovoltaic arrays. This limited OGS to daytime only operations (six to eight hours) and a maximum power of 15W. The reliance on solar power necessitated thermal cycling of the OGS between Mars ambient and OGS operating temperatures. The Lander also limited the total mass of the MIP payload to 7.5 kg with a correspondingly small volume, and the OGS was one of six experiments in the MIP Mass and volume were to be minimized. Another constraint was cost. Mission funding, as always, was tight. Cost was to be minimized. In short the OGS design had to be low power (<15 Watts), low mass (1 kg), low volume, low cost, and be capable of cyclical operations for an extended stay on Mars. After extensive research, a zirconia based solid oxide electrolyzer design was selected.
Author
Mars Missions; Oxygen; Oxygen Production; Extraterrestrial Resources

19990087464 Lunar and Planetary Inst., Houston, TX USA
Abstracts In Situ Resource Utilization (ISRU 3) Technical Interchange Meeting: Abstracts
Kaplan, David, Editor; Clark, Larry D., Editor; 1999; In English; 3rd, 11-12 Feb. 1999, Denver, CO, USA
Contract(s)/Grant(s): NASW-4574
Report No.(s): LPI-Contrib-963; No Copyright; Avail: CASI; A03, Hardcopy; Abstracts Only;

This document represents abstracts of presentations which have been submitted to the Technical Interchange meeting concerning In Situ Resource Utilization. Papers mostly reported on work related to usage of Martian resources to produce propellant, water, and oxygen. Other papers presented research on usage of lunar resources for the production of propellants, and the required cryogenics for propellant production.
CASI
Abstracts; Lunar Resources; Mars (Planet); Conferences; Extraterrestrial Resources

19990054057 Orbital Technologies Corp., Madison, WI USA

Initial Test Firing Results for Solid CO/GOX Cryogenic Hybrid Rocket Engine for Mars ISRU Propulsion Applications

Rice, Eric E.; St. Clair, Christopher P.; Chiaverini, Martin J.; Knuth, William H.; Gustafson, Robert J.; Gramer, Daniel J.; Fifth International Microgravity Combustion Workshop; May 1999; In English; No Copyright; Avail: CASI; A01, Hardcopy

ORBITEC is developing methods for producing, testing, and utilizing Mars-based ISRU fuel/oxidizer combinations to support low cost, planetary surface and flight propulsion and power systems. When humans explore Mars we will need to use in situ resources that are available, such as: energy (solar); gases or liquids for life support, ground transportation, and flight to and from other surface locations and Earth; and materials for shielding and building habitats and infrastructure. Probably the easiest use of Martian resources to reduce the cost of human exploration activities is the use of the carbon and oxygen readily available from the CO2 in the Mars atmosphere. ORBITEC has conducted preliminary R&D that will eventually allow us to reliably use these resources. ORBITEC is focusing on the innovative use of solid CO as a fuel. A new advanced cryogenic hybrid rocket propulsion system is suggested that will offer advantages over LCO/LOX propulsion, making it the best option for a Mars sample return vehicle and other flight vehicles. This technology could also greatly support logistics and base operations by providing a reliable and simple way to store solar or nuclear generated energy in the form of chemical energy that can be used for ground transportation (rovers/land vehicles) and planetary surface power generators. This paper describes the overall concept and the test results of the first ever solid carbon monoxide/oxygen rocket engine firing.

Author

Carbon Monoxide; Test Firing; Extraterrestrial Resources; Cryogenic Rocket Propellants; Chemical Propulsion; Propellant Combustion; Hybrid Propellants; Hybrid Propellant Rocket Engines

19990046122 NASA Johnson Space Center, Houston, TX USA

Exploration of the Moon with Remote Sensing, Ground-Penetrating Radar, and the Regolith-Evolved Gas Analyzer (REGA)

Cooper, B. L.; Hoffman, J. H.; Allen, Carlton C.; McKay, David S.; Workshop on New Views of the Moon: Integrated Remotely Sensed, Geophysical, and Sample Datasets; 1998; In English; No Copyright; Avail: Other Sources; Abstract Only;

There are two important reasons to explore the Moon. First, we would like to know more about the Moon itself: its history, its geology, its chemistry, and its diversity. Second, we would like to apply this knowledge to a useful purpose. namely finding and using lunar resources. As a result of the recent Clementine and Lunar Prospector missions, we now have global data on the regional surface mineralogy of the Moon, and we have good reason to believe that water exists in the lunar polar regions. However, there is still very little information about the subsurface. If we wish to go to the lunar polar regions to extract water, or if we wish to go anywhere else on the Moon and extract (or learn) anything at all, we need information in three dimensions an understanding of what lies below the surface, both shallow and deep. The terrestrial mining industry provides an example of the logical steps that lead to an understanding of where resources are located and their economic significance. Surface maps are examined to determine likely locations for detailed study. Geochemical soil sample surveys, using broad or narrow grid patterns, are then used to gather additional data. Next, a detailed surface map is developed for a selected area, along with an interpretation of the subsurface structure that would give rise to the observed features. After that, further sampling and geophysical exploration are used to validate and refine the original interpretation, as well as to make further exploration/mining decisions. Integrating remotely sensed, geophysical, and sample datasets gives the maximum likelihood of a correct interpretation of the subsurface geology and surface morphology. Apollo-era geophysical and automated sampling experiments sought to look beyond the upper few microns of the lunar surface. These experiments, including ground-penetrating radar and spectrometry, proved the usefulness of these methods for determining the best sites for lunar bases and lunar mining operations.

Author

Lunar Mining; Lunar Resources; Lunar Surface; Lunar Composition; Selenology; Lunar Exploration

19990026767 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA USA

Ice as a Construction Material

Zuppero, Anthony; Lewis, J.; Workshop on Using In Situ resources for Construction of Planetary Outposts; 1998; In English; No Copyright; Avail: Other Sources; Abstract Only;

This presentation shows how water and ice can enable exceptionally simple ways to construct structures in deep space. Practicality is underscored by applying advanced tank methods being developed for Mars missions. Water or ice is now known to be present or abundant on most objects in the solar system, starting with the planet Mercury. Thermal processes alone can be used to melt ice . The cold of space can refreeze water back into ice. The anomalous low vapor pressure of water, about 7 mm Hg, permits bladder containers. Tanks or bladders made with modern polymer fiber and film can exhibit very small (<0.1

%) equivalent tankage and ullage fractions and thus hold thousands of tons of water per ton bladder. Injecting water into a bladder whose shape when inflated is the desired final shape, such as a space vehicle, provides a convenient way to construct large structures. In space, structures of 1O,OOO-T mass become feasible because the bladder mass is low enough to be launched. The bladder can weigh 1OOO times less than its contents, or 10 T. The bladder would be packed like a parachute. Shaped memory materials and/or gas inflation could reestablish the desired structure shape after unpacking. The water comes from space resources. An example examines construction of torus space vehicle with 100-m nominal dimension. People would live inside the torus. A torus, like a tire on an automobile, would spin and provide synthetic gravity at its inner surface. A torus of order 100 m across would provide a gravity with gradients low enough to mitigate against vertigo.
Author
Construction; Extraterrestrial Resources; Ice; Large Space Structures; Spacecraft Structures; Tanks (Containers); Water Resources

19990026739 Lunar and Planetary Inst., Houston, TX USA
Workshop on Using In Situ Resources for Construction of Planetary Outposts
Duke, Michael B., Editor; Workshop on Using In Situ resources for Construction of Planetary Outposts; 1998; In English, 30 Apr. - 1 May 1998, Albuquerque, NM, USA
Contract(s)/Grant(s): NASw-4574
Report No.(s): LPI/TR-98-01; No Copyright; Avail: CASI; A04, Hardcopy

The workshop examined the potential uses of indigenous materials on the Moon and Mars, other than those associated with the production of propellants for space transportation. The papers presented concerned the needs for construction, based on analysis of the current NASA Mars reference Mission and past studies studies of lunar outposts; the availability of materials on the Moon and Mars; construction techniques that make use of the natural environment; materials production and fabrication techniques based on indigenous materials; and new technologies that could promote the use of indigenous materials in construction.
Derived from text
Extraterrestrial Resources; Lunar Resources; Conferences; Mars (Planet); Mars Bases; Lunar Bases

19990025829 NASA Johnson Space Center, Houston, TX USA
In-Situ Resource Utilization (ISRU) Development Program
Sanders, Jerry; HEDS-UP Mars Exploration Forum; 1998; In English; No Copyright; Avail: CASI; A02, Hardcopy

The question ‘Why In-Situ Resource Utilization (ISRU)?’ is addressed in this presentation. The reasons given concentrate on Cost reduction, Mass reduction, Risk reduction, the expansion of human exploration and presence and the enabling of industrial exploitation. A review of the Martian and Lunar resources available for ISRU is presented. Other ISRU concepts (i.e., In-Situ Consumable production (ISCP) and In-Situ Propellant Production (ISPP)) are introduced and further explained. The objectives of a Mars ISRU System Technology (MIST) include (1) the characterization of technology and subsystem performance for mission modeling and technology funding planning, (2) reduce risk and concerns arising from sample return and human missions utilizing ISRU, and (3) demonstrate the environmental suitability of ISRU components/processes and systems. A proof of concept demonstration schedule and a facility overview for MIST is presented.
CASI
Mars (Planet); Propellants; Manned Mars Missions; Mars Exploration; Mars Environment; Mars Surface; Environmental Engineering; Mars Bases; Extraterrestrial Resources

19980210643 Search for Extraterrestrial Intelligence Inst., Moffett Field, CA USA
In Situ identification of mineral resources with an X-ray-optical ‘Hand-Lens’ instrument
Marshall, J.; Koppel, L.; Bratton, C.; Metzger, E.; Hecht, M.; In Situ Resource Utilization (ISRU II) Technical Interchange Meeting; 1997; In English; No Copyright; Avail: CASI; A01, Hardcopy

The recognition of material resources on a planetary surface requires exploration strategies not dissimilar to those employed by early field geologists who searched for ore deposits primarily from surface clues. In order to determine the location of mineral ores or other materials, it will be necessary to characterize host terranes at regional or subregional scales. This requires geographically broad surveys in which statistically significant numbers of samples are rapidly scanned from a roving platform. To enable broad-scale, yet power-conservative planetary-surface exploration, we are developing an instrument that combines x-ray diffractometry (XRD), x-ray fluorescence spectrometry (XRF), and optical capabilities; the instrument can be deployed at the end of a rover’s robotic arm, without the need for sample capture or preparation. The

instrument provides XRD data for identification of mineral species and lithological types; diffractometry of minerals is conducted by ascertaining the characteristic lattice parameters or 'd-spacings' of mineral compounds. D-spacings of 1.4 to 25 angstroms can be determined to include the large molecular structures of hydrated minerals such as clays. The XRF data will identify elements ranging from carbon (Atomic Number = 6) to elements as heavy as barium (Atomic Number = 56).
Derived from text
In Situ Measurement; Extraterrestrial Resources; Mineral Deposits; Lattice Parameters; Lenses; X Ray Imagery; X Ray Optics; Planetary Surfaces

19980210633 NASA Johnson Space Center, Houston, TX USA
Characterization of the Resource Potential of Martian Soil using the Integrated Dust/Soil Experiment Package (IDEP)
Cooper, Bonnie L.; Mckay, David S.; Allen, Carlton C.; Hoffman, John H.; Gittleman, Mark E.; In Situ Resource Utilization (ISRU II) Technical Interchange Meeting; 1997; In English; No Copyright; Avail: CASI; A01, Hardcopy

The Integrated Dust/Soil Experiment Package (IDEP) is a suite of instruments that can detect and quantify the abundances of useful raw materials on Mars. We focus here on its capability for resource characterization in the martian soil; however, it is also capable of detecting and quantifying gases in the atmosphere. This paper describes the scientific rationale and the engineering design behind the IDEP.
Derived from text
Mars Surface; Soil Sampling; Extraterrestrial Resources; Mass Spectroscopy

19980210630 Lunar and Planetary Inst., Houston, TX USA
In Situ Resource Utilization (ISRU II) Technical Interchange Meeting
Kaplan, David, Compiler; Saunders, Stephen R., Compiler; 1997; In English; In Situ Resource Utilization (ISRU II) Technical Interchange Meeting, 18-19 Nov. 1997, Houston, TX, USA
Contract(s)/Grant(s): NASw-4574
Report No.(s): NASA/CR-97-207784; NAS 1.26:207784; LPI-Contrib-930; No Copyright; Avail: CASI; A04, Hardcopy

This volume contains extended abstracts that have been accepted for presentation at the In Situ Resource Utilization (ISRU II) Technical Interchange Meeting, November 18-19, 1997, at the Lunar and Planetary Institute, Houston, Texas. Included are topics which include: Extraterrestrial resources, in situ propellant production, sampling of planetary surfaces, oxygen production, water vapor extraction from the Martian atmosphere, gas generation, cryogenic refrigeration, and propellant transport and storage.
CASI
Abstracts; Resources Management; Planetary Geology; Planetary Environments; Oxygen Production; Mars Surface; Mars Exploration; Extraterrestrial Resources; Propellants

19980147990 NASA Johnson Space Center, Houston, TX USA
Resource Utilization and Site Selection for a Self-Sufficient Martian Outpost
Barker, Donald; Chamitoff, Gregory; James, George; Apr. 1998; In English; Original contains color illustrations
Report No.(s): NASA/TM-98-206538; S-837; NAS 1.15:206538; No Copyright; Avail: CASI; A04, Hardcopy

As a planet with striking similarities to Earth, Mars is an important focus for scientific research aimed at understanding the processes of planetary evolution and the formation of our solar system. Fortunately, Mars is also a planet with abundant natural resources, including assessible materials that can be used to support human life and to sustain a self-sufficient martian outpost. Resources required include water, breathable air, food, shelter, energy, and fuel. Through a mission design based on in situ resource development, we can establish a permanent outpost on Mars beginning with the first manned mission. This paper examines the potential for supporting the first manned mission with the objective of achieving self-sufficiency through well-understood resource development and a program of rigorous scientific research aimed at extending that capability. We examine the potential for initially extracting critical resources from the martian environment, and discuss the scientific investigations required to identify additional resources in the atmosphere, on the surface, and within the subsurface. We also discuss our current state of knowledge of Mars, technical considerations of resource utilization, and using unmanned missions' data for selecting an optimal site. The primary goal of achieving self-sufficiency on Mars would accelerate the development of human colonization beyond Earth, while providing a robust and permanent martian base from which humans can explore and conduct long-term research on planetary evolution, the solar system, and life itself.
Author
Mars Environment; Mission Planning; Site Selection; Mars Exploration; Mars Bases; Space Habitats; Manned Mars Missions; Extraterrestrial Resources

19950058739 NASA Lyndon B. Johnson Space Center, Houston, TX, USA

Utilization of on-site resources for regenerative life support systems at Lunar and Martian outposts

Ming, Douglas W.; Golden, D. C.; Henninger, Donald L.; JAN 1, 1993; ISSN 0148-7191; In English; 23rd International Conference on Environmental Systems, July 12-15, 1993, Colorado Springs, CO, USA

Report No.(s): SAE PAPER 932091; Copyright; Avail: Other Sources

Lunar and martian materials can be processed and used at planetary outposts to reduce the need (and thus the cost) of transportng supplies from Earth. A variety of uses for indigenous, on-site materials have been suggested, including uses as rocket propellants, construction materials, and life support materials. Utilization of on-site resources will supplement Regenerative Life Support Systems (RLSS) that will be needed to regenerate air, water, wastes, and to produce food (e.g., plants) for human consumption during long-duration space missions. Natural materials on the Moon and/or Mars may be used for a variety of RLSS needs including (1) soils or solid-support substrate for plant growth, (2) sources for extraction of essential plant-growth nutrients, (3) sources of O2, H2, CO2, and water, (4) substrates for microbial populations in the degradation of wastes, and (5) shielding materials surrounding outpost structures to protect humans, plants, and microorganisms from radiation. In addition to the regolith, the martian atmosphere will provide additional resources at a Mars outpost, including water, CO2 and other atmospheric gases.

Author (Herner)

Crop Growth; Extraterrestrial Resources; Life Support Systems; Lunar Bases; Lunar Resources; Mars Bases; Space Habitats

19950054276 NASA, Washington, DC, USA

Remote sensing of potential lunar resources. 2: High spatial resolution mapping of spectral reflectance ratios and implications for nearside mare TiO2 content′

Melendrez, David E.; Johnson, Jeffrey R.; Larson, Stephen M.; Singer, Robert B.; Journal of Geophysical Research; March 25, 1994; ISSN 0148-0227; 99, E3; In English

Contract(s)/Grant(s): NAGW-1332; Copyright; Avail: Other Sources

High spatial resolution maps illustrating variations in spectral reflectance 400/560 nm ratio values have been generated for the following mare regions: (1) the border between southern Mare Serenitatis and northern Mare Tranquillitatis (including the MS-2 standard area and Apollo 17 landing site), (2) central Mare Tranquillitatis, (3) Oceanus Procellarum near Seleucus, and (4) southern Oceanus Procellarum and Flamsteed. We have also obtained 320-1000 nm reflectance spectra of several sites relative to MS-2 to facilitate scaling of the images and provide additional information on surface composition. Inferred TiO2 abundances for these mare regions have been determined using an empirical calibration which relates the weight percent TiO2 in mature mare regolith to the observed 400/560 nm ratio. Mare areas with high TiO2 abundances are probably rich in ilmenite (FeTiO3) a potential lunar resource. The highest potential TiO2 concentrations we have identified in the nearside maria occur in central Mare Tranquillitatis. Inferred TiO2 contents for these areas are greater than 9 wt% and are spatially consistent with the highest-TiO2 regions mapped previously at lower spatial resolution. We note that the morphology of surface units with high 400/560 nm ratio values increases in complexity at higher spatial resolutions. Comparisons have been made with previously published geologic maps, Lunar Orbiter IV, and ground-based images, and some possible morphologic correlatins have been found between our mapped 400/560 nm ratio values and volcanic landforms such as lava flows, mare domes, and collapse pits.

Author (revised by Herner)

Lunar Maps; Lunar Resources; Mapping; Moon; Remote Sensing; Spectral Reflectance; Titanium Oxides

19950049260 NASA, Washington, DC, USA

Mining the air: How far have we progressed?

Ramohalli, Kumar; Planetary Report; March-April 1994; ISSN 0736-3680; 14, 2; In English; Copyright; Avail: Other Sources

A brief discussion of oxygen-extraction technology and equipment developed by the Space Engineering Research Center (SERC) is presented. Lunar and martian oxygen production from in situ materials and the development of oxygen factories are covered briefly.

Herner

Electrochemical Cells; Extraction; Extraterrestrial Resources; Lunar Resources; Oxygen Production; Oxygen Supply Equipment

19950032543 NASA, Washington, DC, USA

Martian resource utilization. 1: Plant design and transportation selection criteria

Kaloupis, Peter; Nolan, Peter E.; Cutler, Andrew H.; Space Power - Resources, Manufacturing and Development; 1992; ISSN 0883-6272; 11, 3-4; In English

Contract(s)/Grant(s): NAGW-1332; Copyright; Avail: Other Sources

Indigenous Space Materials Utilization (ISMU) provides an opportunity to make Mars exploration mission scenarios more affordable by reducing the initial mass necessary in Low Earth Orbit (LEO). Martian propellant production is discussed in terms of simple design and economic tradeoffs. Fuel and oxidizer combinations included are H2/O2, CH4/O2, and CO/O2. Process flow diagrams with power and mass flow requirements are presented for a variety of processes, and some design requirements are derived. Maximum allowable plant masses for single use amortization are included.

Author (Herner)

Carbon Monoxide; Chemical Reactors; Electrolysis; Extraterrestrial Resources; Fuel Production; Hydrogen Fuels; Hydrogen Production; Liquid Rocket Propellants; Mars Atmosphere; Mars Exploration; Methane; Oxygen Production; Sabatier Reaction; Water Splitting

19950028432 NASA Lyndon B. Johnson Space Center, Houston, TX, USA

Reduction of lunar basalt 70035: Oxygen yield and reaction product analysis

Gibson, Michael A.; Knudsen, Christian W.; Bruenemen, David J.; Allen, Carlton C.; Kanamori, Hiroshi; Mckay, David S.; Journal of Geophysical Research; May 1994; ISSN 0148-0227; 99, E5; In English; Copyright; Avail: Other Sources

Oxygen production from a lunar rock has been experimentally demonstrated for the first time. A 10 g sample of high-Ti basalt 70035 was reduced with hydrogen in seven experiments at temperatures of 900-1050 C and pressures of 14.7-150 psia. In all experiments, water evolution began almost immediately and was essentially complete in tens of minutes. Oxygen yields ranged from 2.93 to 4.61% of the starting sample weight, and showed weak dependence on temperature and pressure. Analysis of the solid samples demonstrated total reduction of Fe(2+) in ilmenite and small degrees of reduction in olivine and pyroxene. Ti O2 was also partially reduced to one or more suboxides. Data from these experiments provide a basis for predicting the yield of oxygen from lunar basalt as well as new constraints on natural reduction in the lunar regolith.

Author (revised by Herner)

Basalt; Lunar Resources; Lunar Rocks; Oxygen Production; Reduction (Chemistry)

19950027035 NASA Lyndon B. Johnson Space Center, Houston, TX, USA

The Moon as a way station for planetary exploration

Duke, M. B.; ESA, International Lunar Workshop: Towards a World Strategy for the Exploration and Utilisation of Our Natural Satellite; Nov 1, 1994; In English; Copyright; Avail: CASI; A01, Hardcopy

The Moon can be on the pathway to the exploration of other planets in the solar system in three distinct ways: science, systems and technology experience, and as a fuel depot. The most important of these from the point of view of near term potential is to provide systems and technology development that increases capability and reduces the cost and risk of Mars exploration. The development of capability for a lunar program, if planned properly, can significantly influence strategies for sending humans to Mars. In conclusion, the exploration of the Moon should come before the exploration of Mars. This is a statement of developmental and operational logic that is almost self evident. Technological advancement could, however, make a different strategy reasonable. Principally, the development of a propulsion capability that could substantially reduce round trip mission times to Mars (to say 6 to 12 months) could eliminate much of the argument that the Moon is an essential stepping stone. This would reduce the problem to one of similitude with current space station program concepts. However, for any reasonably near term program, such technology does not appear likely to be available. Thus, the answer remains that lunar exploration should come first, and the expectation that it will make Mars exploration much more affordable and safe. The use of lunar propellant in an Earth-Mars transportation system is not practical with current propulsion systems; however, the discovery of caches of water ice at a lunar pole could change considerably the strategy for utilization of lunar resources in planetary exploration.

ESA

Lunar Resources; Mars (Planet); Moon; Refueling; Space Exploration

19950008255 Science Applications International Corp., Torrance, CA, USA

Engine system assessment study using Martian propellants

Pelaccio, Dennis; Jacobs, Mark; Scheil, Christine; Collins, John; Jun 1, 1992; In English

Contract(s)/Grant(s): NAS3-25809; RTOP 506-42-72

Report No.(s): NASA-CR-189188; NAS 1.26:189188; E-0265-079; No Copyright; Avail: CASI; A15, Hardcopy

A top-level feasibility study was conducted that identified and characterized promising chemical propulsion system designs which use two or more of the following propellant combinations: LOX/H2, LOX/CH4, and LOX/CO. The engine systems examined emphasized the usage of common subsystem/component hardware where possible. In support of this study, numerous mission scenarios were characterized that used various combinations of Earth, lunar, and Mars propellants to establish engine system requirements to assess the promising engine system design concept examined, and to determine overall exploration leverage of such systems compared to state-of-the-art cryogenic (LOX/H2) propulsion systems. Initially in the study, critical propulsion system technologies were assessed. Candidate expander and gas generator cycle LOX/H2/CO, LOX/H2/CH4, and LOX/CO/CH4 engine system designs were parametrically evaluated. From this evaluation baseline, tripropellant Mars Transfer Vehicle (MTV) LOX cooled and bipropellant Lunar Excursion Vehicle (LEV) and Mars Excursion Vehicle (MEV) engine systems were identified. Representative tankage designs for a MTV were also investigated. Re-evaluation of the missions using the baseline engine design showed that in general the slightly lower performance, smaller, lower weight gas generator cycle-based engines required less overall mission Mars and in situ propellant production (ISPP) infrastructure support compared to the larger, heavier, higher performing expander cycle engine systems.
Author
Carbon Monoxide; Chemical Propulsion; Fuel Production; Liquid Hydrogen; Liquid Oxygen; Liquid Rocket Propellants; Lunar Resources; Mars Exploration; Methane; Rocket Engine Design

19950007095 Georgia Inst. of Tech., Atlanta, GA, USA, Universities Space Research Association, Columbia, MD, USA
Glass microsphere lubrication
Geiger, Michelle; Goode, Henry; Ohanlon, Sean; Pieloch, Stuart; Sorrells, Cindy; Willette, Chris; JAN 1, 1991; In English
Contract(s)/Grant(s): NASW-4435
Report No.(s): NASA-CR-197157; NAS 1.26:197157; No Copyright; Avail: CASI; A05, Hardcopy

The harsh lunar environment eliminated the consideration of most lubricants used on earth. Considering that the majority of the surface of the moon consists of sand, the elements that make up this mixture were analyzed. According to previous space missions, a large portion of the moon's surface is made up of fine grained crystalline rock, about 0.02 to 0.05 mm in size. These fine grained particles can be divided into four groups: lunar rock fragments, glasses, agglutinates (rock particles, crystals, or glasses), and fragments of meteorite material (rare). Analysis of the soil obtained from the missions has given chemical compositions of its materials. It is about 53 to 63 percent oxygen, 16 to 22 percent silicon, 10 to 16 percent sulfur, 5 to 9 percent aluminum, and has lesser amounts of magnesium, carbon, and sodium. To be self-supporting, the lubricant must utilize one or more of the above elements. Considering that the element must be easy to extract and readily manipulated, silicon or glass was the most logical choice. Being a ceramic, glass has a high strength and excellent resistance to temperature. The glass would also not contaminate the environment as it comes directly from it. If sand entered a bearing lubricated with grease, the lubricant would eventually fail and the shaft would bind, causing damage to the system. In a bearing lubricated with a solid glass lubricant, sand would be ground up and have little effect on the system. The next issue was what shape to form the glass in. Solid glass spheres was the only logical choice. The strength of the glass and its endurance would be optimal in this form. To behave as an effective lubricant, the diameter of the spheres would have to be very small, on the order of hundreds of microns or less. This would allow smaller clearances between the bearing and the shaft, and less material would be needed. The production of glass microspheres was divided into two parts, production and sorting. Production includes the manufacturing of the microspheres, while sorting entails deciphering the good microspheres from the bad ones. Each process is discussed in detail.
Derived from text
Glass; Lunar Resources; Lunar Soil; Microparticles; Solid Lubricants; Spacecraft Lubrication

19950007084 Georgia Inst. of Tech., Atlanta, GA, USA
Lunar vertical-shaft mining system
Introne, Steven D., editor; Krause, Roy; Williams, Erik; Baskette, Keith; Martich, Frederick; Weaver, Brad; Meve, Jeff; Alexander, Kyle; Dailey, Ron; White, Matt, et al.; Mar 1, 1994; In English
Contract(s)/Grant(s): NASW-4435
Report No.(s): NASA-CR-197154; NAS 1.26:197154; No Copyright; Avail: CASI; A09, Hardcopy

This report proposes a method that will allow lunar vertical-shaft mining. Lunar mining allows the exploitation of mineral resources imbedded within the surface. The proposed lunar vertical-shaft mining system is comprised of five subsystems: structure, materials handling, drilling, mining, and planning. The structure provides support for the exploration and mining equipment in the lunar environment. The materials handling subsystem moves mined material outside the structure and mining and drilling equipment inside the structure. The drilling process bores into the surface for the purpose of collecting soil

samples, inserting transducer probes, or locating ore deposits. Once the ore deposits are discovered and pinpointed, mining operations bring the ore to the surface. The final subsystem is planning, which involves the construction of the mining structure.
Author (revised)
Drilling; Exploitation; Lunar Excavation Equipment; Lunar Mining; Materials Handling; Mineral Deposits

19950006413 Washington Univ., Seattle, WA, USA, Universities Space Research Association, Columbia, MD, USA
Project Hyreus: Mars sample return mission utilizing in situ propellant production
Abrego, Anita; Bair, Chris; Hink, Anthony; Kim, Jae; Koch, Amber; Kruse, Ross; Ngo, Dung; Nicholson, Heather; Nill, Laurie; Perras, Craig, et al.; Jul 31, 1993; In English
Contract(s)/Grant(s): NASW-4435
Report No.(s): NASA-CR-197189; NAS 1.26:197189; No Copyright; Avail: CASI; A17, Hardcopy

Project Hyreus is an unmanned Mars sample return mission that utilizes propellants manufactured in situ from the Martian atmosphere for the return voyage. A key goal of the mission is to demonstrate the considerable benefits of using indigenous resources and to test the viability of this approach as a precursor to manned Mars missions. The techniques, materials, and equipment used in Project Hyreus represent those that are currently available or that could be developed and readied in time for the proposed launch date in 2003. Project Hyreus includes such features as a Mars-orbiting satellite equipped with ground-penetrating radar, a large rover capable of sample gathering and detailed surface investigations, and a planetary science array to perform on-site research before samples are returned to Earth. Project Hyreus calls for the Mars Landing Vehicle to land in the Mangala Valles region of Mars, where it will remain for approximately 1.5 years. Methane and oxygen propellant for the Earth return voyage will be produced using carbon dioxide from the Martian atmosphere and a small supply of hydrogen brought from Earth. This process is key to returning a large Martian sample to Earth with a single Earth launch.
Author
Carbon Dioxide; Extraterrestrial Resources; Fuel Production; Hydrogen Production; Liquid Rocket Propellants; Mars Sample Return Missions; Mars Surface; Methane; Oxygen Production; Research Projects; Sabatier Reaction; Unmanned Spacecraft

19950006409 Washington Univ., Seattle, WA, USA, Universities Space Research Association, Columbia, MD, USA
Project Genesis: Mars in situ propellant technology demonstrator mission
Acosta, Francisco Garcia; Anderson, Scott; Andrews, Jason; Deger, Matt; Hedman, Matt; Kipp, Jared; Kobayashi, Takahisa; Marcelo, Mohrli; Mark, Karen; Matheson, Mark, et al.; Jul 31, 1994; In English
Contract(s)/Grant(s): NASW-4435
Report No.(s): NASA-CR-197166; NAS 1.26:197166; No Copyright; Avail: CASI; A11, Hardcopy

Project Genesis is a low cost, near-term, unmanned Mars mission, whose primary purpose is to demonstrate in situ resource utilization (ISRU) technology. The essence of the mission is to use indigenously produced fuel and oxidizer to propel a ballistic hopper. The Mars Landing Vehicle/Hopper (MLVH) has an Earth launch mass of 625 kg and is launched aboard a Delta 117925 launch vehicle into a conjunction class transfer orbit to Mars. Upon reaching its target, the vehicle performs an aerocapture maneuver and enters an elliptical orbit about Mars. Equipped with a ground penetrating radar, the MLVH searches for subsurface water ice deposits while in orbit for several weeks. A deorbit burn is then performed to bring the MLVH into the Martian atmosphere for landing. Following aerobraking and parachute deployment, the vehicle retrofires to a soft landing on Mars. Once on the surface, the MLVH begins to acquire scientific data and to manufacture methane and oxygen via the Sabatier process. This results in a fuel-rich O2/CH4 mass ratio of 2, which yields a sufficiently high specific impulse (335 sec) that no additional oxygen need be manufactured, thus greatly simplifying the design of the propellant production plant. During a period of 153 days the MLVH produces and stores enough fuel and oxidizer to make a 30 km ballistic hop to a different site of scientific interest. At this new location the MLVH resumes collecting surface and atmospheric data with the onboard instrumentation. Thus, the MLVH is able to provide a wealth of scientific data which would otherwise require two separate missions or separate vehicles, while proving a new and valuable technology that will facilitate future unmanned and manned exploration of Mars. Total mission cost, including the Delta launch vehicle, is estimated to be $200 million.
Author
Carbon Dioxide; Delta Launch Vehicle; Extraterrestrial Resources; Fuel Production; Hoppers; Mars Landing; Mars Sample Return Missions; Methane; Oxygen; Propellants; Sabatier Reaction; Unmanned Spacecraft

19940030909 NASA Lyndon B. Johnson Space Center, Houston, TX, USA

Lunar mineral feedstocks from rocks and soils: X-ray digital imaging in resource evaluation

Chambers, John G.; Patchen, Allan; Taylor, Lawrence A.; Higgins, Stefan J.; Mckay, David S.; Lunar and Planetary Inst., The Twenty-Fifth Lunar and Planetary Science Conference. Part 1: A-G; JAN 1, 1994; In English; No Copyright; Avail: CASI; A01, Hardcopy

The rocks and soils of the Moon provide raw materials essential to the successful establishment of a lunar base. Efficient exploitation of these resources requires accurate characterization of mineral abundances, sizes/shapes, and association of 'ore' and 'gangue' phases, as well as the technology to generate high-yield/high-grade feedstocks. Only recently have x-ray mapping and digital imaging techniques been applied to lunar resource evaluation. The topics covered include inherent differences between lunar basalts and soils and quantitative comparison of rock-derived and soil-derived ilmenite concentrates. It is concluded that x-ray digital-imaging characterization of lunar raw materials provides a quantitative comparison that is unattainable by traditional petrographic techniques. These data are necessary for accurately determining mineral distributions of soil and crushed rock material. Application of these techniques will provide an important link to choosing the best raw material for mineral beneficiation.

Derived from text

Basalt; Beneficiation; Digital Techniques; Ilmenite; Imaging Techniques; Lunar Geology; Lunar Resources; Lunar Rocks; Lunar Soil; Minerals; Petrography; X Ray Imagery

19940024883 Florida State Univ., Tallahassee, FL, USA

Lunar surface operations. Volume 4: Lunar rover trailer

Shields, William; Feteih, Salah; Hollis, Patrick; Jul 1, 1993; In English

Contract(s)/Grant(s): NASW-4435

Report No.(s): NASA-CR-195554; NAS 1.26:195554; No Copyright; Avail: CASI; A05, Hardcopy

The purpose of the project was to design a lunar rover trailer for exploration missions. The trailer was designed to carry cargo such as lunar geological samples, mining equipment and personnel. It is designed to operate in both day and night lunar environments. It is also designed to operate with a maximum load of 7000 kilograms. The trailer has a ground clearance of 1.0 meters and can travel over obstacles 0.75 meters high at an incline of 45 degrees. It can be transported to the moon fully assembled using any heavy lift vehicle with a storage compartment diameter of 5.0 meters. The trailer has been designed to meet or exceed the performance of any perceivable lunar vehicle.

Author

Lunar Mining; Lunar Roving Vehicles; Lunar Surface; Trailers

19940022871 Brubaker Group, Los Angeles, CA, USA

A widely adaptable habitat construction system utilizing space resources

Wykes, Harry B.; NASA. Lewis Research Center, Vision 21: Interdisciplinary Science and Engineering in the Era of Cyberspace; Dec 1, 1993; In English; No Copyright; Avail: CASI; A02, Hardcopy

This study suggests that the cost of providing accommodations for various manned activities in space may be reduced by the extensive use of resources that are commonly found throughout the solar system. Several concepts are proposed for converting these resources into simple products with many uses. Concrete is already being considered as a possible moonbase material. Manufacturing equipment should be as small and simple as possible, which leads to the idea of molding it into miniature modules that can be produced and assembled in large numbers to create any conceivable shape. Automated equipment could build up complex structures by laying down layer after layer in a process resembling stereolithography. These tiny concrete blocks handle compression loads and provide a barrier to harmful radiation. They are joined by a web of tension members that could be made of wire or fiber-reinforced plastic. The finished structure becomes air-tight with the addition of a flexible liner. Wire can be made from the iron modules found in lunar soil. In addition to its structural role, a relatively simple apparatus can bend and weld it into countless products like chairs and shelving that would otherwise need to be supplied from Earth. Wire woven into a loose blanket could be an effective micrometeoroid shield, tiny wire compression beams could be assembled into larger beams which in turn form larger beams to create very large space-frame structures. A technology developed with lunar materials could be applied to the moons of Mars or the asteroids. To illustrate its usefulness several designs for free-flying habitats are presented. They begin with a minimal self-contained living unit called the Cubicle. It may be multiplied into clusters called Condos. These are shown in a rotating tether configuration that provides a substitute for gravity. The miniature block proposal is compared with an alternate design based on larger triangular components and a tetrahedral geometry. The overall concept may be expanded to envision city-sized self-sufficient environments where humans could confortably live their entire lives. One such proposal is the Hive. It is configured around a unique sunlight collection

system that could provide all its energy needs and that could be scaled up to compensate for the reduced solar intensity at greater distances from the sun. Its outer perimeter consists of a cylindrical section mated to two conical end walls that taper inwards toward a small aperture at the center of rotation. Light collected by two huge mirrors of unusual design enters the aperture and is redirected to the inside of the cylinder. The conical end walls are shielded from direct sunlight and are designed to radiate heat into space. They are lined with air ducts that passively recirculate the atmosphere while extracting moisture by condensation. Although there is no immediate demand for spacecraft on this scale, their consideration can influence even the earliest stages of the development process.
Author
Asteroids; Casting; Concretes; Construction; Extraterrestrial Resources; Fiber Composites; Lunar Rocks; Lunar Soil; Manufacturing; Radiation Shielding; Space Habitats; Space Manufacturing

19940020145 Cincinnati Univ., OH, USA
Design of a lunar propellant processing facility. NASA/USRA advanced program
Batra, Rajesh; Bell, Jason; Campbell, J. Matt; Cash, Tom; Collins, John; Dailey, Brian; France, Angelique; Gareau, Will; Gleckler, Mark; Hamilton, Charles, et al.; Jul 28, 1993; In English
Contract(s)/Grant(s): NASW-4435
Report No.(s): NASA-CR-195502; NAS 1.26:195502; No Copyright; Avail: CASI; A14, Hardcopy

Mankind's exploration of space will eventually lead to the establishment of a permanent human presence on the Moon. Essential to the economic viability of such an undertaking will be prudent utilization of indigenous lunar resources. The design of a lunar propellant processing system is presented. The system elements include facilities for ore processing, ice transportation, water splitting, propellant storage, personnel and materials transportation, human habitation, power generation, and communications. The design scenario postulates that ice is present in the lunar polar regions, and that an initial lunar outpost was established. Mining, ore processing, and water transportation operations are located in the polar regions. Water processing and propellant storage facilities are positioned near the equator. A general description of design operations is outlined below. Regolith containing the ice is mined from permanently-shaded polar craters. Water is separated from the ore using a microwave processing technique, and refrozen into projectiles for launch to the equatorial site via railgun. A mass-catching device retrieves the ice. This ice is processed using fractional distillation to remove impurities, and the purified liquid water is fed to an electrolytic cell that splits the water into vaporous hydrogen and oxygen. The hydrogen and oxygen are condensed and stored separately in a tank farm. Electric power for all operations is supplied by SP-100 nuclear reactors. Transportation of materials and personnel is accomplished primarily using chemical rockets. Modular living habitats are used which provide flexibility for the placement and number of personnel. A communications system consisting of lunar surface terminals, a lunar relay satellite, and terrestrial surface stations provides capabilities for continuous Moon-Moon and Moon-Earth transmissions of voice, picture, and data.
Author (revised)
Lunar Bases; Lunar Mining; Lunar Resources; Propellant Storage; Regolith; Rocket Propellants; Space Commercialization

19940017287 NASA Lewis Research Center, Cleveland, OH, USA
Powdered aluminum and oxygen rocket propellants: Subscale combustion experiments
Meyer, Mike L.; Dec 1, 1993; In English; 30th JANNAF Combustion Subcommittee Meeting, 15-19 Nov. 1993, Monterey, CA, USA
Contract(s)/Grant(s): RTOP 232-01-OA
Report No.(s): NASA-TM-106439; E-8281; NAS 1.15:106439; No Copyright; Avail: CASI; A03, Hardcopy

Aluminum combined with oxygen has been proposed as a potential lunar in situ propellant for ascent/descent and return missions for future lunar exploration. Engine concepts proposed to use this propellant have not previously been demonstrated, and the impact on performance from combustion and two-phase flow losses could only be estimated. Therefore, combustion tests were performed for aluminum and aluminum/magnesium alloy powders with oxygen in subscale heat-sink rocket engine hardware. The metal powder was pneumatically injected, with a small amount of nitrogen, through the center orifice of a single element O-F-O triplet injector. Gaseous oxygen impinged on the fuel stream. Hot-fire tests of aluminum/oxygen were performed over a mixture ratio range of 0.5 to 3.0, and at a chamber pressure of approximately 480 kPa (70 psia). The theoretical performance of the propellants was analyzed over a mixture ratio range of 0.5 to 5.0. In the theoretical predictions the ideal one-dimensional equilibrium rocket performance was reduced by loss mechanisms including finite rate kinetics, two-dimensional divergence losses, and boundary layer losses. Lower than predicted characteristic velocity and specific impulse performance efficiencies were achieved in the hot-fire tests, and this was attributed to poor mixing of the propellants

and two-phase flow effects. Several tests with aluminum/9.8 percent magnesium alloy powder did not indicate any advantage over the pure aluminum fuel.
Author
Aluminum Alloys; Engine Tests; Exhaust Velocity; Lunar Exploration; Lunar Resources; Metal Propellants; Oxygen; Powdered Aluminum; Specific Impulse

19940016348 Tennessee Univ., Knoxville, TN, USA
Production of O2 on the Moon: A lab-top demonstration of ilmenite reduction with hydrogen
Taylor, Lawrence A.; Jerde, Eric A.; Mckay, David S.; Gibson, Michael A.; Knudsen, Christian W.; Kanamori, Hiroshi; Lunar and Planetary Inst., Twenty-Fourth Lunar and Planetary Science Conference. Part 3: N-Z; JAN 1, 1993; In English; No Copyright; Avail: Other Sources

Estimates of the costs of transporting materials from Earth to the Moon are around $25,000 per pound. Therefore, it is imperative that we learn to utilize the resources on the Moon to partially offset these ‘astronomical’ expenses. The production of oxygen on the Moon utilizing indigenous materials is crucial to the establishment and development of an autonomous lunar colony. Besides obvious biologic needs, this lunar liquid oxygen (LLOX) could result in tremendous cost savings on fuel for effective transportation systems, particularly with its export to low-Earth orbit. Over 20 different process concepts were proposed and evaluated for the production of oxygen from lunar materials. Simplicity, low energy, easily attainable feedstock, and low resupply mass are the keywords for the process(es) which will ultimately be selected for the initial production of oxygen on the Moon. One of these schemes, which has received considerable study to date, is the hydrogen reduction of ilmenite. In fact, Carbotek, Inc. (Houston, TX) patented an ilmenite, hydrogen-reduction technique involving a three-stage, fluidized-bed process for the production of LLOX. A lab-top demonstration unit of the basic concepts of this oxygen generation process that was constructed by our group at the University of Tennessee is explained. It utilizes many of the principles which must be addressed in designing an effective production plant for operation on the Moon.
Author (revised)
Ilmenite; Liquid Oxygen; Lunar Resources; Oxidation-Reduction Reactions; Oxygen Production

19940014486 NASA, Washington, DC, USA
Future energy source
Oct 1, 1990; In English
Report No.(s): ASR-254; NASA-TM-109363; NONP-NASA-VT-94-198210; No Copyright; Avail: CASI; B01, Videotape-Beta; V01, Videotape-VHS

This video describes the efforts of the Center for the Commercial Development of Space in Wisconsin to develop a strategy for mining Helium-3, an efficient, environmentally safe alternative to fossil fuels that exists on the moon. Animated sequences depict the equipment that could mine the lunar surface, boil away Helium-3 to be transported back to earth, and return the soil to the moon without destroying the lunar surface.
CASI
Helium Isotopes; Lunar Excavation Equipment; Lunar Mining; Lunar Resources; Space Commercialization

19940011955 Lamar Univ., Beaumont, TX, USA
Helium-3 inventory of lunar samples: A potential future energy resource for mankind?
Murali, A. V.; Jordan, J. L.; Lunar and Planetary Inst., Twenty-Fourth Lunar and Planetary Science Conference. Part 2: G-M; JAN 1, 1993; In English
Contract(s)/Grant(s): NAS9-17900; No Copyright; Avail: Other Sources

Recent public concern over the safety, cost, and environmental impact of the worldwide fission reactors has focused the attention of scientists and engineers towards perfecting fusion technology because it promises a much more environmentally acceptable ‘clean’ energy supply. The fusion reaction D-2 + He-3 yields p(14.7 MeV) + He-4(3.6 MeV) has long been recognized as an ideal candidate for producing commercially ‘safer and cleaner’ fusion power. Naturally occurring He-3 is scarce on earth; however, lunar regolith is a potential ore for He-3 because the high He-3 in solar wind has been implanted in the lunar regolith for more than 4 x 10(exp 9) years, along with other volatile species. The helium abundance in lunar soils is dependent not only on the maturity of soils (I(sub S)/FeO) but also on their mineralogy. The titanium-rich (ilmenite) lunar soils are important repositories for volatiles, which may be released by heating these soils up to approximately 700 C.
CASI
Clean Energy; Fuel Production; Helium Isotopes; Lunar Resources; Regolith; Solar Wind

19940007775 Bechtel Corp., San Francisco, CA, USA

Terrestrial case studies of ilmenite exploration and lunar implications

Feldman, S. C.; Franklin, H. A.; Lunar and Planetary Inst., Twenty-fourth Lunar and Planetary Science Conference. Part 1: A-F; JAN 1, 1993; In English; No Copyright; Avail: Other Sources

The Space Exploration Initiative (SEI) includes space resource utilization as one of the four architectures to achieve U.S. goals in space. Space resource utilization will make use of lunar resources to support long term activities on the lunar surface. Lunar ilmenite and regolith are two of the materials that can be mined and processed for lunar oxygen production. During this investigation, several sources were reviewed to assess terrestrial exploration methods used for locating ilmenite resources. These sources included published reports on terrestrial ilmenite exploration methods, analytical methods, case histories, chemical and physical properties, and associations with other minerals. Using a terrestrial analog and considering the differences between terrestrial and lunar environmental conditions, rocks, and minerals, exploration methods and analytical instruments can be recommended for a lunar orbiter and lander for assessing lunar resources. Twelve terrestrial case histories were reviewed to gain insight into ilmenite exploration on the Moon. All exploration case histories follow the same pattern. They begin with a model, use remote geophysical techniques, define regional sampling sites from the model and geophysics, narrow down the area of exploration based on the preceding work, collect more samples and cores, and perform laboratory analyses of samples. An important part of this process is the collection of samples to determine the correctness of the model. Surface and core samples are collected in areas expected to contain both high and low concentration of the commodity to test the model. After samples are analyzed and the area of mineralization is defined, reserves are calculated to determine the cost/benefit ratio, the necessary capacity of the processing plant, and the life of the mine. The exploration methods used for locating terrestrial ilmenite resources are reviewed with respect to the petrology, chemistry, and mineral associations of the terrestrial and lunar environments.

Author

Ilmenite; Lunar Exploration; Lunar Mining; Lunar Resources; Mineral Exploration; Planetary Geology; Space Exploration; Terrain Analysis

19940005052 Eagle Engineering, Inc., Houston, TX, USA

Analysis of lunar propellant production

Dec 9, 1985; In English

Report No.(s): NASA-CR-188266; NAS 1.26:188266; EEI-85-103B; No Copyright; Avail: CASI; A03, Hardcopy

A methodology for the analysis of lunar propellant production schemes is developed. This methodology was first applied to the case of approximately 1,400 metric tons (MT) per year of lunar produced oxygen delivered to low Earth orbit (LEO) by a variety of propulsion schemes, some of which include the use of lunar hydrogen. Given many assumptions concerning cost, it appears difficult to deliver oxygen to LEO for less than the projected delivery cost of a large Shuttle derived vehicle (SDV). The projected cost difference between the two methods of delivery is not large however, a factor of two or less in most cases. An increase in the market size in LEO to 4,316 metric tons/year further narrows the cost difference. Minimum development and transportation of infrastructure costs of 30 to 60 billion dollars are estimated. The development cost estimate does not include the SDV or base lander orbital transfer vehicle (OTV), and includes only 50 percent of the minimum surface base development costs. If the government absorbs this 30 to 60 billion up front capital cost, and does not require payback, oxygen delivery to LEO may be profitable, particularly for the large market case.

Author

Cost Effectiveness; Lunar Resources; Propellants; Space Manufacturing; Space Transportation; Spacecraft Propulsion

19940004538 Utah State Univ., Logan, UT, USA

Lunar shuttle

Voyer, P.; Garcia, M.; Higham, D.; Spackman, D.; Garcia, J.; Chapman, T.; Cook, M.; Jelke, J.; Slingerland, G.; Anderson, K., et al.; USRA, NASA(USRA University Advanced Design Program Fifth Annual Summer Conference; JAN 1, 1989; In English; 1 functional color page; No Copyright; Avail: CASI; A01, Hardcopy; 1 functional color page

Current plans for the extension of human presence into the solar system include the establishment of a permanently occupied base on the Moon for use as a source of raw materials, a transportation node, a facility for the fabrication and launch of elements of the space exploration infrastructure, and a base for scientific investigation and astronomical observatories. All of the aforementioned uses of a lunar base foresee the requirement for a lunar shuttle to operate from the lunar surface to one or more orbiting space stations located in low lunar orbits (LLO). The Utah State University lunar shuttle design is baslined for implementation after a mature lunar base has been established. The shuttle is designed to operate between the lunar base and a space station located in a 400-km-altitude orbit. This orbit was chosen with reference to Apollo experience, which has

indicated that very low orbits, on the order of 100-km, may be unstable over periods of many months. After a thorough investigation of the anticipated needs and production capabilities of a lunar base, several design requirements were placed upon the shuttle. These requirements are (1) maximum use of lunar-derived propellant; (2) modularity and payload versatility; (3) two-way transport of 25-metric-ton cargo; (4) human transport capability; (5) satellite servicing; and (6) 3000-kg mass budget.
Author (revised)
Lunar Orbiter; Lunar Orbits; Lunar Resources; Lunar Spacecraft; Rocket Propellants; Spacecraft Design

19940004528 North Dakota Univ., Grand Forks, ND, USA
Lunar mining equipment
Bekkedahl, S.; Breidenbach, T.; Brown, M.; Francis, C.; Freeman, J.; Scharnott, M.; Thon, R.; USRA, NASA(USRA University Advanced Design Program Fifth Annual Summer Conference; JAN 1, 1989; In English; 1 functional color page; No Copyright; Avail: CASI; A02, Hardcopy; 1 functional color page

This document contains preliminary concepts for mining and beneficiation of lunar regolith from a 50 metric ton/day mine. Assumptions for the design are outlined below. Lunar regolith is the material to be mined. Since it is already a fine-grained material, the two steps of crushing and breakup from a rock surface are eliminated. The size of the operation was set at 50 metric tons of regolith/day for a three-year period. Operations will occur around the clock to make most efficient use of equipment, thus we assume 24 hr/day. For simplicity we have assumed that the lunar regolith has a uniform density of 1.68 and that it can be mined to a depth of 6 m. No research was done on power supply or distribution. It was left to others to consider the various trade-offs between nuclear and solar power and to design the needed utility system.
Author (revised)
Lunar Mining; Lunar Resources; Lunar Rocks; Regolith

19940004521 Georgia Inst. of Tech., Atlanta, GA, USA
Lunar deep drill apparatus
USRA, NASA(USRA University Advanced Design Program Fifth Annual Summer Conference; JAN 1, 1989; In English; 1 functional color page; No Copyright; Avail: CASI; A01, Hardcopy; 1 functional color page

Proposed as a baseline configuration, this rotary drill apparatus is designed to produce 100-mm diameter holes in the lunar surface at depths up to 50 meters. The drill is intended to acquire samples for scientific analysis, mineral resource location, calibration of electronic exploration devices, and foundation analysis at construction sites. It is also intended to prepare holes for emplacement of scientific instruments, the setting of structural anchors, and explosive methods in excavation and mining activities. Defined as a deep drill because of the modular drill string, it incorporates an automatic rod changer. The apparatus is teleoperated from a remote location, such as earth, utilizing supervisory control techniques. It is thus suitable for unmanned and man-tended operation. Proven terrestrial drilling technology is used to the extent it is compatible with the lunar environment. Augers and drive tubes form holes in the regolith and may be used to acquire loose samples. An inertial cutting removal system operates intermittently while rock core drilling is in progress. The apparatus is carried to the work site by a three-legged mobile platform which also provides a 2-meter feed along the hole centerline, an off-hole movement of approximately .5 meters, an angular alignment of up to 20 deg. from gravity vertical, and other dexterity required in handling rods and samples. The technology can also be applied using other carriers which incorporate similar motion capabilities. The apparatus also includes storage racks for augers, rods, and ancillary devices such as the foot-plate that holds the down-hole tooling during rod changing operations.
Derived from text
Core Sampling; Drilling; Drills; Lunar Excavation Equipment; Lunar Surface Vehicles

19940004517 Colorado Univ., Boulder, CO, USA
Cislunar space infrastructure: Lunar technologies
Faller, W.; Hoehn, A.; Johnson, S.; Moos, P.; Wiltberger, N.; USRA, NASA(USRA University Advanced Design Program Fifth Annual Summer Conference; JAN 1, 1989; In English; 1 functional color page; No Copyright; Avail: CASI; A03, Hardcopy; 1 functional color page

Continuing its emphasis on the creation of a cisluar infrastructure as an appropriate and cost-effective method of space exploration and development, the University of Colorado explores the technologies necessary for the creation of such an infrastructure, namely (1) automation and robotics; (2) life support systems; (3) fluid management; (4) propulsion; and (5) rotating technologes. The technological focal point is on the development of automated and robotic systems for the

implementation of a Lunar Oasis produced by automation and robotics (LOARS). Under direction from the NASA Office of Exploration, automation and robotics have been extensively utilized as an initiating stage in the return to the Moon. A pair of autonomous rovers, modular in design and built from interchangeable and specialized components, is proposed. Utilizing a 'buddy system', these rovers will be able to support each other and to enhance their individual capabilities. One rover primarily explores and maps while the second rover tests the feasibility of various materials-processing techniques. The automated missions emphasize availability and potential uses of lunar resources and the deployment and operations of the LOAR program. An experimental bio-volume is put into place as the precursor to a Lunar Environmentally Controlled Life Support System. The bio-volume will determine the reproduction, growth and production characteristics of various life forms housed on the lunar surface. Physiochemical regenerative technologies and stored resources will be used to buffer biological disturbances of the bio-volume environment. The in situ lunar resources will be both tested and used within this bio-volume. Second phase development on the lunar surface calls for manned operations. Repairs and reconfiguration of the initial framework will ensue. An autonomously initiated, manned Lunar Oasis can become an essential component of the USA space program. The Lunar Oasis will provide support to science, technology, and commerce. It will enable more cost-effective space exploration to the planets and beyond.
Author
Cislunar Space; Fluid Management; Life Support Systems; Lunar Bases; Lunar Exploration; Lunar Resources; Lunar Roving Vehicles; Robotics; Space Habitats; Spacecraft Propulsion

19940004271 Colorado School of Mines, Golden, CO, USA
Lunar construction/mining equipment
Ozdemir, Levent; Colorado Univ., Second Annual Symposium; JAN 1, 1990; In English; No Copyright; Avail: CASI; A03, Hardcopy

For centuries, mining has utilized drill and blast as the primary method of rock excavation. Although this technique has undergone significant improvements, it still remains a cyclic, labor intensive operation with inherent safety hazards. Other drawbacks include damage to the surrounding ground, creation of blast vibrations, rough excavation walls resulting in increased ventilation requirements, and the lack of selective mining ability. Perhaps the most important shortcoming of drill and blast is that it is not conducive to full implementation of automation or robotics technologies. Numerous attempts have been made in the past to automate drill and blast operations to remove personnel from the hazardous work environment. Although most of the concepts devised look promising on paper, none of them was found workable on a sustained production basis. In particular, the problem of serious damage to equipment during the blasting cycle could not be resolved regardless of the amount of charge used in excavation. Since drill and blast is not capable of meeting the requirements of a fully automated rock fragmentation method, its role is bound to gradually decrease. Mechanical excavation, in contrast, is highly suitable to automation because it is a continuous process and does not involve any explosives. Many of the basic principles and trends controlling the design of an earth-based mechanical excavator will hold in an extraterrestrial environment such as on the lunar surface. However, the economic and physical limitations for transporting materials to space will require major rethinking of these machines. In concept, then, a lunar mechanical excavator will look and perform significantly different from one designed for use here on earth. This viewgraph presentation gives an overview of such mechanical excavator systems.
Author (revised)
Boring Machines; Excavation; Lunar Construction Equipment; Lunar Excavation Equipment; Lunar Mining

19940004269 Colorado Univ., Boulder, CO, USA
Extraterrestrial engineering
Sture, Stein; Ko, Hon-Yim; Perkins, Steven W.; Popiel, Stephanie; Second Annual Symposium; JAN 1, 1990; In English; No Copyright; Avail: CASI; A03, Hardcopy

The focus of this viewgraph presentation is on the development of technology needed for constructing and maintaining outposts and bases on the moon. This includes characterizing the mechanical properties of lunar soils (regolith), developing analytical models of lunar soil, analyzing space system structure-soil interactions, designing foundation and support systems for constructed facilities, simulating and testing foundation/support designs in geo-technical centrifuge, and modifying in-situ materials for construction purposes.
Derived from text
Extraterrestrial Environments; Lunar Bases; Lunar Excavation Equipment; Lunar Soil; Mechanical Properties; Structural Engineering

19940003301 Eagle Engineering, Inc., Houston, TX, USA

Sketches for the National Commission on Space

Sep 1, 1985; In English

Contract(s)/Grant(s): NAS9-17878

Report No.(s): NASA-CR-188263; NAS 1.26:188263; EEI-85-107; No Copyright; Avail: CASI; A06, Hardcopy

This is a collection of 40 sketches covering a Periodic Space Station (PSS) in its different stages including low Earth orbit (LEO), and details of lunar and Mars spacebases, including transportation, cargo vehicles, habitation modules, greenhouses, and construction materials. Configurations of surface plants for the production of O2 on Mars, Phobos, and the Earth's moon are also shown. Detailed descriptions accompany each sketch.

CASI

Extraterrestrial Resources; Interplanetary Transfer Orbits; Mars (Planet); Moon; Phobos; Planetary Bases; Space Stations

19930074819 Old Dominion Univ., Norfolk, VA, USA

Mars oxygen processor demonstration project

USRA, Agenda of the Third Annual Summer Conference, NASA(USRA University Advanced Design Program; JAN 1, 1987; In English; No Copyright; Avail: CASI; A01, Hardcopy

The objective of the 1986-87 space system design project was to design and procure the hardware necessary to demonstrate continuous production of oxygen from simulated Mars atmosphere. The work was an extension of a design project that was started during the previous academic year. A yttria stabilized, zirconium oxide electrochemical cell was operated in a controlled temperature environment to separate oxygen, which has been dissociated thermally from the primary constituent of the Martian atmosphere-carbon dioxide. This system was perhaps the most primitive chemical processor that could be developed as part of an extraterrestrial chemicals production demonstration project. The course began in January, 1987. Speakers were brought in to discuss the Martian environment, concepts for resource extraction and system requirements for an autonomous chemical processor. The class simultaneously refined its work plans, which were developed as part of the fall semester senior seminar course. Hardware was purchased using funds provided by the Planetary Society. However, the key hardware element was the zirconia cell. Development of that type of cell is beyond the capabilities of undergraduate engineering students. Consequently, the cell was borrowed. The design elements emphasized in this project were as follows: (1) System reliability analysis; (2) Autonomous operation and control; (3) High temperature seal design; (4) Design for minimum thermal stress; (5) Passive shut down environmental control; (6) Integrated instrumentation concepts; (7) Identification of extraterrestrial resources; (8) Evaluation of chemical processor concepts; (9) Integrated hardware design; and (10) Finite element analysis.

Derived from text

Automatic Control; Electrochemical Cells; Extraterrestrial Resources; Mars Atmosphere; Mars Environment; Oxygen; Temperature Control

19930074811 Houston Univ., TX, USA

Project LEAP (lunar ecosystem and architectural prototype)

USRA, Agenda of the Third Annual Summer Conference, NASA(USRA University Advanced Design Program; JAN 1, 1987; In English; No Copyright; Avail: CASI; A01, Hardcopy

University of Houston's The Sasakawa International Center for Space Architecture is pursuing research and design studies for permanent lunar settlements. One such study, Project LEAP, has produced staged growth concepts for a habitat to support lunar mining operations. The principal purpose assumed for the development is to produce liquid oxygen and hydrogen propellant for Advanced Space Transportation System and future orbital infrastructure consumption use. The base has been designed to grow over a ten year period from an initial six-person crew occupancy to an advanced facility capable of accommodating as many as one hundred and fifty people. Evolutionary growth stages would rely increasingly upon acquisition, processing and utilization of lunar materials to optimize self-sufficiency. Project LEAP's study objectives have sought to identify incremental site development and facility requirements; to identify candidate site development and construction options; to propose site layout and habitat design/growth concepts; and to survey requirements to achieve a high level of self-sufficiency. As an ongoing research and development program, the project has evolved from research and data collection for concept and design through three dimensional solids computer modeling. The University of Houston project is funded through the advanced Missions Office of the Johnson Space Center. Project representatives are guests of the Johnson Space Center at this conference.

Author

Computerized Simulation; Habitats; Lunar Mining; Prototypes; Space Transportation System; Three Dimensional Models

19930074544 Florida Agricultural and Mechanical Univ., Tallahassee, FL, USA

Design of a lunar transportation system

USRA, NASA(USRA University Advanced Design Program Fourth Annual Summer Conference; JAN 1, 1988; In English; 1 functional color page; No Copyright; Avail: CASI; A01, Hardcopy; 1 functional color page

The establishment of lunar bases is the next logical step in the exploration of space. Permanent lunar bases will support scientific investigation, the industrialization of space, and the development of self-sufficiency on the Moon. Scientific investigation and research and development would lead to applications utilizing lunar material resources. By utilizing these resources, the industrialization of space can become a reality. The above two factors coupled with the development of key and enabling technologies would lead to achievement of self-sufficiency of the lunar base. Attention was focused on specific design(s) to be pursued during subsequent stages in advanced courses. Some of the objectives in the project included: (1) minimizing the transportation of construction material and fuel from earth, or maximizing the use of the lunar material; (2) use of novel materials and light weight structures; (3) use of new manufacturing methods and technology such as magnetically levitated, or superconducting materials; and (4) innovative concepts of effectively utilizing the exotic lunar conditions, i.e. high thermal gradients, lack of atmosphere, zero wind forces, and lower gravity, etc.

Derived from text

Lunar Bases; Lunar Resources; Manufacturing; Space Commercialization; Space Industrialization; Space Transportation System

19930074399 NASA Lyndon B. Johnson Space Center, Houston, TX, USA

In-Situ Resource Utilization (ISRU): Surface systems program area of the exploration technology program

Mckay, David S.; NASA, Washington, SSTAC(ARTS Review of the Draft Integrated Technology Plan (ITP). Volume 4: Materials and Structures 21 p (SEE N93-71834 13-81); JAN 1, 1991; In English; No Copyright; Avail: CASI; A03, Hardcopy

The topics presented are covered in viewgraph form and include the following: (1) utilization of Lunar and Mars resources; (2) oxygen - an example of cost savings; (3) In Space Resource Utilization (ISRU); (4) basic resource processing methods; (5) planetary mining; (6) raw materials preparation; (7) validation, testbeds, and flight experiments; (8) mission readiness schedule; and (9) ISRU budget guideline.

CASI

Cost Reduction; Lunar Resources; Mars (Planet); Mining; Mission Planning; Schedules

19930074390 NASA Lyndon B. Johnson Space Center, Houston, TX, USA, Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA

Space science technology: In-situ science. Sample Acquisition, Analysis, and Preservation Project summary

Aaron, Kim; NASA, Washington, SSTAC(ARTS Review of the Draft Integrated Technology Plan (ITP). Volume 4: Materials and Structures 15 p (SEE N93-71834 13-81); JAN 1, 1991; In English; No Copyright; Avail: CASI; A03, Hardcopy

The Sample Acquisition, Analysis, and Preservation Project is summarized in outline and graphic form. The objective of the project is to develop component and system level technology to enable the unmanned collection, analysis and preservation of physical, chemical and mineralogical data from the surface of planetary bodies. Technology needs and challenges are identified and specific objectives are described.

CASI

Extraterrestrial Resources; Planetary Surfaces; Sampling

19930073140 NASA Ames Research Center, Moffett Field, CA, USA

Mars Human Exploration Science Strategy. Report of the Mars Science Workshop

Stoker, C. R., compiler; Mckay, C. P., compiler; Haberle, R. M., compiler; Andersen, D. T., compiler; JAN 1, 1989; In English, 30-31 Aug. 1989, Moffett Field, CA, USA

Report No.(s): NASA-TM-108094; NAS 1.15:108094; No Copyright; Avail: CASI; A04, Hardcopy

The scientific objectives of Mars exploration can be framed within two themes: (1) planetary evolution, climate change, and life; and (2) human habitability. Within these themes, the exploration objectives for the fields of exobiology, climate and atmosphere, and geology are examined. Human exploration will proceed in four major phases: (1) precursor missions to obtain environmental knowledge necessary for human exploration; (2) emplacement phase missions including the first few human missions in which humans will explore the local area of the landing site; (3) consolidation phase missions which will begin permanent base build up and crews will be capable of detailed exploration over regional scales; and (4) utilization phase in which a continuously occupied permanent Mars base exists, and humans will be capable of detailed global exploration of the

Martian surface. Site selection for human missions to Mars must consider the 30+ year time frame of these four phases. It is suggested that operations in the first two phases be focused in the regional area containing the Coprates Quadrangle and adjacent areas. The key question for human habitability of Mars is whether Martian resources can be used to support a permanent human presence. Evaluating the location and accessibility of key resources, particularly water, will be an important science objective for all phases of exploration. The phases of human exploration differ primarily in the range and capabilities of human mobility. In the emplacement phase, an unpressurized rover will be used and the range will be limited by the duration of the space suit life support system. In the consolidation phase, mobility will be via a pressurized all-terrain vehicle capable of two week expeditions from the base site. In the utilization phase, humans will be capable of 90 day long expeditions to any point on the surface of Mars using a suborbital rocket equipped with habitat, lab, and return vehicle. Because of human mobility limitations, it is important to extend the range and duration of exploration in all phases by using teleoperated rover vehicles. Local teleoperated rovers operated within line of sight of the landing site can be used in the emplacement phase to extend human exploration range to the 100 km scale. Satellite controlled teleoperated rovers will help humans to explore Mars in the later phases.
L.R.R.
Extraterrestrial Resources; Manned Mars Missions; Manned Space Flight; Mars (Planet); Mars Atmosphere; Mission Planning; Planetary Evolution; Planetary Geology; Space Exploration

19930058188 NASA, Washington, DC, USA
Apollo 11 ilmenite revisited
Cameron, E. N.; In: Engineering, construction, and operations in space - III: Space '92; Proceedings of the 3rd International Conference, Denver, CO, May 31-June 4, 1992. Vol. 2 (A93-41976 17-12); 1992; In English
Contract(s)/Grant(s): NAGW-975; Copyright; Avail: Other Sources

An account is given of the problems associated with beneficiation of the high-Ti regolith represented by Apollo 11's ilmenite sample. Magnetic and electrostatic separation, combined with sizing to reject all but the best fractions of the lunar regolith, will be essential; the production of high-grade ilmenite concentrates on the scale required for lunar oxygen production may still, however, be unachievable. These findings suggest that ilmenite production directly from high-Ti-content basalt may be a superior alternative.
AIAA
Apollo 11 Flight; Ilmenite; Lunar Resources; Lunar Surface; Regolith

19930058084 NASA, Washington, DC, USA
Vacuum melting and mechanical testing of simulated lunar glasses
Carsley, J. E.; Blacic, J. D.; Pletka, B. J.; In: Engineering, construction, and operations in space III: Space '92; Proceedings of the 3rd International Conference, Denver, CO, May 31-June 4, 1992. Vol. 2 (A93-41976 17-12); 1992; In English
Contract(s)/Grant(s): NASW-4486; Copyright; Avail: Other Sources

Lunar silicate glasses may possess superior mechanical properties compared to terrestrial glasses because the anhydrous lunar environment should prevent hydrolytic weakening of the strong Si-O bonds. This hypothesis was tested by melting, solidifying, and determining the fracture toughness of simulated mare and highlands composition glasses in a high vacuum chamber. The fracture toughness, K(IC), of the resulting glasses was obtained via microindentation techniques. K(IC) increased as the testing environment was changed from air to a vacuum of 10 exp -7 torr. However, this increase in toughness may not result solely from a reduction in the hydrolytic weakening effect; the vacuum-melting process produced both the formation of spinel crystallites on the surfaces of the glass samples and significant changes in the compositions which may have contributed to the improved K(IC).
AIAA
Lunar Environment; Lunar Resources; Mechanical Properties; Silica Glass; Stress Corrosion Cracking; Vacuum Melting

19930058083 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Sintering of lunar glass and basalt
Allen, Carlton C.; Hines, Joy A.; Mckay, David S.; Morris, Richard V.; In: Engineering, construction, and operations in space III: Space '92; Proceedings of the 3rd International Conference, Denver, CO, May 31-June 4, 1992. Vol. 2 (A93-41976 17-12); 1992; In English; Copyright; Avail: Other Sources

Experiments were conducted to study the sintering behavior of glass and basalt lunar soil simulants. The degree of sintering was assessed by compressive strength testing and microanalysis. Both crushed glass and basalt sinter significantly

at 1000 C, with the basalt attaining its maximum strength at 1100 C. Initial sintering occurs in less than 15 min, and the degree of sintering does not increase significantly with time after about 30 min. Glass sinters more readily than crystalline material. Sintering and devitrification both occur on a time scale of minutes in the heated glass, but sintering is apparently more rapid. The processes of sintering and oxygen release by hydrogen reduction of lunar soil are synergistic, and could be combined to produce two extremely useful products at a lunar base.
AIAA
Basalt; Construction Materials; Glass; Lunar Bases; Lunar Resources; Sintering

19930058081 NASA, Washington, DC, USA
Design criteria for an underground lunar mine
Siekmeier, John A.; In: Engineering, construction, and operations in space - III: Space '92; Proceedings of the 3rd International Conference, Denver, CO, May 31-June 4, 1992. Vol. 1 (A93-41976 17-12); 1992; In English; Copyright; Avail: Other Sources

Underground excavation and construction techniques have been well developed terrestrially and provide an attractive option for lunar mining and habitat construction. The lunar mine, processing facilities and habitats could be located beneath the lunar surface in basaltic rock that would protect the crew and equipment from the hazardous surface environment. A terrestrial-like atmosphere would be created within the underground structures allowing more conventional technologies to be utilized. In addition, the basalt would likely contain higher quality mineral deposits than the regolith (lunar soil) since the minerals in the regolith have been degraded by meteorite bombardment. The conditions that would affect the design of an underground lunar mine are described and a lunar rock mass rated to assess its quality using terrestrial rock mass classification systems. Design criteria are established and a construction scenario proposed. Parameters having the greatest effect on stability are identified based on distinct element computer modeling and terrestrial experience.
AIAA
Lunar Bases; Lunar Geology; Lunar Mining; Mines (Excavations); Space Habitats

19930058078 NASA, Washington, DC, USA
Transfer of terrestrial technology for lunar mining
Hall, Robert A.; Green, Patricia A.; In: Engineering, construction, and operations in space - III: Space '92; Proceedings of the 3rd International Conference, Denver, CO, May 31-June 4, 1992. Vol. 1 (A93-41976 17-12); 1992; In English; Copyright; Avail: Other Sources

The functions, operational procedures, and major items of equipment that comprise the terrestrial mining process are characterized. These data are used to synthesize a similar activity on the lunar surface. Functions, operations, and types of equipment that can be suitably transferred to lunar operation are identified. Shortfalls, enhancements, and technology development needs are described. The lunar mining process and what is required to adapt terrestrial equipment are highlighted. It is concluded that translation of terrestrial mining equipment and operational processes to perform similar functions on the lunar surface is practical. Adequate attention must be given to the harsh environment and logistical constraints of the lunar setting. By using earth-based equipment as a forcing function, near- and long-term benefits are derived (i.e., improved terrestrial mining in the near term vis-a-vis commercial production of helium-3 in the long term.
AIAA
Lunar Excavation Equipment; Lunar Mining; Technology Transfer

19930058071 NASA Ames Research Center, Moffett Field, CA, USA
Mobile continuous lunar excavation
Paterson, John L.; In: Engineering, construction, and operations in space - III: Space '92; Proceedings of the 3rd International Conference, Denver, CO, May 31-June 4, 1992. Vol. 1 (A93-41976 17-12); 1992; In English; Copyright; Avail: Other Sources

A novel approach to the concept of lunar mining and the use of in situ oxygen, metallics, and ceramics is presented. The EVA time required to set up, relocate, and maintain equipment, as well as the cost per pound of shipping the mining and processing equipment to the moon are considered. The proposed soil fracturing/loading mechanisms are all based loosely on using the Apollo Lunar Roving Vehicle (LRV) Frame. All use motor driven tracks for mobility in the forward/reverse and left/right direction. All mechanisms employ the concept of rototillers which are attached to a gantry which, through the use of motor-driven lead screws, provide the rototillers with an up/down capability. A self-reactant excavator, a local mass enhanced excavator, and a soil reactant excavator are illustrated.
AIAA
Lunar Excavation Equipment; Lunar Mining; Lunar Soil; Systems Engineering

19930058070 NASA Lyndon B. Johnson Space Center, Houston, TX, USA

Beneficiation of lunar rocks and regolith - Concepts and difficulties

Taylor, Lawrence A.; Mckay, David S.; In: Engineering, construction, and operations in space - III: Space '92; Proceedings of the 3rd International Conference, Denver, CO, May 31-June 4, 1992. Vol. 1 (A93-41976 17-12); 1992; In English
Contract(s)/Grant(s): NAG9-409; Copyright; Avail: Other Sources

Some of the inherent differences between lunar rocks and the finer portion of the regolith, the soil, are discussed. A brief outline of the formation of lunar soil is presented. Beneficiation of rocks vs regolith for the production of an ilmenite feedstock is addressed in particular, but the concepts and principles considered are applicable to other situations as well. The overall systems design must take the range of available feedstocks into account. Decisions on design that will influence feedstock requirements must be made.

AIAA

Lunar Mining; Lunar Resources; Lunar Rocks; Lunar Soil; Regolith

19930058043 NASA Lyndon B. Johnson Space Center, Houston, TX, USA

The feasibility of processes for the production of oxygen on the moon

Taylor, Lawrence A.; Carrier, W. D., III; In: Engineering, construction, and operations in space - III: Space '92; Proceedings of the 3rd International Conference, Denver, CO, May 31-June 4, 1992. Vol. 1 (A93-41976 17-12); 1992; In English
Contract(s)/Grant(s): NAG9-409; Copyright; Avail: Other Sources

An evaluation of the perceived feasibility of 20 different processs for the production of oxygen on the moon is presented. Many of them are largely untested and/or extremely complicated and difficult to implement. Simplicity, low energy, easily attainable feedstock, and resupply mass are the principal criteria for the processes that will ultimately be selected for the initial production of oxygen on the moon. An evaluation of the 20 processes resulted in a ranking according to overall feasibility. The eight processes considered to be the most likely candidates, at this time, for oxygen production on the moon are: ilmenite reduction of H2, CO2, and CH4; glass reduction with H2; molten silicate electrolysis; fluxed molten silicate electrolysis; vapor pyrolysis; and ion plasma pyrolysis.

AIAA

Ilmenite; Liquid Oxygen; Lunar Resources; Oxygen Production; Space Processing

19930058040 NASA, Washington, DC, USA

Materials and structure synergistic with in-space materials utilization

Ramohalli, Kumar; Shadman, Farhang; Sridhar, K. R.; In: Engineering, construction, and operations in space - III: Space '92; Proceedings of the 3rd International Conference, Denver, CO, May 31-June 4, 1992. Vol. 1 (A93-41976 17-12); 1992; In English; Copyright; Avail: Other Sources

The significant advances made recently toward actual hardware realizations of various concepts for the application of in-space materials utilization (ISMU) are demonstrated. The overall plan for taking innovative concepts through technical feasibility, small-scale tests, scale-up, computer modeling, and larger-scale execution is outlined. Two specific fields of endeavor are surveyed: one has direct applications to construction on the moon, while the other has more basic implications, in addition to the practical aspects of lunar colonies. Several fundamental scientific advances made in the characterization of the physical and chemical processes that need to be elucidated for any intelligent application of the ISMU concepts in future space missions are described. A rigorous quantitative technique for the unambiguous evaluation of various components and component technology that form any space (or terrestrial mission) is also described.

AIAA

Extraterrestrial Resources; Oxygen Production; Recycling; Resources Management

19930058036 NASA, Washington, DC, USA

Steady state composition with low Fe(2+) concentrations for efficient O2 production by 'magma' electrolysis of lunar soils

Haskin, Larry A.; Colson, Russell O.; In: Engineering, construction, and operations in space - III: Space '92; Proceedings of the 3rd International Conference, Denver, CO, May 31-June 4, 1992. Vol. 1 (A93-41976 17-12); 1992; In English; Copyright; Avail: Other Sources

Parameters are estimated for a hypothetical, well stirred, continuous-feed electrolytic cell that converts 20 percent of a lunar soil feedstock to O2 gas, 26 percent to Fe-Si metal, 13 percent to spinel, and 41 percent to slag. Advantages of a molten Fe-Si cathode for trapping metal on reduction, a relatively conductive steady-state composition in equilibrium with spinel (a

proposed container material), and close electrodes (less than 1 cm cathode-anode distance) are discussed. To produce 1 ton of O2, about 6 MHW of energy are required for the electrolysis and IR heating within the melt, and another about 6 MHW may be introduced as waste heat through internal resistance of the electrodes. Thus, to produce 1 ton of O2 per 24 hours, about 0.5 MW of power delivered to the cell would be required.
AIAA
Chemical Composition; Electrolysis; Lunar Resources; Lunar Soil; Oxygen Production; Steady State

19930058035 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
A modified sulfate process to lunar oxygen
Sullivan, Thomas A.; In: Engineering, construction, and operations in space - III: Space '92; Proceedings of the 3rd International Conference, Denver, CO, May 31-June 4, 1992. Vol. 1 (A93-41976 17-12); 1992; In English; Copyright; Avail: Other Sources

A modified sulfate process which produces oxygen from iron oxide-bearing minerals in lunar soil is under development. Reaction rates of ilmenite in varying strength sulfuric acid have been determined. Quantitative conversion of ilmenite to ferrous sulfate was observed over a range of temperatures and concentrations. Data has also been developed on the calcination of by-product sulfates. System engineering for overall operability and simplicity has begun, suggesting that a process separating the digestion and sulfate dissolution steps may offer an optimum process.
AIAA
Ilmenite; Lunar Resources; Lunar Soil; Oxygen Production; Sulfates

19930058034 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Lunar oxygen - The reduction of glass by hydrogen
Allen, Carlton C.; Mckay, David S.; Morris, Richard V.; In: Engineering, construction, and operations in space - III: Space '92; Proceedings of the 3rd International Conference, Denver, CO, May 31-June 4, 1992. Vol. 1 (A93-41976 17-12); 1992; In English; Copyright; Avail: Other Sources

The direct reduction of volcanic glass by hydrogen has been proposed as a method of extracting oxygen from the lunar soil. Experiments using lunar simulant glasses reacted with flowing hydrogen gas have demonstrated reduction at temperatures from 1000 to 1200 C. For melted samples ferrous iron was reduced to the metal, which formed large crystals at the expense of the glass. Samples held below the melting point rapidly devitrified, and iron was formed from submicrometer crystals of ilmenite and pyroxene. Weight losses of 3.6 - 4.5 percent, depending on glass composition, were achieved in 3 hours at 1100 C. A lunar oxygen plant operating at this efficiency and utilizing Apollo 17 orange glass as a feedstock could produce 50 kg of oxygen per ton of soil. The processes of reduction and sintering of lunar soil are synergistic, and could be combined to produce both oxygen and construction material at a moon base.
AIAA
Glass; Lunar Resources; Lunar Soil; Oxygen Production; Reduction (Chemistry)

19930058032 NASA, Washington, DC, USA
Environmental aspects of lunar helium-3 mining
Kulcinski, G. L.; Cameron, E. N.; Carrier, W. D., III; Schmitt, H. H.; In: Engineering, construction, and operations in space - III: Space '92; Proceedings of the 3rd International Conference, Denver, CO, May 31-June 4, 1992. Vol. 1 (A93-41976 17-12); 1992; In English; Copyright; Avail: Other Sources

Three potential detrimental effects of lunar He-3 mining have been identified; visual changes, atmospheric contamination, and solid waste disposal. The removal of small craters (less than 20 m diameter) and the change in the albedo of the surface may cause a slight darkening of the regolith. However, it is not expected that this change will be visible from the earth even with powerful telescopes. The release of lunar volatile gases and their effect on the lunar 'atmosphere' is expected to be both local and temporary (on the order of a few weeks from the time of release). The solution to solid waste disposal is to recycle as much as possible and to bury the nonrecyclable waste. The lack of wind and water means that the waste will stay localized indefinitely and cause no contamination of the environment. The positive benefits of using lunar He-3 in terrestrial fusion plants far outweigh the detrimental effects of mining. The reduction in radioactive waste, greenhouse and acid gases, and the reduction in terrestrial mining for fossil fuels could have a major impact on the quality of life in the 21st century.
AIAA
Air Pollution; Helium Isotopes; Lunar Atmosphere; Lunar Mining; Solid Wastes

19930058026 NASA, Washington, DC, USA
In-situ release of solar wind gases from lunar soil
Wittenberg, Layton J.; In: Engineering, construction, and operations in space - III: Space '92; Proceedings of the 3rd International Conference, Denver, CO, May 31-June 4, 1992. Vol. 1 (A93-41976 17-12); 1992; In English; Copyright; Avail: Other Sources

A concept is described which has the potential to perform the in situ heating of the lunar regolith in order to release the solar wind gases. The poor thermal conductivity of the lunar soil is increased approximately 100-fold by the introduction of an artificial hydrogen atmosphere at 1 atm pressure enclosed in an inflatable structure. The leakage rate of H2 through the soil is minimal because of the close-packed nature of the soil and the design and operation of the facility.
AIAA
Lunar Resources; Lunar Soil; Regolith; Solar Wind; Thermal Conductivity

19930058025 NASA, Washington, DC, USA
Structural materials from lunar simulants through thermal liquefaction
Desai, Chandra S.; Girdner, Kirsten; In: Engineering, construction, and operations in space - III: Space '92; Proceedings of the 3rd International Conference, Denver, CO, May 31-June 4, 1992. Vol. 1 (A93-41976 17-12); 1992; In English; Copyright; Avail: Other Sources

Thermal liquefaction that allows development of intermediate ceramic composites from a lunar simulant with various admixtures is used to develop structural materials for construction on the moon. Bending and compressive properties of resulting composites are obtained from laboratory tests and evaluated with respect to the use of three different types and fibers.
AIAA
Construction Materials; Liquefaction; Lunar Resources; Lunar Soil

19930058009 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
The challenge of constraining mass for planetary construction
Connolly, John F.; In: Engineering, construction, and operations in space - III: Space '92; Proceedings of the 3rd International Conference, Denver, CO, May 31-June 4, 1992. Vol. 1 (A93-41976 17-12); 1992; In English; Copyright; Avail: Other Sources

The challenges facing the designers of planetary construction machinery, construction methods, and indigenous construction materials are examined. Machinery and methods are studied from the perspective of mass and power constraints, and indigenous material use is viewed from a technical and mass-benefit vantage point. It is argued that the value of an object on the lunar surface is inexorably linked to its mass due to the high cost of space transportation. Payload capabilities and delivery costs for selected U.S. launch vehicles are given in tabular form. Power vs mass for selected construction vehicles and lunar surface hardware is illustrated. It is concluded that construction materials must be evaluated on their mass-cost of production vs the mass of equal materials delivered direct. Machinery must be designed to be both mass and power efficient, with a premium on performance per unit of mass and power.
AIAA
Construction; Lunar Bases; Lunar Resources; Space Habitats

19930057979 NASA Lyndon B. Johnson Space Center, Houston, TX, USA, NASA, Washington, DC, USA
Engineering, construction, and operations in space - III: Space '92; Proceedings of the 3rd International Conference, Denver, CO, May 31-June 4, 1992. Vols. 1 & 2
Sadeh, Willy Z., editor; Sture, Stein, editor; Miller, Russell J., editor; 1992; In English; See also A93-41977 through A93-42185; Copyright; Avail: Other Sources

The present volume on engineering, construction, and operations in space discusses surface structures on the moon and Mars, surface equipment, construction, and transportation on the moon and Mars, in situ materials use and processing, and space energy. Attention is given to such orbital structures as LEO and the space station, space mining and excavation, space materials, space automation and robotics, and space life support systems. Topics addressed include lunar-based astronomy, space systems integration, terrestrial support for space functions, and space education. Also discussed are space plans, policy, and history, space science and engineering, geoengineering and space exploration, and the construction and development of a human habitat on Mars.
AIAA
Conferences; Construction Materials; Design Analysis; Extraterrestrial Resources; Lunar Bases; Lunar Resources; Lunar Soil; Mars Environment; Orbital Assembly; Planetary Bases; Power Supplies; Space Bases; Structural Design

19930048411 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Production of oxygen on the moon - Which processes are best and why
Taylor, Lawrence A.; Carrier, W. D., III; AIAA Journal; Dec. 1992; ISSN 0001-1452; 30, 12; In English
Contract(s)/Grant(s): NAG9-409; Copyright; Avail: Other Sources
Lunar Resources; Oxygen Production; Pyrolysis; Reduction (Chemistry)

19930046915 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Rover concepts for lunar exploration
Connolly, John F.; Feb 1, 1993; In English; AIAA, AHS, and ASEE, Aerospace Design Conference, Feb. 16-19, 1993, Irvine, CA, USA
Report No.(s): AIAA PAPER 93-0996; Copyright; Avail: Other Sources

The paper describes the requirements and design concepts developed for the First Lunar Outpost (FLO) and the follow-on lunar missions by the Human Planet Surface Project Office at the Johnson Space Center, which include inputs from scientists, technologists, operators, personnel, astronauts, mission designers, and program managers. Particular attention is given to the requirements common to all rover concepts, the precursor robotic missions, the FLO scenario and capabilities, and the FLO evolution.
AIAA
Lunar Exploration; Lunar Resources; Lunar Roving Vehicles; Lunar Surface; Teleoperators

19930034748 NASA, Washington, DC, USA
Lunar magnetic fields - Implications for utilization and resource extraction
Hood, Lon L.; Journal of Geophysical Research; Nov. 25, 1992; ISSN 0148-0227; 97, E11; In English
Contract(s)/Grant(s): NAGW-1881; Copyright; Avail: Other Sources

Numerical simulations are used to show that solar wind ion deflection by strong lunar magnetic anomalies can produce local increases, as well as decreases, in the implantation rate of solar wind hydrogen. Model simulations suggest that the ability of magnetic anomalies to shield the surface from incident ions increases with the angle of incidence and therefore for most particle sources, with selenographic latitude. The possibility that relatively strong anomalies can provide significant protection of materials and men against major solar flare particle events is found to be unlikely.
AIAA
Lunar Crust; Lunar Magnetic Fields; Lunar Resources; Magnetic Anomalies; Mineral Exploration

19930033439 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Planetary science and resource utilization at a lunar outpost - Chemical analytical facility requirements
Taylor, Lawrence A.; In: A lunar-based chemical analysis laboratory (A93-17426 04-51); 1992; In English
Contract(s)/Grant(s): NAG9-62; Copyright; Avail: Other Sources

Unresolved issues of lunar geology are reviewed and the role of a lunar outpost in helping to address them is considered. Plans for in situ resource utilization of lunar materials are examined. Concepts for a lunar outpost are described.
AIAA
Analytical Chemistry; Lunar Bases; Lunar Geology; Lunar Resources

19930029856 NASA, Washington, DC, USA
The engineering of a nuclear thermal landing and ascent vehicle utilizing indigenous Martian propellant
Zubrin, Robert M.; In: Space nuclear power systems; Proceedings of the 8th Symposium, Albuquerque, NM, Jan. 6-10, 1991. Pt. 2 (A93-13751 03-20); 1991; In English; Copyright; Avail: Other Sources

The following paper reports on a design study of a novel space transportation concept known as a ‘NIMF’ (Nuclear rocket using Indigenous Martian Fuel). The NIMF is a ballistic vehicle which obtains its propellant out of the Martian air by compression and liquefaction of atmospheric CO2. This propellant is subsequently used to generate rocket thrust at a specific impulse of 264 s by being heated to high temperature (2800 K) gas in the NIMFs’ nuclear thermal rocket engines. The vehicle is designed to provide surface to orbit and surface to surface transportation, as well as housing, for a crew of three astronauts. It is capable of refueling itself for a flight to its maximum orbit in less than 50 days. The ballistic NIMF has a mass of 44.7 tonnes and, with the assumed 2800 K propellant temperature, is capable of attaining highly energetic (250 km by 34,000 km elliptical) orbits. This allows it to rendezvous with interplanetary transfer vehicles which are only very loosely bound into orbit around Mars. If a propellant temperature of 2000 K is assumed, then low Mars orbit can be attained; while if 3100 K is

assumed, then the ballistic NIMF is capable of injecting itself onto a minimum energy transfer orbit to Earth in a direct ascent from the Martian surface.
AIAA
Extraterrestrial Resources; Manned Mars Missions; Nuclear Propulsion; Nuclear Rocket Engines; Spacecraft Propulsion

19930020428 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Method for producing oxygen from lunar materials
Sullivan, Thomas A., inventor; Jul 13, 1993; In English; See also N92-12079
Patent Info.: Filed 24 Sep. 1991; US-PATENT-5,227,032; US-PATENT-APPL-SN-764581; NASA-CASE-MSC-21759-1; No Copyright; Avail: US Patent and Trademark Office

This invention is related to producing oxygen from lunar or Martian materials, particularly from lunar ilmenite in situ. The process includes producing a slurry of the minerals and hot sulfuric acid, the acid and minerals reacting to form sulfates of the metal. Water is added to the slurry to dissolve the minerals into an aqueous solution, the first aqueous solution is separated from unreacted minerals from the slurry, and the aqueous solution is electrolyzed to produce the metal and oxygen.
Official Gazette of the U.S. Patent and Trademark Office
Electrolysis; Lunar Resources; Lunar Rocks; Lunar Soil; Oxygen Production; Slurries

19930019633 Science Applications International Corp., Albuquerque, NM, USA, Grumman Aerospace Corp., Bethpage, NY, USA
Use of particle beams for lunar prospecting
Toepfer, A. J.; Eppler, D.; Friedlander, A.; Weitz, R.; Lunar and Planetary Inst., Workshop on Advanced Technologies for Planetary Instruments, Part 1; JAN 1, 1993; In English
Contract(s)/Grant(s): DASG60-90-C-0103; No Copyright; Avail: Other Sources

A key issue in choosing the appropriate site for a manned lunar base is the availability of resources, particularly oxygen and hydrogen for the production of water, and ores for the production of fuels and building materials. NASA has proposed two Lunar Scout missions that would orbit the Moon and use, among other instruments, a hard X-ray spectrometer, a neutron spectrometer, and a Ge gamma ray spectrometer to map the lunar surface. This passive instrumentation will have low resolution (tens of kilometers) due to the low signal levels produced by natural radioactivity and the interaction of cosmic rays and the solar wind with the lunar surface. This paper presents the results of a concept definition effort for a neutral particle beam lunar mapper probe. The idea of using particle beam probes to survey asteroids was first proposed by Sagdeev et al., and an ion beam device was fielded on the 1988 Soviet probe to the Mars moon Phobos. During the past five years, significant advances in the technology of neutral particle beams (NPB) have led to a suborbital flight of a neutral hydrogen beam device in the SDIO-sponsored BEAR experiment. An orbital experiment, the Neutral Particle Beam Far Field Optics Experiment (NPB-FOX) is presently in the preliminary design phase. The development of NPB accelerators that are space-operable leads one to consider the utility of these devices for probing the surface of the Moon using gamma ray, X-ray, and optical/UV spectroscopy to locate various elements and compounds. We consider the utility of the NPB-FOX satellite containing a 5-MeV particle beam accelerator as a probe in lunar orbit. Irradiation of the lunar surface by the particle beam will induce secondary and back scattered radiation from the lunar surface to be detected by a sensor that may be co-orbital with or on the particle beam satellite platform, or may be in a separate orbit. The secondary radiation is characteristic of the make-up of the lunar surface. The size of the spot irradiated by the beam is less than 1 km wide along the ground track of the satellite, resulting in the potential for high resolution. The fact that the probe could be placed in polar orbit would result in global coverage of the lunar surface. The orbital particle beam probe could provide the basis for selection of sites for more detailed prospecting by surface rovers.
Author (revised)
Lunar Resources; Lunar Surface; Neutral Beams; Particle Beams; Remote Sensing

19930018791 National Inst. of Standards and Technology, Gaithersburg, MD, USA
Intelligent robots for planetary exploration and construction
Albus, James S.; Arizona Univ., Proceedings of the Lunar Materials Technology Symposium; Feb 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

Robots capable of practical applications in planetary exploration and construction will require realtime sensory-interactive goal-directed control systems. A reference model architecture based on the NIST Real-time Control System (RCS) for real-time intelligent control systems is suggested. RCS partitions the control problem into four basic elements: behavior

generation (or task decomposition), world modeling, sensory processing, and value judgment. It clusters these elements into computational nodes that have responsibility for specific subsystems, and arranges these nodes in hierarchical layers such that each layer has characteristic functionality and timing. Planetary exploration robots should have mobility systems that can safely maneuver over rough surfaces at high speeds. Walking machines and wheeled vehicles with dynamic suspensions are candidates. The technology of sensing and sensory processing has progressed to the point where real-time autonomous path planning and obstacle avoidance behavior is feasible. Map-based navigation systems will support long-range mobility goals and plans. Planetary construction robots must have high strength-to-weight ratios for lifting and positioning tools and materials in six degrees-of-freedom over large working volumes. A new generation of cable-suspended Stewart platform devices and inflatable structures are suggested for lifting and positioning materials and structures, as well as for excavation, grading, and manipulating a variety of tools and construction machinery.
Author (revised)
Automatic Control; Autonomous Navigation; Construction; Lunar Construction Equipment; Lunar Excavation Equipment; Obstacle Avoidance; Positioning Devices (Machinery); Robot Control; Robots; Space Exploration; Trajectory Planning; Walking Machines

19930018789 Lockheed Engineering and Sciences Co., Houston, TX, USA
Assessment of the state of the art in life support environmental control for SEI
Simonds, Charles H.; Noyes, Gary P.; Arizona Univ., Proceedings of the Lunar Materials Technology Symposium; Feb 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

This paper defines the types of technology that would be used in a lunar base for environmental control and life support system and how it might relate to in situ materials utilization (ISMU) for the Space Exploration Initiative (SEI). There are three types of interaction between ISMU and the Environmental Control and Life Support System (ECLSS): (1) ISMU can reduce cost of water, oxygen, and possibly diluent gasses provided to ECLSS--a corollary to this fact is that the availability of indigenous resources can dramatically alter life support technology trade studies; (2) ISMU can use ECLSS waste systems as a source of reductant carbon and hydrogen; and (3) ECLSS and ISMU, as two chemical processing technologies used in spacecraft, can share technology, thereby increasing the impact of technology investments in either area.
Author (revised)
Closed Ecological Systems; Environmental Control; Life Support Systems; Lunar Bases; Lunar Resources; Space Exploration; Technology Assessment

19930018785 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Options for a lunar base surface architecture
Roberts, Barney B.; Arizona Univ., Proceedings of the Lunar Materials Technology Symposium; Feb 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

The Planet Surface Systems Office at the NASA Johnson Space Center has participated in an analysis of the Space Exploration Initiative architectures described in the Synthesis Group report. This effort involves a Systems Engineering and Integration effort to define point designs for evolving lunar and Mars bases that support substantial science, exploration, and resource production objectives. The analysis addresses systems-level designs; element requirements and conceptual designs; assessments of precursor and technology needs; and overall programmatics and schedules. This paper focuses on the results of the study of the Space Resource Utilization Architecture. This architecture develops the capability to extract useful materials from the indigenous resources of the Moon and Mars. On the Moon, a substantial infrastructure is emplaced which can support a crew of up to twelve. Two major process lines are developed: one produces oxygen, ceramics, and metals; the other produces hydrogen, helium, and other volatiles. The Moon is also used for a simulation of a Mars mission. Significant science capabilities are established in conjunction with resource development. Exploration includes remote global surveys and piloted sorties of local and regional areas. Science accommodations include planetary science, astronomy, and biomedical research. Greenhouses are established to provide a substantial amount of food needs.
Author (revised)
Computerized Simulation; Extraterrestrial Resources; Lunar Bases; Lunar Resources; Mars (Planet); Oxygen Production; Space Bases; Space Missions; Technology Assessment

19930018784 Aerojet TechSystems Co., Sacramento, CA, USA
On-site manufacture of propellant oxygen from lunar resources
Rosenberg, Sanders D.; Arizona Univ., Proceedings of the Lunar Materials Technology Symposium; Feb 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

The Aerojet Carbothermal Process for the manufacture of oxygen from lunar resources has three essential steps: the reduction of silicate with methane to form carbon monoxide and hydrogen; the reduction of carbon monoxide with hydrogen to form methane and water; and the electrolysis of water to form oxygen and hydrogen. This cyclic process does not depend upon the presence of water or water precursors in the lunar materials; it will produce oxygen from silicates regardless of their precise composition and fine structure. Research on the first step of the process was initiated by determining some of the operating conditions required to reduce igneous rock with carbon and silicon carbide. The initial phase of research on the second step is completed; quantitative conversion of carbon monoxide and hydrogen to methane and water was achieved with a nickel-on-kieselguhr catalyst. The equipment used in and the results obtained from these process studies are reported in detail.
Author (revised)
Electrolysis; Liquid Rocket Propellants; Lunar Resources; Lunar Rocks; Lunar Soil; Oxygen; Oxygen Production; Water Splitting

19930018783 Boeing Defense and Space Group, Seattle, WA, USA
Lunar materials processing system integration
Sherwood, Brent; Arizona Univ., Proceedings of the Lunar Materials Technology Symposium; Feb 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

The theme of this paper is that governmental resources will not permit the simultaneous development of all viable lunar materials processing (LMP) candidates. Choices will inevitably be made, based on the results of system integration trade studies comparing candidates to each other for high-leverage applications. It is in the best long-term interest of the LMP community to lead the selection process itself, quickly and practically. The paper is in five parts. The first part explains what systems integration means and why the specialized field of LMP needs this activity now. The second part defines the integration context for LMP -- by outlining potential lunar base functions, their interrelationships and constraints. The third part establishes perspective for prioritizing the development of LMP methods, by estimating realistic scope, scale, and timing of lunar operations. The fourth part describes the use of one type of analytical tool for gaining understanding of system interactions: the input/output model. A simple example solved with linear algebra is used to illustrate. The fifth and closing part identifies specific steps needed to refine the current ability to study lunar base system integration. Research specialists have a crucial role to play now in providing the data upon which this refinement process must be based.
Author (revised)
Lunar Bases; Lunar Resources; Lunar Rocks; Lunar Soil; Materials Handling; Refining; Systems Integration

19930018782 Corning Glass Works, NY, USA
Glasses, ceramics, and composites from lunar materials
Beall, George H.; Arizona Univ., Proceedings of the Lunar Materials Technology Symposium; Feb 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

A variety of useful silicate materials can be synthesized from lunar rocks and soils. The simplest to manufacture are glasses and glass-ceramics. Glass fibers can be drawn from a variety of basaltic glasses. Glass articles formed from titania-rich basalts are capable of fine-grained internal crystallization, with resulting strength and abrasion resistance allowing their wide application in construction. Specialty glass-ceramics and fiber-reinforced composites would rely on chemical separation of magnesium silicates and aluminosilicates as well as oxides titania and alumina. Polycrystalline enstatite with induced lamellar twinning has high fracture toughness, while cordierite glass-ceramics combine excellent thermal shock resistance with high flexural strengths. If sapphire or rutile whiskers can be made, composites of even better mechanical properties are envisioned.
Author (revised)
Abrasion Resistance; Ceramics; Crystallization; Fiber Composites; Glass; Lunar Resources; Lunar Rocks; Lunar Soil; Silicates

19930018781 Electrochemical Technology Corp., Seattle, WA, USA
Metals production
Beck, Theodore S.; Arizona Univ., Proceedings of the Lunar Materials Technology Symposium; Feb 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

Existing procedures for design of electrochemical plants can be used for design of lunar processes taking into consideration the differences in environmental conditions. These differences include: 1/6 Earth gravity, high vacuum, solar electrical and heat source, space radiation heat sink, long days and nights, and different availability and economics of

materials, energy, and labor. Techniques have already been developed for operation of relatively small scale hydrogen-oxygen fuel cell systems used in the U.S. lunar landing program. Design and operation of lunar aqueous electrolytic process plants appears to be within the state-of-the-art. Finding or developing compatible materials for construction and designing of fused-magma metal winning cells will present a real engineering challenge.
Author (revised)
Construction; Electrochemistry; Fuel Cells; Heat Sinks; High Vacuum; Lunar Landing; Lunar Resources; Metals; Microgravity

19930018780 Arizona Univ., Tucson, AZ, USA
Propellant production and useful materials: Hardware data from components and the systems
Ramohalli, Kumar; Proceedings of the Lunar Materials Technology Symposium; Feb 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

Research activities at the University of Arizona/NASA Space Engineering Research Center are described; the primary emphasis is on hardware development and operation. The research activities are all aimed toward introducing significant cost reductions through the utilization of resources locally available at extraterrestrial sites. The four logical aspects include lunar, Martian, support, and common technologies. These are described in turn. The hardware realizations are based upon sound scientific principles which are used to screen a host of interesting and novel concepts. Small scale feasibility studies are used as the screen to allow only the most promising concepts to proceed. Specific examples include: kg/day-class oxygen plant that uses CO2 as the feed stock, spent stream utilization to produce methane and 'higher' compounds (using hydrogen from a water electrolysis plant), separation of CO from the CO2, reduction of any iron bearing silicate (lunar soils), production of structural components, smart sensors and autonomous controls, and quantitative computer simulation of extraterrestrial plants. The most important feature of all this research continues to be the training of high-quality students for our future in space.
Author (revised)
Cost Reduction; Electrolysis; Extraterrestrial Resources; Feasibility Analysis; Fuel Production; Hardware; Lunar Soil; Mars (Planet); Reduction (Chemistry); Water Splitting

19930018779 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Magnetic beneficiation of lunar soils
Mckay, D. S; Oder, R. R.; Graf, J.; Taylor, L. A.; Arizona Univ., Proceedings of the Lunar Materials Technology Symposium; Feb 1, 1992; In English; No Copyright; Avail: CASI; A02, Hardcopy

We will present a review of recent laboratory results obtained in dry magnetic separation of one gram samples of the minus 1 mm size fraction of five lunar soils of widely differing maturities. Two highland soils were investigated as potential sources of low iron content feed stocks for space manufacture of metals, including aluminum, silicon, and calcium. Pure anorthite was separated from the diamagnetic fraction of immature highland regolith. Three high titanium mare soils were investigated as potential sources of ilmenite for production of hydrogen and for recovery of He-3. Ilmenite and pyroxene were separated from the paramagnetic fractions of the mare basalts. Agglutinates and other fused soil components containing metallic iron were separated from the strongly magnetic fractions of all soils. We will present conceptual magnetic separation flow sheets developed from the laboratory data and designed for production of anorthite from highland soils and for production of ilmenite from mare soils. Using these flow sheets, we will discuss problems and opportunities associated with the magnetic separation of lunar soils. Separation of high-grade anorthite or other diamagnetic components at moderately high recovery can be achieved in processing immature highland soils. Further, while magnet weight is always an issue in magnetic separation technology, recent developments in both low temperature and high temperature superconductivity present unusual opportunities for magnet design specific to the lunar environment.
Author (revised)
Basalt; Beneficiation; Hydrogen Production; Ilmenite; Lunar Resources; Lunar Soil; Magnetic Fields; Regolith; Separators

19930018778 Bechtel National, Inc., San Francisco, CA, USA
Oxygen production on the Lunar materials processing frontier
Altenberg, Barbara H.; Arizona Univ., Proceedings of the Lunar Materials Technology Symposium; Feb 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

During the pre-conceptual design phase of an initial lunar oxygen processing facility, it is essential to identify and compare the available processes and evaluate them in order to ensure the success of such an endeavor. The focus of this paper is to provide an overview of materials processing to produce lunar oxygen as one part of a given scenario of a developing lunar

occupation. More than twenty-five techniques to produce oxygen from lunar materials have been identified. While it is important to continue research on any feasible method, not all methods can be implemented at the initial lunar facility. Hence, it is necessary during the pre-conceptual design phase to evaluate all methods and determine the leading processes for initial focus. Researchers have developed techniques for evaluating the numerous proposed methods in order to suggest which processes would be best to go to the Moon first. As one section in this paper, the recent evaluation procedures that have been presented in the literature are compared and contrasted. In general, the production methods for lunar oxygen fall into four categories: thermochemical, reactive solvent, pyrolytic, and electrochemical. Examples from two of the four categories are described, operating characteristics are contrasted, and terrestrial analogs are presented when possible. In addition to producing oxygen for use as a propellant and for life support, valuable co-products can be derived from some of the processes. This information is also highlighted in the description of a given process.
Author (revised)
Life Support Systems; Lunar Bases; Lunar Resources; Lunar Rocks; Lunar Soil; Oxygen; Oxygen Production; Production Engineering; Thermochemistry

19930018777 Boeing Defense and Space Group, Huntsville, AL, USA
Electrical power integration for lunar operations
Woodcock, Gordon; Arizona Univ., Proceedings of the Lunar Materials Technology Symposium; Feb 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

Electrical power for future lunar operations is expected to range from a few kilowatts for an early human outpost to many megawatts for industrial operations in the 21st century. All electrical power must be imported as chemical, solar, nuclear, or directed energy. The slow rotation of the Moon and consequent long lunar night impose severe mass penalties on solar systems needing night delivery from storage. The cost of power depends on the cost of the power systems the cost of its transportation to the Moon, operating cost, and, of course, the life of the power system. The economic feasibility of some proposed lunar ventures depends in part on the cost of power. This paper explores power integration issues, costs, and affordability in the context of the following representative lunar ventures: (1) early human outpost (10 kWe); (2) early permanent lunar base, including experimental ISMU activities (100 kWe); (3) lunar oxygen production serving an evolved lunar base (500 kWe); (4) lunar base production of specialized high-value products for use on Earth (5 kWe); and (5) lunar mining and production of helium-3 (500 kWe). The schema of the paper is to project likely costs of power alternatives (including integration factors) in these power ranges, to select the most economic, to determine power cost contribution to the product or activities, to estimate whether the power cost is economically acceptable, and, finally, to offer suggestions for reaching acceptability where cost problems exist.
Author (revised)
Chemical Energy; Cost Analysis; Economic Analysis; Lunar Bases; Lunar Mining; Lunar Resources; Oxygen Production; Solar Energy; Space Power Reactors; Systems Integration

19930018772 Little (Arthur D.), Inc., Boston, MA, USA
Energy for lunar resource exploitation
Glaser, Peter E.; Arizona Univ., Proceedings of the Lunar Materials Technology Symposium; Feb 1, 1992; In English; No Copyright; Avail: CASI; A02, Hardcopy

Humanity stands at the threshold of exploiting the known lunar resources that have opened up with the access to space. America's role in the future exploitation of space, and specifically of lunar resources, may well determine the level of achievement in technology development and global economic competition. Space activities during the coming decades will significantly influence the events on Earth. The 'shifting of history's tectonic plates' is a process that will be hastened by the increasingly insistent demands for higher living standards of the exponentially growing global population. Key to the achievement of a peaceful world in the 21st century, will be the development of a mix of energy resources at a societally acceptable and affordable cost within a realistic planning horizon. This must be the theme for the globally applicable energy sources that are compatible with the Earth's ecology. It is in this context that lunar resources development should be a primary goal for science missions to the Moon, and for establishing an expanding human presence. The economic viability and commercial business potential of mining, extracting, manufacturing, and transporting lunar resource based materials to Earth, Earth orbits, and to undertake macroengineering projects on the Moon remains to be demonstrated. These extensive activities will be supportive of the realization of the potential of space energy sources for use on Earth. These may include generating

electricity for use on Earth based on beaming power from Earth orbits and from the Moon to the Earth, and for the production of helium 3 as a fuel for advanced fusion reactors.
Author (revised)
Economic Factors; Lunar Mining; Lunar Resources; Space Commercialization; Space Industrialization; Space Manufacturing

19930018771 Bechtel National, Inc., San Francisco, CA, USA
An engineer/constructor's view of lunar resource development
Jones, Carleton H.; Arizona Univ., Proceedings of the Lunar Materials Technology Symposium; Feb 1, 1992; In English; No Copyright; Avail: Other Sources

A strawman lunar outpost scenario has been postulated as a special focus to guide the papers in this symposium. This scenario describes an evolving facility with basic components, personnel, and activities intended to support lunar missions that lead to a permanent occupation on the lunar surface. The engineer/constructor's view of establishing a lunar outpost is largely concerned with identifying and analyzing the logistics needed to transform the engineering designs on paper into a constructed and operating facility. This means that all aspects of the outpost design will be examined to satisfy constructability requirements and to develop a construction management plan that leads to successful facility startup and routine operations. Whether the facility is to be devoted to materials production, vehicle refueling, or science projects will influence the construction plan in its details, but the construction of all lunar facilities will be mainly governed by the difficult logistics path from Earth to the lunar surface.
Author (revised)
Construction; Lunar Bases; Lunar Resources; Management Planning; Refueling; Space Logistics

19930018769 Tennessee Univ., Knoxville, TN, USA
Return to the Moon: Lunar robotic science missions
Taylor, Lawrence A.; Arizona Univ., Proceedings of the Lunar Materials Technology Symposium; Feb 1, 1992; In English; No Copyright; Avail: CASI; A02, Hardcopy

There are two important aspects of the Moon and its materials which must be addressed in preparation for a manned return to the Moon and establishment of a lunar base. These involve its geologic science and resource utilization. Knowledge of the Moon forms the basis for interpretations of the planetary science of the terrestrial planets and their satellites; and there are numerous exciting explorations into the geologic science of the Moon to be conducted using orbiter and lander missions. In addition, the rocks and minerals and soils of the Moon will be the basic raw materials for a lunar outpost; and the In-Situ Resource Utilization (ISRU) of lunar materials must be considered in detail before any manned return to the Moon. Both of these fields -- planetary science and resource assessment -- will necessitate the collection of considerable amounts of new data, only obtainable from lunar-orbit remote sensing and robotic landers. For over fifteen years, there have been a considerable number of workshops, meetings, etc. with their subsequent 'white papers' which have detailed plans for a return to the Moon. The Lunar Observer mission, although grandiose, seems to have been too expensive for the austere budgets of the last several years. However, the tens of thousands of man-hours that have gone into 'brainstorming' and production of plans and reports have provided the precursor material for today's missions. It has been only since last year (1991) that realistic optimism for lunar orbiters and soft landers has come forth. Plans are for 1995 and 1996 'Early Robotic Missions' to the Moon, with the collection of data necessary for answering several of the major problems in lunar science, as well as for resource and site evaluation, in preparation for soft landers and a manned-presence on the Moon.
Author (revised)
Lunar Bases; Lunar Exploration; Lunar Resources; Robotics

19930018767 Arizona Univ., Tucson, AZ, USA
Proceedings of the Lunar Materials Technology Symposium
Feb 1, 1992; In English, 20-22 Feb. 1992, Tuscon, AZ, USA; See also N93-27957 through N93-27988
Contract(s)/Grant(s): NAGW-1332
Report No.(s): NASA-CR-192881; NAS 1.26:192881; No Copyright; Avail: CASI; A16, Hardcopy

The meeting was organized around a possible lunar outpost scenario, featuring industrial technologies, systems, and components applicable to the extraction, processing, and fabrication of local materials. Acknowledged space resources experts as well as investigators from outside the field whose knowledge could be applied to space development activities were brought together. Presentations came from a variety of specialists in fields such as minerals processing, environmental control, and communications. The sessions of the symposium were divided into the following areas: resource characterization, energy management, materials processing, environment control, and automation and communications.

Automatic Control; Conferences; Environmental Control; Life Support Systems; Lunar Bases; Lunar Resources; Resources Management; Space Colonies; Space Communication; Space Habitats; Technology Utilization

19930017506 Environmental Research Lab., Gulf Breeze, FL, USA

In-situ materials processing systems and bioregenerative life support systems interrelationships

Mignon, George V.; Frye, Robert J.; Arizona Univ., NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1992; In English; 1 functional color page; No Copyright; Avail: CASI; A01, Hardcopy; 1 functional color page

The synergy and linkages between bioregenerative life support systems and the materials produced by in-situ materials processing systems was investigated. Such systems produce a broad spectrum of byproducts such as oxygen, hydrogen, processed soil material, ceramics, refractory, and other materials. Some of these materials may be utilized by bioregenerative systems either directly or with minor modifications. The main focus of this project was to investigate how these materials can be utilized to assist a bioregenerative life support system. Clearly the need to provide a sustainable bioregenerative life support system for long term human habitation of space is significant.

Author (revised)

Closed Ecological Systems; Food Production (In Space); Lunar Resources; Space Processing; Waste Treatment; Water Treatment

19930017503 Arizona Univ., Tucson, AZ, USA

Abundance of He-3 and other solar-wind-derived volatiles in lunar soil

Swindle, Timothy D.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1992; In English; 1 functional color page; No Copyright; Avail: CASI; A02, Hardcopy; 1 functional color page

Volatiles implanted into the lunar regolith by the solar wind are potentially important lunar resources. Wittenberg et al. (1986) have proposed that lunar He-3 could be used as a fuel for terrestrial nuclear fusion reactors. They argue that a fusion scheme involving D and He-3 would be cleaner and more efficient than currently-proposed schemes involving D and T. However, since the terrestrial inventory of He-3 is so small, they suggest that the lunar regolith, with concentrations of the order of parts per billion (by mass) would be an economical source of He-3. Solar-wind implantation is also the primary source of H, C, and N in lunar soil. These elements could also be important, particularly for life support and for propellant production. In a SERC study of the feasibility of obtaining the necessary amount of He-3, Swindle et al. (1990) concluded that the available amount is sufficient for early reactors, at least, but that the mining problems, while not necessarily insurmountable, are prodigious. The volatiles H, C, and N, on the other hand, come in parts per million level abundances. The differences in abundances mean that (1) a comparable amount of H, C, and/or N could be extracted with orders of magnitude smaller operations than required for He-3, and (2) if He-3 extraction ever becomes important, huge quantities of H, C, and N will be produced as by-products.

Author (revised)

Abundance; Helium Isotopes; Lunar Resources; Solar Wind; Volatility

19930017498 Arizona Univ., Tucson, AZ, USA

Development and mechanical properties of construction materials from lunar simulant

Desai, Chandra S.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1992; In English; 1 functional color page; No Copyright; Avail: CASI; A03, Hardcopy; 1 functional color page

Development of versatile engineering materials from locally available materials in space is an important step toward the establishment of outposts on the Moon and Mars. Development of the technologies for manufacture of structural and construction materials on the Moon, utilizing local lunar soil (regolith), without the use of water, is an important element for habitats and explorations in space. It is also vital that the mechanical behavior such as strength and tensile, flexural properties, fracture toughness, ductility, and deformation characteristics are defined toward establishment of the ranges of engineering applications of the materials developed. The objectives include two areas: (1) thermal ‘liquefaction’ of lunar simulant (at about 1100 C) with different additives (fibers, powders, etc.), and (2) development and use of a new triaxial test device in which lunar simulants are first compacted under cycles of loading, and then tested with different vacuums and initial confining or in situ stress. Details of the development of intermediate ceramic composites (ICC) and testing for their flexural and compression characteristics were described in various reports and papers. The subject of behavior of compacted simulant under vacuum was

described in previous progress reports and publications; since the presently available device allows vacuum levels up to only 10(exp -4) torr, it is recommended that a vacuum pump that can allow higher levels of vacuum be utilized for further investigation.
Author (revised)
Construction Materials; Liquefaction; Lunar Resources; Mechanical Properties; Space Manufacturing

19930017496 Arizona Univ., Tucson, AZ, USA
Melt-processing of lunar ceramics
Fabes, B. D.; Poisl, W. H.; Allen, D.; Minitti, M.; Hawley, S.; Beck, T.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

The goal of this project is to produce useful ceramics materials from lunar resources using the by products of lunar oxygen production processes. Emphasis is being placed on both fabrication of a variety of melt-processed ceramics, and on understanding the mechanical properties of these materials. Previously, glass-ceramics were formed by casting large glass monoliths and heating these to grow small crystallites. The strengths of the resulting glass-ceramics were found to vary with the inverse square root of the crystal grain size. The highest strengths (greater than 300 MPa) were obtained with the smallest crystal sizes (less than 10 microns). During the past year, the kinetics of crystallization in simulated lunar regolith were examined in an effort to optimize the microstructure and, hence, mechanical properties of glass ceramics. The use of solar energy for melt-processing of regolith was examined, and strong (greater than 630 MPa) glass fibers were successfully produced by melt-spinning in a solar furnace. A study of the mechanical properties of simulated lunar glasses was completed during the past year. As on Earth, the presence of moisture was found to weaken simulated lunar glasses, although the effects of surface flaws was shown to outweigh the effect of atmospheric moisture on the strength of lunar glasses. The effect of atmospheric moisture on the toughness was also studied. As expected, toughness was found to increase only marginally in an anhydrous atmosphere. Finally, our efforts to involve undergraduates in the research lab fluorished this past year. Four undergraduates worked on various aspects of these projects; and two of them were co-authors on papers which we published.
Author (revised)
Ceramics; Crystallization; Glass Fibers; Lunar Resources; Melt Spinning; Space Processing

19930017495 Arizona Univ., Tucson, AZ, USA
Dehydration kinetics and thermochemistry of selected hydrous phases, and simulated gas release pattern in carbonaceous chondrites
Bose, Kunal; Ganguly, J.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1992; In English; 1 functional color page; No Copyright; Avail: CASI; A03, Hardcopy; 1 functional color page

As part of our continued program of study on the volatile bearing phases and volatile resource potential of carbonaceous chondrite, results of our experimental studies on the dehydration kinetics of talc as a function of temperature and grain size (50 to 0.5 microns), equilibrium dehydration boundary of talc to 40 kbars, calorimetric study of enthalpy of formation of both natural and synthetic talc as a function of grain size, and preliminary results on the dehydration kinetics of epsomite are reported. In addition, theoretical calculations on the gas release pattern of Murchison meteorite, which is a C2(CM) carbonaceous chondrite, were performed. The kinetic study of talc leads to a dehydration rate constant for 40-50 microns size fraction of k = (3.23 x 10(exp 4))exp(-Q/RT)/min with the activation energy Q = 376 (plus or minus 20) kJ/mole. The dehydration rate was found to increase somewhat with decreasing grain size. The enthalpy of formation of talc from elements was measured to be -5896(10) kJ/mol. There was no measurable effect of grain size on the enthalpy beyond the limits of precision of the calorimetric studies. Also the calorimetric enthalpy of both synthetic and natural talc was found to be essentially the same, within the precision of measurements, although the natural talc had a slightly larger field of stability in our phase equilibrium studies. The high pressure experimental data the dehydration equilibrium of talc (talc = enstatite + coesite + H2O) is in strong disagreement with that calculated from the available thermochemical data, which were constrained to fit the low pressure experimental results. The calculated gas release pattern of Murchison meteorite were in reasonable agreement with that determined by stepwise heating in a gas chromatograph.
Author (revised)
Carbonaceous Chondrites; Dehydration; Extraterrestrial Resources; Murchison Meteorite; Talc; Thermochemistry

19930017494 Arizona Univ., Tucson, AZ, USA
Oxygen production on Mars and the Moon
Sridhar, K. R.; Vaniman, B.; Miller, S.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1992; In English; 1 functional color page; No Copyright; Avail: CASI; A03, Hardcopy; 1 functional color page

Significant progress was made in the area of in-situ oxygen production in the last year. In order to reduce sealing problems due to thermal expansion mismatch in the disk configuration, several all-Zirconia cells were constructed and are being tested. Two of these cells were run successfully for extended periods of time. One was run for over 200 hours and the other for over 800 hours. These extended runs, along with gas sample analysis, showed that the oxygen being produced is definitely from CO2 and not from air leaks or from the disk material. A new tube system is being constructed that is more rugged, portable, durable, and energy efficient. The important operating parameters of this system will be better controlled compared to previous systems. An electrochemical compressor will also be constructed with a similar configuration. The electrochemical compressor will use less energy since the feed stock is already heated in the separation unit. In addition, it does not have moving parts.
Author
Electrochemical Cells; Electrochemistry; Extraterrestrial Resources; Oxygen Production; Sealing

19930017493 Arizona Univ., Tucson, AZ, USA
Extraction of volatiles and metals from extraterrestrial materials
Lewis, J. S.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1992; In English; 1 functional color page; No Copyright; Avail: CASI; A02, Hardcopy; 1 functional color page

Recent progress in defining the physical, orbital, and chemical properties of the Earth-crossing asteroid and comet population was integrated into an elaborate Monte Carlo model of the fluxes of bodies in the inner Solar System. This model is of use in projecting flight opportunities to as-yet undiscovered near-Earth objects and in assessing the impact hazard to life on Earth and the evolutionary consequences of impacts on the other terrestrial planets. Further progress was made in defining desirable transportation system architectures for the use of non-terrestrial volatiles and metals, including the delivery of propellants to near-Earth space for fueling of space exploration initiative (SEI) type expeditions, the construction and resupply of Solar Power Satellite constellations in various Earth orbits (including geosynchronous earth orbit (GEO) and Highly Eccentric Earth Orbit (HEEO)), and retrieval of He-3 for use as a clean fusion fuel on Earth. These studies suggest a greater future role for SERC in the exploration of space energy sources to meet Earth's 21st-century energy requirements. Laboratory studies of volatilization and deposition of ferrous metal alloys demonstrated deposition of strong iron films from carbonyl chemical vapor deposition (CVD), showing the crucial role of additive gases in governing the CVD process, and pointing the way to specific experiments on extraction and deposition of ferrous metals from nonterrestrial materials.
Author
Asteroids; Comets; Extraction; Extraterrestrial Resources; Ferrous Metals; Monte Carlo Method

19930017491 Arizona State Univ., Tempe, AZ, USA
Lunar mining of oxygen using fluorine
Burt, Donald M.; Tyburczy, James A.; Roberts, Jeffery J.; Balasubramanian, Rajan; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1992; In English; 1 functional color page; No Copyright; Avail: CASI; A02, Hardcopy; 1 functional color page

Experiments during the first year of the project were directed towards generating elemental fluorine via the electrolysis of anhydrous molten fluorides. Na2SiF6 was dissolved in either molten NaBF4 or a eutectic (minimum-melting) mixture of KF-LiF-NaF and electrolyzed between 450 and 600 C to Si metal at the cathode and F2 gas at the anode. Ar gas was continuously passed through the system and F2 was trapped in a KBr furnace. Various anode and cathode materials were investigated. Despite many experimental difficulties, the capability of the process to produce elemental fluorine was demonstrated.
Author (revised)
Electrode Materials; Electrolysis; Fluorine; Lunar Mining; Oxygen Production

19930017490 EMEC Consultants, Export, PA, USA
Experimental study of the electrolysis of silicate melts
Keller, Rudolf; Arizona Univ., NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1992; In English; 1 functional color page; No Copyright; Avail: CASI; A02, Hardcopy; 1 functional color page

Melting and electrolyzing lunar silicates yields oxygen gas and potentially can be practiced in situ to produce oxygen. With the present experiments conducted with simulant oxides at 1425-1480 C, it was ascertained that oxygen can be obtained anodically at feasible rates and current efficiencies. An electrolysis cell was operated with platinum anodes in a sealed vessel,

and the production of gas was monitored. In these electrolysis experiments, stability of anodes remained a problem, and iron and silicon did not reduce readily into the liquid silver cathode.
Author (revised)
Electrolysis; Lunar Resources; Melting; Oxides; Oxygen Production; Silicates

19930017488 Arizona Univ., Tucson, AZ, USA
Innovative techniques for the production of energetic radicals for lunar processing including cold plasma processing of local planetary ores
Bullard, D.; Lynch, D. C.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1992; In English; 1 functional color page; No Copyright; Avail: CASI; A02, Hardcopy; 1 functional color page

Hydrogen reduction of ilmenite has been studied by a number of investigators as a potential means for recovery of oxygen from lunar soil. Interest in this process has always rested with the simplicity of the flow diagram and the utilization of established technology. Effective utilization of hydrogen in the reduction process at temperatures of 1200 C and below has always been disappointing and, as such, has led other investigators to focus attention on other systems. Effective utilization of hydrogen in the reduction of ilmenite can be significantly enhanced in the presence of a non-equilibrium hydrogen plasma. Ilmenite at solid specimen temperatures of 600 C to 970 C were reacted in a hydrogen plasma. Those experiments revealed that hydrogen utilization can be significantly enhanced. At a specimen temperature of 850 C the fraction of H2 reacted was 24 percent compared to the 7 percent theoretical limit calculated with thermodynamic theory for the same temperature. An added advantage for a hydrogen plasma involves further reduction of TiO2. Reduction of the iron oxide in ilmenite yields TiO2 and metallic iron as by products. Titanium forms a number of oxides including TiO, Ti2O3, Ti3O5 and the Magneli oxides (Ti4O7 to Ti50O99). In conventional processing of ilmenite with hydrogen it is possible to reduce TiO2 to Ti7O13 within approximately an hour, but with poor utilization of hydrogen on the order of one mole of H2 per thousand. In the cold or non-equilibrium plasma TiO2 can be rapidly reduced to Ti2O3 with hydrogen utilization exceeding 10 percent. Based on design considerations of the plasma reactor greater utilization of the hydrogen in the reduction of TiO2 is possible.
Author (revised)
Cold Plasmas; Hydrogen Plasma; Hydrogen Production; Ilmenite; Lunar Resources; Oxygen Production

19930017487 Arizona Univ., Tucson, AZ, USA
Reduction of iron-bearing lunar minerals for the production of oxygen
Massieon, Charles; Cutler, Andrew; Shadman, Farhang; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1992; In English; 1 functional color page; No Copyright; Avail: CASI; A03, Hardcopy; 1 functional color page

The kinetics and mechanism of the reduction of simulants of the iron-bearing lunar minerals olivine ((Fe,Mg)2SiO4), pyroxene ((Fe,Mg,Ca)SiO3), and ilmenite (FeTiO3) are investigated, extending previous work with ilmenite. Fayalite is reduced by H2 at 1070 K to 1480 K. A layer of mixed silica glass and iron forms around an unreacted core. Reaction kinetics are influenced by permeation of hydrogen through this layer and a reaction step involving dissociated hydrogen. Reaction mechanisms are independent of Mg content. Augite, hypersthene, and hedenbergite are reduced in H2 at the same temperatures. The products are iron metal and lower iron silicates mixed throughout the mineral. Activation energy rises with calcium content. Ilmenite and fayalite are reduced with carbon deposited on partially reduced minerals via the CO disproportionation reaction. Reduction with carbon is rapid, showing the carbothermal reduction of lunar minerals is possible.
Author (revised)
Lunar Resources; Lunar Rocks; Lunar Soil; Mineral Deposits; Oxygen Production; Reaction Kinetics

19930017486 Arizona Univ., Tucson, AZ, USA
Propellant production and useful materials: Hardware data from components and the systems
Ramohalli, Kumar; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1992; In English; 1 functional color page; No Copyright; Avail: CASI; A03, Hardcopy; 1 functional color page

During the past year significant progress included: a major breakthrough in oxygen production through discs (instead of tubes) that resulted in two orders-of-magnitude increase in the yield rates, proving that oxygen production from any iron-bearing silicate (avoiding costly beneficiation) in lunar in-situ resource utilization (ISRU); construction of a half-scale robotic soil processor; production of melt-spun fibers in a solar furnace; and the culmination of first-stage research in the construction (and delivery to NASA LaRC) of a self-contained portable oxygen plant that incorporates the first generation ISRU technologies developed at UA SERC. In addition, further reductions in mass and power needs were achieved in two

smaller oxygen plants, which, however, have far greater production rates. SERC continued to attract bright students both at the undergraduate and graduate levels, and several area high school students through the Professional Internship Program (PIP) administered by the local school district. Invited lectures at elementary schools continue to draw enthusiastic response. Another important first was the creation of the Freshman Colloquium, 'Space in Our Future, and Our Future in Space,' geared toward women and minority students. This course proved to be a success, with more than one-half of the enrollment composed of women. In recognition of these important contributions, the author was appointed to the NRC Committee on Space Science Technologies.
Author (revised)
Extraterrestrial Resources; Lunar Soil; Oxygen Production; Propellant Chemistry; Robotics

19930017485 Arizona Univ., Tucson, AZ, USA
NASA Space Engineering Research Center for utilization of local planetary resources
JAN 1, 1992; In English; See also N93-26675 through N93-26699; 1 functional color page
Contract(s)/Grant(s): NAGW-1332
Report No.(s): NASA-CR-192883; NAS 1.26:192883; APR-92; No Copyright; Avail: CASI; A14, Hardcopy; 1 functional color page

Reports covering the period from 1 Nov. 1991 to 31 Oct. 1992 and documenting progress at the NASA Space Engineering Research Center are included. Topics covered include: (1) processing of propellants, volatiles, and metals; (2) production of structural and refractory materials; (3) system optimization discovery and characterization; (4) system automation and optimization; and (5) database development.
Extraterrestrial Resources; Planetary Environments; Research and Development

19930017225 Colorado Univ., Boulder, CO, USA
Design concepts for pressurized lunar shelters utilizing indigenous materials
Happel, John Amin; Willam, Kaspar; Shing, Benson; Center for Space Construction Third Annual Symposium; JAN 1, 1991; In English; No Copyright; Avail: CASI; A03, Hardcopy

The objective is to design a pressurized shelter build of indigenous lunar material. The topics are presented in viewgraph form and include the following: lunar conditions which impact design; secondary factors; review of previously proposed concepts; cross section of assembly facility; rationale for indigenous materials; indigenous material choices; cast basalt properties; design variables; design 1, cylindrical segments; construction sequence; design 2, arch-slabs with post-tensioned ring girders; and future research.
Derived from text
Construction; Design Analysis; Girders; Lunar Based Equipment; Lunar Bases; Lunar Construction Equipment; Lunar Resources; Lunar Rocks; Lunar Shelters; Lunar Soil; Structural Design

19930017224 Colorado Univ., Boulder, CO, USA
Indigenous lunar construction materials
Rogers, Wayne; Sture, Stein; Center for Space Construction Third Annual Symposium; JAN 1, 1991; In English; No Copyright; Avail: CASI; A03, Hardcopy

The objectives are the following: to investigate the feasibility of the use of local lunar resources for construction of a lunar base structure; to develop a material processing method and integrate the method with design and construction of a pressurized habitation structure; to estimate specifications of the support equipment necessary for material processing and construction; and to provide parameters for systems models of lunar base constructions, supply, and operations. The topics are presented in viewgraph form and include the following: comparison of various lunar structures; guidelines for material processing methods; cast lunar regolith; examples of cast basalt components; cast regolith process; processing equipment; mechanical properties of cast basalt; material properties and structural design; and future work.
Derived from text
Basalt; Castings; Casts; Construction; Construction Materials; Lunar Bases; Lunar Construction Equipment; Lunar Resources; Lunar Rocks; Regolith

19930017216 Colorado Univ., Boulder, CO, USA
Center for Space Construction Third Annual Symposium
JAN 1, 1991; In English, 21-22 Nov. 1991, Boulder, CO, USA; See also N93-26406 through N93-26417
Contract(s)/Grant(s): NAGW-1334
Report No.(s): NASA-CR-192688; NAS 1.26:192688; No Copyright; Avail: CASI; A13, Hardcopy

Viewgraphs from presentations given at the symposium are presented. The topics covered include the following: orbital assembly, large space structures, space stations, expert systems, lunar regolith and structure mechanics, lunar shelter construction from lunar resources, telerobotic rovers, lunar construction equipment, lunar based equipment, and lunar construction.

Conferences; Construction; Large Space Structures; Lunar Based Equipment; Lunar Bases; Lunar Construction Equipment; Lunar Resources; Lunar Shelters; Orbital Assembly; Space Stations

19930017206 NASA Lewis Research Center, Cleveland, OH, USA

Representative systems for space exploration

Graham, Scott R.; Electrical and Chemical Interactions at Mars Workshop. Part 2: Appendix; JAN 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

The topics are presented in viewgraph form and include the following: an overview of the synthesis report; specific architecture 4 implementations; and specific power systems/environment issues.

Derived from text

Extraterrestrial Resources; Mars (Planet); Mission Planning; Orbit Transfer Vehicles; Space Exploration; Space Missions; Space Power Reactors

19930012375 Arizona Univ., Tucson, AZ, USA

NASA Space Engineering Research Center for utilization of local planetary resources

Ramohalli, Kumar; Lewis, John S.; JAN 1, 1991; In English

Contract(s)/Grant(s): NAGW-1332

Report No.(s): NASA-CR-191989; NAS 1.26:191989; APR-91/F; No Copyright; Avail: CASI; A16, Hardcopy

Because of a change in the NASA funding cycle, the present reporting period covers only the six months from March to September 1991. Nevertheless, remarkable progress was made in a number of areas, some of the most noteworthy of which are: (1) Engineering operation of a breadboard CO2 yields O2 demonstration plant that produced over 10 grams of oxygen per day during several runs of over 100 hours each with a single electrolytic cell. Complete automation of controls, monitoring of various inputs/outputs and critical internal variables, diagnostics, and emergency shutdown in an orderly manner were also included. Moreover, 4-cell and 16-cell units, capable of much higher rates of production, were assembled and tested. (2) Demonstration of a 200 percent increase in the carbothermal reduction of ilmenite through vapor deposition of carbon layers on particles of that material. (3) Demonstration of the deposition of strong iron films from carbonyl chemical vapor deposition, establishing the crucial role of additive gases in governing the process. (4) Discovery of an apparent 800 percent increase in the conversion rates of a modified ilmenite simulant in a plasma-augmented reactor, including direct enhancement by solar radiation absorption. (5) Proof that test specimens of lunar soil with small amounts of metallic additives, recrystallized at moderate temperatures, exhibit an improvement of several orders of magnitude in ductility/tensile strength. (6) Experiments establishing the feasibility of producing silicon-based polymers from indigenous lunar materials. (7) Application of CCD technology to the production of maps of TiO2 abundance, defining primary ilmenite deposits, on the disk of the full moon. (8) Attainment of a discovery rate of approximately 3 new near-Earth asteroids per month by Spacewatch, more than doubling the previous global rate. (9) Coordination of industry and university magma electrolysis investigations in a workshop designed to define remaining problem areas and propose critical experiments.

Author (revised)

Breadboard Models; Carbonyl Compounds; Lunar Resources; Marine Resources; Metal Films

19930012365 Arizona Univ., Tucson, AZ, USA

NASA Space Engineering Research Center for utilization of local planetary resources

JAN 1, 1990; In English; 6 functional color pages

Contract(s)/Grant(s): NAGW-1332

Report No.(s): NASA-CR-191992; NAS 1.26:191992; No Copyright; Avail: CASI; A03, Hardcopy; 6 functional color pages

In 1987, responding to widespread concerns about both the health of American space technology development and the academic preparation of 21st-century space professionals, NASA announced a nationwide competition to establish a number of Space Engineering Research Centers. These centers were to be founded on the campuses of nine Universities with strong Doctoral programs in Engineering. Over 115 proposals were received by NASA in November 1987. The University of Arizona's proposal was selected in May as one of the winners, with a budget of approximately $7 million guaranteed by NASA for a minimum funding period of five years. The role of the University of Arizona SERC is to develop the technologies

necessary to produce a wide variety of useful products using the materials and sources of energy that occur naturally in near-Earth space. An additional purpose is to lower the cost and extend the scope of large-scale activities. A brief description of the Center's activities for the 1989-1990 period is presented.
Derived from text
Extraterrestrial Resources; Lunar Resources; Materials Recovery; NASA Programs; University Program

19930012364 Arizona Univ., Tucson, AZ, USA
NASA Space Engineering Research Center for utilization of local planetary resources
JAN 1, 1992; In English; 16 functional color pages
Contract(s)/Grant(s): NAGW-1332
Report No.(s): NASA-CR-191991; NAS 1.26:191991; No Copyright; Avail: CASI; A03, Hardcopy; 16 functional color pages

In 1987, responding to widespread concern about America's competitiveness and future in the development of space technology and the academic preparation of our next generation of space professionals, NASA initiated a program to establish Space Engineering Research Centers (SERC's) at universities with strong doctoral programs in engineering. The goal was to create a national infrastructure for space exploration and development, and sites for the Centers would be selected on the basis of originality of proposed research, the potential for near-term utilization of technologies developed, and the impact these technologies could have on the U.S. space program. The Centers would also be charged with a major academic mission: the recruitment of topnotch students and their training as space professionals. This document describes the goals, accomplishments, and benefits of the research activities of the University of Arizona/NASA SERC. This SERC has become recognized as the premier center in the area known as In-Situ Resource Utilization or Indigenous Space Materials Utilization.
Derived from text
Extraterrestrial Resources; Lunar Resources; Materials Recovery; Research and Development; Space Programs; University Program

19930009603 Washington Univ., Saint Louis, MO, USA
Resource availability at Taurus-Littrow
Haskin, Larry A.; Colson, R. O.; Lunar Science Inst., Workshop on Geology of the Apollo 17 Landing Site; Dec 2, 1992; In English; No Copyright; Avail: CASI; A02, Hardcopy

Early lunar technologies will probably use a common lunar material as ore. They will be robust to minor fluctuations in feedstock composition and will not require appreciable feedstock beneficiation such as rock grinding or mineral concentration. Technologies using unprocessed soil and indifferent to its composition will have the advantage. Nevertheless, the size and grade of the ore body must be confirmed for even the most indiscriminate process. Simple uses such as heaping unprocessed lunar soil for thermal insulation or radiation shielding onto a habitat require that we know the depth of the regolith, the size distributions of its soils, the locations of large boulders, and the ease of excavation. Costs of detailed site surveys trade against restrictions on site selection and conservative engineering design to accommodate unknown conditions of a poorly explored site. Given the above considerations, we consider briefly some abundant lunar materials, their proposed uses, and technologies for their preparation, with particular attention to the Taurus-Littrow site.
Author
Beneficiation; Cost Analysis; Excavation; Lunar Bases; Lunar Geology; Lunar Resources; Lunar Rocks; Lunar Soil; Minerals; Radiation Shielding; Thermal Insulation

19930009598 Lockheed Engineering and Sciences Co., Houston, TX, USA
Lunar resources: Oxygen from rocks and soil
Allen, C. C.; Gibson, M. A.; Knudsen, C. W.; Kanamori, H.; Morris, R. V.; Keller, L. P.; Mckay, D. S.; Lunar Science Inst., Workshop on Geology of the Apollo 17 Landing Site; Dec 2, 1992; In English; No Copyright; Avail: CASI; A01, Hardcopy

The first set of hydrogen reduction experiments to use actual lunar material was recently completed. The sample, 70035, is a coarse-grained vesicular basalt containing 18.46 wt. percent FeO and 12.97 wt. percent TiO2. The mineralogy includes pyroxene, ilmenite, plagioclase, and minor olivine. The sample was crushed to a grain size of less than 500 microns. The crushed basalt was reduced with hydrogen in seven tests at temperatures of 900-1050 C and pressures of 1-10 atm for 30-60 minutes. A capacitance probe, measuring the dew point of the gas stream, was used to follow reaction progress. Experiments were also conducted using a terrestrial basalt similar to some lunar mare samples. Minnesota Lunar Simulant (MLS-1) contains 13.29 wt. percent FeO, 2.96 wt. percent Fe2O3, and 6.56 wt. percent TiO2. The major minerals include plagioclase, pyroxene, olivine, ilmenite, and magnetite. The rock was ground and seived, and experiments were run on the less than 74-

and 500-1168-micron fractions. Experiments were also conducted on less than 74-micron powders of olivine, pyroxene, synthetic ilmenite, and TiO2. The terrestrial rock and mineral samples were reduced with flowing hydrogen at 1100 C in a microbalance furnace, with reaction progress monitored by weight loss. Experiments were run at atmospheric pressure for durations of 3-4 hr. Solid samples from both sets of experiments were analyzed by Mossbauer spectroscopy, petrographic microscopy, scanning electron microscopy, tunneling electron microscopy, and x-ray diffraction. Apollo 17 soil 78221 was examined for evidence of natural reduction in the lunar environment. This sample was chosen based on its high maturity level (I sub s/FeO = 93.0). The FeO content is 11.68 wt. percent and the TiO2 content is 3.84 wt. percent. A polished thin section of the 90-150 micron size fraction was analyzed by petrographic microscopy and scanning electron microscopy.
Author
Hydrogen; Hydrogen Production; Lunar Resources; Lunar Rocks; Lunar Soil; Oxygen Production; Water Splitting

19930008975 Texas Univ., Austin, TX, USA
Asteroid exploration and utilization: The Hawking explorer
Carlson, Alan; Date, Medha; Duarte, Manny; Erian, Neil; Gafka, George; Kappler, Peter; Patano, Scott; Perez, Martin; Ponce, Edgar; Radovich, Brian, et al.; Dec 15, 1991; In English
Contract(s)/Grant(s): NASW-4435
Report No.(s): NASA-CR-192027; NAS 1.26:192027; No Copyright; Avail: CASI; A06, Hardcopy

The Earth is nearing depletion of its natural resources at a time when human beings are rapidly expanding the frontiers of space. The resources which may exist on asteroids could have enormous potential for aiding and enhancing human space exploration as well as life on Earth. With the possibly limitless opportunities that exist, it is clear that asteroids are the next step for human existence in space. This report comprises the efforts of NEW WORLDS, Inc. to develop a comprehensive design for an asteroid exploration/sample return mission. This mission is a precursor to proof-of-concept missions that will investigate the validity of mining and materials processing on an asteroid. Project STONER (Systematic Transfer of Near Earth Resources) is based on two utilization scenarios: (1) moving an asteroid to an advantageous location for use by Earth; and (2) mining an asteroids and transporting raw materials back to Earth. The asteroid explorer/sample return mission is designed in the context of both scenarios and is the first phase of a long range plane for humans to utilize asteroid resources. The report concentrates specifically on the selection of the most promising asteroids for exploration and the development of an exploration scenario. Future utilization as well as subsystem requirements of an asteroid sample return probe are also addressed.
Author
Asteroid Missions; Extraterrestrial Resources; Space Exploration; Spacecraft Design; University Program

19930008829 Texas Univ., Austin, TX, USA
Conceptual design of a fleet of autonomous regolith throwing devices for radiation shielding of lunar habitats
Armstrong, Karem; Mcadams, Daniel A.; Norrell, Jeffery L.; JAN 1, 1992; In English
Report No.(s): NASA-CR-192030; NAS 1.26:192030; No Copyright; Avail: CASI; A03, Hardcopy

This report presents refinements in two areas of the initial design presented in the report entitled ‘Conceptual Design of a Fleet of Autonomous Regolith Throwing Devices for Radiation Shielding of Lunar Habitats’. The first section presents an evaluation of the critical areas of the design and presents alternative solutions for these areas. The areas for design refinement are the traction required by the device and the stability of the device when throwing regolith. Several alternative methods are presented to solve these problems. First, the issue of required traction is covered. Next, the design is refined to provide a more stable device. The issue of stability is addressed both by presenting solutions for the configuration chosen for the computer simulation and by presenting two more device configurations. The next section presents the selected solutions. To prevent inadequate traction, the depth of dig-per-pass is reduced. A method combining a dynamic counterweight and an outrigger is chosen to provide a stable device.
Author
Automatic Control; Lunar Bases; Lunar Construction Equipment; Lunar Excavation Equipment; Lunar Rocks; Radiation Shielding; Regolith; Space Habitats; University Program

19930008610 Science Applications International Corp., Schaumburg, IL, USA
In situ propellant production: Alternatives for Mars exploration
Stancati, Michael L.; Jacobs, Mark K.; Cole, Kevin J.; Collins, John T.; Oct 1, 1991; In English
Contract(s)/Grant(s): NAS3-25809
Report No.(s): NASA-CR-187192; NAS 1.26:187192; SAIC-91/1052; No Copyright; Avail: CASI; A06, Hardcopy

Current planning for the Space Exploration Initiative (SEI) recognizes the need for extraterrestrial resources to sustain long-term human presence and to attain some degree of self-sufficiency. As a practical matter, reducing the need to carry large supplies of propellant from Earth will make space exploration more economical. For nearly every round trip planned with conventional propulsion, the actual payload is only a small fraction - perhaps 10-15 percent - of the mass launched from Earth. The objective of this study was to analyze the potential application for SEI missions of propellants made exclusively from lunar or martian resources. Using such propellants could minimize or eliminate the cost of carrying propellant for surface excursion vehicles and return transfers through two high-energy maneuvers: Earth launch and trans-Mars injection. Certain chemical mono- and bipropellants are candidates for this approach; they could be recovered entirely from in situ resources on the Moon and Mars, without requiring a continuing Earth-based resupply of propellant constituents (e.g., fuel to mix with a locally obtained oxidizer) and, perhaps, with minimal need to resupply consumables (e.g., reagents or catalyst for process reactions). A complete assessment of the performance potential of these propellants must include the requirements for installation, operations, maintenance, and resupply of the chemical processing facility.
Author
Extraterrestrial Resources; Liquid Rocket Propellants; Lunar Resources; Mars (Planet); Mars Exploration; Monopropellants; Space Exploration; Spacecraft Propulsion

19930008586 Georgia Inst. of Tech., Atlanta, GA, USA
Lunar preform manufacturing
Leong, Gregory N.; Nease, Sandra; Lager, Vicky; Yaghjian, Raffy; Waller, Chris; Dorrity, J. Lewis; JAN 1, 1992; In English
Contract(s)/Grant(s): NASW-4435
Report No.(s): NASA-CR-192064; NAS 1.26:192064; No Copyright; Avail: CASI; A03, Hardcopy
A design for a machine to produce hollow, continuous fiber reinforced composite rods of lunar glass and a liquid crystalline matrix using the pultrusion process is presented. The glass fiber will be produced from the lunar surface, with the machine and matrix being transported to the moon. The process is adaptable to the low gravity and near-vacuum environment of the moon through the use of a thermoplastic matrix in fiber form as it enters the pultrusion process. With a power consumption of 5k W, the proposed machine will run continuously, unmanned in fourteen day cycles, matching the length of moon days. A number of dies could be included that would allow the machine to produce rods of varying diameter, I-beams, angles, and other structural members. These members could then be used for construction on the lunar surface or transported for use in orbit. The benefits of this proposal are in the savings in weight of the cargo each lunar mission would carry. The supply of glass on the moon is effectively endless, so enough rods would have to be produced to justify its transportation, operation, and capital cost. This should not be difficult as weight on lunar mission is at a premium.
Author
Fiber Composites; Glass Fibers; Low Gravity Manufacturing; Lunar Resources; Lunar Surface; Matrix Materials; Preforms; Pultrusion; Rods; Space Manufacturing; Thermoplasticity

19930008267 New Mexico State Univ., Las Cruces, NM, USA
An artificially generated atmosphere near a lunar base
Burns, Jack O.; Fernini, Ilias; Sulkanen, Martin; Duric, Nebojsa; Taylor, G. Jeffrey; Johnson, Stewart W.; NASA. Johnson Space Center, The Second Conference on Lunar Bases and Space Activities of the 21st Century, Volume 1; Sep 1, 1992; In English; No Copyright; Avail: CASI; A01, Hardcopy
We discuss the formation of an artificial atmosphere generated by vigorous lunar base activity in this paper. We developed an analytical, steady-state model for a lunar atmosphere based upon previous investigations of the Moon's atmosphere from Apollo. Constant gas-injection rates, ballistic trajectories, and a Maxwellian particle distribution for an oxygen-like gas are assumed. Even for the extreme case of continuous He-3 mining of the lunar regolith, we find that the lunar atmosphere would not significantly degrade astronomical observations beyond about 10 km from the mining operation.
Author
Atmospheric Composition; Controlled Atmospheres; Helium Isotopes; Lunar Atmosphere; Lunar Bases; Lunar Mining

19930008246 Wisconsin Univ., Madison, WI, USA
Helium mining on the Moon: Site selection and evaluation
Cameron, Eugene N.; NASA. Johnson Space Center, The Second Conference on Lunar Bases and Space Activities of the 21st Century, Volume 1; Sep 1, 1992; In English; No Copyright; Avail: CASI; A02, Hardcopy
The feasibility of recovering helium (He) from the Moon as a source of fusion energy on Earth is currently being studied

at the University of Wisconsin. Part of this study is selection and evaluation of potential sites for lunar He mining. Selection and evaluation of potential mining sites are based on four salient findings by various investigators of lunar samples: (1) Regoliths from areas underlain by highland materials contain less than 20 wppm He; (2) Certain maria regoliths contain less than 20 wppm He, but other contain 25 to 49 wppm; (3) The He content of a mare regolith is a function of its composition; regoliths rich in Ti are relatively rich in He; and (4) He is concentrated in the less than 100-micron size fractions of regoliths. The first three findings suggest that maria are the most promising mining sites, specifically, those that have high-Ti regoliths. Information on the regional distribution and extent of high-Ti regoliths comes mainly from two sources: direct sampling by various Apollo and Luna missions, and remote sensing by gamma-ray spectroscopy and Earth-based measurements of lunar spectral reflectance. Sampling provides essential control on calibration and interpretation of data from remote sensing. These data indicate that Mare Tranquillitatis is the principal area of high-Ti regolith of the eastern nearside, but large areas of high-Ti regolith are indicated in the Imbrium and Procellarum regions. Recovery of significant amounts of He-3 will require mining billions of tonnes of regolith. Large individual areas suitable for mining must therefore be delineated. The concentration of He in the finer size fractions and considerations of ease of mining mean that mining areas must be as free as possible of sizable craters and blocks of rock. Pending additional lunar missions, information regarding these features must be obtained from lunar photographs, photogeologic maps, and radar surveys. The present study is decidedly preliminary; available information is much to limited to permit even a close approach to final evaluations. As a prelude to recovery of He from the Moon, systematic exploration and sampling of high-Ti regoliths should therefore have a high priority in future lunar missions.
Author
Helium; Lunar Geology; Lunar Maria; Lunar Mining; Lunar Resources; Lunar Soil; Site Selection

19930008235 Wisconsin Univ., Madison, WI, USA
Lunar He-3, fusion propulsion, and space development
Santarius, John F.; NASA. Johnson Space Center, The Second Conference on Lunar Bases and Space Activities of the 21st Century, Volume 1; Sep 1, 1992; In English; No Copyright; Avail: CASI; A02, Hardcopy

The recent identification of a substantial lunar resource of the fusion energy fuel He-3 may provide the first terrestrial market for a lunar commodity and, therefore, a major impetus to lunar development. The impact of this resource-when burned in D-He-3 fusion reactors for space power and propulsion-may be even more significant as an enabling technology for safe, efficient exploration and development of space. One possible reactor configuration among several options, the tandem mirror, illustrates the potential advantages of fusion propulsion. The most important advantage is the ability to provide either fast, piloted vessels or high-payload-fraction cargo vessels due to a range of specific impulses from 50 sec to 1,000,000 sec at thrust-to-weight ratios from 0.1 to 5x10(exp -5). Fusion power research has made steady, impressive progress. It is plausible, and even probable, that fusion rockets similar to the designs presented here will be available in the early part of the twenty-first century, enabling a major expansion of human presence into the solar system.
Author
Fusion Reactors; Helium Isotopes; Lunar Resources; Nuclear Fuels; Nuclear Propulsion; Nuclear Rocket Engines; Spacecraft Propulsion

19930008080 Los Alamos National Lab., NM, USA
A combined XRD/XRF instrument for lunar resource assessment
Vaniman, D. T.; Bish, D. L.; Chipera, S. J.; Blacic, J. D.; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: Other Sources

Robotic surface missions to the Moon should be capable of measuring mineral as well as chemical abundances in regolith samples. Although much is already known about the lunar regolith, our data are far from comprehensive. Most of the regolith samples returned to Earth for analysis had lost the upper surface, or it was intermixed with deeper regolith. This upper surface is the part of the regolith most recently exposed to the solar wind; as such it will be important to resource assessment. In addition, it may be far easier to mine and process the uppermost few centimeters of regolith over a broad area than to engage in deep excavation of a smaller area. The most direct means of analyzing the regolith surface will be by studies in situ. In addition, the analysis of the impact-origin regolith surfaces, the Fe-rich glasses of mare pyroclastic deposits, are of resource interest, but are inadequately known; none of the extensive surface-exposed pyroclastic deposits of the Moon have been systematically sampled, although we know something about such deposits from the Apollo 17 site. Because of the potential importance of pyroclastic deposits, methods to quantify glass as well as mineral abundances will be important to resource evaluation. Combined x ray diffraction (XRD) and x ray fluorescence (XRF) analysis will address many resource characterization problems on the Moon. XRF methods are valuable for obtaining full major-element abundances with high precision. Such data, collected in parallel with quantitative mineralogy, permit unambiguous determination of both mineral

and chemical abundances where concentrations are high enough to be of resource grade. Collection of both XRD and XRF data from a single sample provides simultaneous chemical and mineralogic information. These data can be used to correlate quantitative chemistry and mineralogy as a set of simultaneous linear equations, the solution of which can lead to full characterization of the sample. The use of Rietveld methods for XRD data analysis can provide a powerful tool for quantitative mineralogy and for obtaining crystallographic data on complex minerals.
Author
Chemical Analysis; Lunar Composition; Lunar Resources; Mineralogy; X Ray Diffraction; X Ray Fluorescence

19930008079 Hawaii Univ., Honolulu, HI, USA
Remote assessment of lunar resource potential
Taylor, G. Jeffrey; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: Other Sources

Assessing the resource potential of the lunar surface requires a well-planned program to determine the chemical and mineralogical composition of the Moon’s surface at a range of scales. The exploration program must include remote sensing measurements (from both Earth’s surface and lunar orbit), robotic in situ analysis of specific places, and eventually, human field work by trained geologists. Remote sensing data is discussed. Resource assessment requires some idea of what resources will be needed. Studies thus far have concentrated on oxygen and hydrogen production for propellant and life support, He-3 for export as fuel for nuclear fusion reactors, and use of bulk regolith for shielding and construction materials. The measurement requirements for assessing these resources are given and discussed briefly.
Author
Chemical Composition; Lunar Composition; Lunar Resources; Lunar Surface; Mineralogy; Regolith; Remote Sensing

19930008077 Lunar and Planetary Inst., Houston, TX, USA
Lunar resource assessment: Strategies for surface exploration
Spudis, Paul D.; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: Other Sources

Use of the indigenous resources of space to support long-term human presence is an essential element of the settlement of other planetary bodies. We are in a very early stage of understanding exactly how and under what circumstances space resources will become important. The materials and processes to recover them that we now think are critical may not ultimately be the raison d’etre for a resource utilization program. However, the need for strategic thinking proceeds in parallel with efforts to implement such plans and it is not too soon to begin thinking how we could and should use the abundant resources of materials and energy available from the Moon. The following commodities from the Moon are discussed: (1) bulk regolith, for shielding and construction on the lunar surface (ultimately for export to human-tended stations in Earth-Moon space), and (2) oxygen and hydrogen, for propellant and life support.
Author
Hydrogen Production; Lunar Bases; Lunar Resources; Lunar Surface; Oxygen Production; Regolith

19930008074 Los Alamos National Lab., NM, USA
Combined gamma ray/neutron spectroscopy for mapping lunar resources
Reedy, R. C.; Byrd, R. C.; Drake, D. M.; Feldman, W. C.; Masarik, J.; Moss, C. E.; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: Other Sources

Some elements in the Moon can be resources, such as hydrogen and oxygen. Other elements, like Ti or the minerals in which they occur, such as ilmenite, could be used in processing lunar materials. Certain elements can also be used as tracers for other elements or lunar processes, such as hydrogen for mature regoliths with other solar-wind-implanted elements like helium, carbon, and nitrogen. A complete knowledge of the elemental composition of a lunar region is desirable both in identifying lunar resources and in lunar geochemical studies, which also helps in identifying and using lunar resources. The use of gamma ray and neutron spectroscopy together to determine abundances of many elements in the top few tens of centimeters of the lunar surface is discussed. To date, very few discussions of elemental mapping of planetary surfaces considered measurements of both gamma rays and the full range of neutron energies. The theories for gamma ray and neutron spectroscopy of the Moon and calculations of leakage fluxes are presented here with emphasis on why combined gamma ray/neutron spectroscopy is much more powerful than measuring either radiation alone.
Author
Chemical Composition; Gamma Ray Spectrometers; Lunar Composition; Lunar Resources; Lunar Surface; Neutron Spectrometers

19930008069 NASA Lyndon B. Johnson Space Center, Houston, TX, USA

Moessbauer spectroscopy for lunar resource assessment: Measurement of mineralogy and soil maturity

Morris, R. V.; Agresti, D. G.; Shelfer, T. D.; Pimperl, M. M.; Shen, M.-H.; Gibson, M. A.; Wills, E. L.; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: Other Sources

First-order assessment of lunar soil as a resource includes measurement of its mineralogy and maturity. Soils in which the mineral ilmenite is present in high concentrations are desirable feedstock for the production of oxygen at a lunar base. The maturity of lunar soils is a measure of their relative residence time in the upper 1 mm of the lunar surface. Increasing maturity implies increasing load of solar wind species (e.g., N, H, and He-3), decreasing mean grain size, and increasing glass content. All these physicochemical properties that vary in a regular way with maturity are important parameters for assessing lunar soil as a resource. For example, He-3 can be extracted and potentially used for nuclear fusion. A commonly used index for lunar soil maturity is I(sub s)/FeO, which is the concentration of fine-grained metal determined by ferromagnetic resonance (I(sub s)) normalized to the total iron content (as FeO). I(sub s)/FeO has been measured for virtually every soil returned by the Apollo and Luna missions to the Moon. Because the technique is sensitive to both oxidation state and mineralogy, iron Moessbauer spectroscopy (FeMS) is a viable technique for in situ lunar resource assessment. Its utility for mineralogy is apparent from examination of published FeMS data for lunar samples. From the data published, it can be inferred that FeMS data can also be used to determine soil maturity. The use of FeMS to determine mineralogy and maturity and progress on development of a FeMS instrument for lunar surface use are discussed.

Author

Ferromagnetic Resonance; Gamma Ray Spectrometers; Ilmenite; Lunar Resources; Mineralogy; Mossbauer Effect

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Lunar prospector: A preliminary surface remote sensing resource assessment for the Moon

Mardon, A. A.; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: Other Sources

The potential existence of lunar volatiles is a scientific discovery that could distinctly change the direction of pathways of inner solar system human expansion. With a dedicated germanium gamma ray spectrometer launched in the early 1990's, surface water concentrations of 0.7 percent could be detected immediately upon full lunar polar orbit operations. The expense of lunar base construction and operation would be dramatically reduced over a scenario with no lunar volatile resources. Global surface mineral distribution could be mapped out and integrated into a GIS database for lunar base site selection. Extensive surface lunar mapping would also result in the utilization of archived Apollo images. A variety of remote sensing systems and their parameters have been proposed for use in the detection of these lunar ice masses. The detection or nondetection of subsurface and surface ice masses in lunar polar crater floors could dramatically direct the development pathways that the human race might follow in its radiation from the Earth to habitable locales in the inner terran solar system. Potential sources of lunar volatiles are described. The use of remote sensing to detect lunar volatiles is addressed.

Author

Gamma Ray Spectrometers; Lunar Maps; Lunar Resources; Lunar Surface; Remote Sensing

19930008065 Los Alamos National Lab., NM, USA

An in situ technique for elemental analysis of lunar surfaces

Kane, K. Y.; Cremers, D. A.; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: Other Sources

An in situ analytical technique that can remotely determine the elemental constituents of solids has been demonstrated. Laser-Induced Breakdown Spectroscopy (LIBS) is a form of atomic emission spectroscopy in which a powerful laser pulse is focused on a solid to generate a laser spark, or microplasma. Material in the plasma is vaporized, and the resulting atoms are excited to emit light. The light is spectrally resolved to identify the emitting species. LIBS is a simple technique that can be automated for inclusion aboard a remotely operated vehicle. Since only optical access to a sample is required, areas inaccessible to a rover can be analyzed remotely. A single laser spark both vaporizes and excites the sample so that near real-time analysis (a few minutes) is possible. This technique provides simultaneous multielement detection and has good sensitivity for many elements. LIBS also eliminates the need for sample retrieval and preparation preventing possible sample contamination. These qualities make the LIBS technique uniquely suited for use in the lunar environment.

Author

Laser Spectroscopy; Lunar Resources; Lunar Surface; Microplasmas; Spectral Resolution

19930008063 Rockwell International Science Center, Thousand Oaks, CA, USA

Mapping the Moon in soft x rays: Promises and challenges

Housley, R. M.; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: Other Sources

Recent ROSAT images reported by Schmitt et el. show that the sunlit part of the Moon is a significant source of very soft x rays. Stimulated by these observations, Edwards et al. have made an analysis of the response of the Moon to the solar soft x ray and EUV spectrum. They argue that much of the observed emission is in the form of discrete fluorescence lines in the energy range 25 to 100 eV, and that these lines are generally much stronger than the adjacent directly scattered solar background. On this basis they suggest that soft x ray fluorescence can be used to remotely obtain high-precision elemental maps of the lunar surface. Edwards et al. have continued to develop this idea and have suggested a system using soft x ray telescopes in lunar orbit, which could also obtain very good spatial resolution. This combination could be extremely valuable in furthering our understanding of lunar chemistry and potential resource distributions. High spatial resolution combined with the thin surface layer from which these soft x rays arise suggests the exciting possibility that x ray telescopes could map lunar volcanic volatiles from orbit.

Author

Imaging Techniques; Lunar Maps; Lunar Resources; Lunar Surface; X Ray Fluorescence

19930008062 Arizona Univ., Tucson, AZ, USA

Lunar magnetic fields: Implications for resource utilization

Hood, L. L.; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: Other Sources

It is well known that solar-wind-implanted hydrogen and helium-3 in lunar soils are potentially usable resources for future manned activities. For economical mining of these implanted gases, it is desirable that relative concentrations exceed that of typical soils. It has previously been noted that the monthly variation of solar wind flux on the surface due to lunar immersion in the geomagnetic tail may have measurable consequences for resource utilization. It is pointed out that, for a constant external flux, locally strong lunar crustal magnetic fields will exert the dominant influence on solar wind volatile implantation rates. In particular, the strongest lunar crustal magnetic fields will both deflect and focus incident ions in local regions leading to local enhancements of the incident ion flux. Thus, the most economical sites for extraction of solar-wind-implanted volatiles may be within or adjacent to strong crustal magnetic fields. In addition, solar wind ion deflection by crustal magnetic fields must be considered in evaluating the issue of whether remnant cometary ice or water-bearing minerals have survived in permanently shadowed regions near the lunar poles. This is because sputter erosion of water ice by solar wind ions has been suggested to be an important ice loss mechanism within permanently shadowed regions. Thus, permanently shadowed regions that are also shielded from the solar wind by locally strong crustal fields could be the most promising locations for the survival of cometary ice. Additional numerical simulations are employed to show that solar wind ion deflection by strong lunar magnetic anomalies can produce local increases in the implantation rate of solar wind gases such as hydrogen.

Author

Helium Isotopes; Lunar Composition; Lunar Magnetic Fields; Lunar Resources; Mining; Water

19930008061 NASA Lyndon B. Johnson Space Center, Houston, TX, USA

The target: H2O on the Moon

Green, J.; Wys, J. Negusde; Zuppero, A.; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: Other Sources

The importance of H2O on the lunar surface has long been identified as a high priority for the existence of a human colony for mining activities and, more recently, for space fuel. Using the Earth as an analog, volcanic activity would suggest the generation of water during lunar history. Evidence of volcanism is found not only in present lunar morphology, but in over 400 locations of lunar transient events cataloged by Middlehurst and Kuiper in the 1960's. These events consisted of sightings since early history of vapor emissions and bright spots or flares. Later infrared scanning by Saari and Shorthill showed 'hot spots', many of which coincided with transient event sites. Many of the locations of Middlehurst and Kuiper were the sites of repeat events, leading to the conclusion that these were possibly volcanic in nature. The detection and use of H2O from the lunar surface is discussed.

Author

Lunar Environment; Lunar Resources; Lunar Surface; Volcanology; Water Resources

19930008060 Nevada Univ., Reno, NV, USA

Economic geology of the Moon: Some considerations

Gillett, Stephen L.; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: Other Sources

Supporting any but the smallest lunar facility will require indigenous resources due to the extremely high cost of bringing material from Earth. The Moon has also attracted interest as a resource base to help support near-Earth space activities, because of the potential lower cost once the necessary infrastructure has been amortized. Obviously, initial lunar products will be high-volume, bulk commodities, as they are the only ones for which the economics of lunar production are conceivably attractive. Certain rarer elements, such as the halogens, C, and H, would also be extremely useful (for propellant, life support, and/or reagents), and indeed local sources of such elements would vastly improve the economics of lunar resource extraction. The economic geology of the Moon is discussed.

Author

Economics; Lunar Environment; Lunar Geology; Lunar Resources

19930008059 Lockheed Engineering and Sciences Co., Houston, TX, USA

Radon as a tracer for lunar volatiles

Friesen, Larry Jay; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: Other Sources

Radon and its decay product polonium can be used as tracers to search for lunar volatiles. One effective technique to look for them would be by using alpha-particle spectrometers from lunar orbit. Alpha spectrometers were flown in the Apollo Service Modules during the Apollo 15 and 16 missions, and did observe Rn-222 and its decay product Po-210 on the lunar surface from orbit. This demonstrates that radon and polonium can be observed from orbit; what must next be shown is that such observations can reveal something about the locations of volatiles on the Moon.

Author

Deposits; Lunar Resources; Lunar Surface; Polonium 210; Radon Isotopes; Tracers

19930008058 Brown Univ., Providence, RI, USA

Lunar resources using moderate spectral resolution visible and near-infrared spectroscopy: Al/Si and soil maturity

Fischer, Erich M.; Pieters, Carle M.; Head, James W.; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: Other Sources

Modern visible and near-infrared detectors are critically important for the accurate identification and relative abundance measurement of lunar minerals; however, even a very small number of well-placed visible and near-infrared bandpass channels provide a significant amount of general information about crucial lunar resources. The Galileo Solid State Imaging system (SSI) multispectral data are an important example of this. Al/Si and soil maturity will be discussed as examples of significant general lunar resource information that can be gleaned from moderate spectral resolution visible and near-infrared data with relative ease. Because quantitative-albedo data are necessary for these kinds of analyses, data such as those obtained by Galileo SSI are critical. SSI obtained synoptic digital multispectral image data for both the nearside and farside of the Moon during the first Galileo Earth-Moon encounter in December 1990. The data consist of images through seven filters with bandpasses ranging from 0.40 microns in the ultraviolet to 0.99 microns in the near-infrared. Although these data are of moderate spectral resolution, they still provide information for the following lunar resources: (1) titanium content of mature mare soils based upon the 0.40/0.56-micron (UV/VIS) ratio; (2) mafic mineral abundance based upon the 0.76/0.99-micron ratio; and (3) the maturity or exposure age of the soils based upon the 0.56-0.76-micron continuum and the 0.76/0.99-micron ratio. Within constraints, these moderate spectral resolution visible and near-infrared reflectance data can also provide elemental information such as Al/Si for mature highland soils.

Author

Imaging Techniques; Infrared Spectroscopy; Lunar Composition; Lunar Resources; Spectral Resolution

19930008057 Bechtel Corp., San Francisco, CA, USA

Lunar resource assessment: An industry perspective

Feldman, S. C.; Altenberg, B. H.; Franklin, H. A.; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: Other Sources

The goals of the U.S. space program are to return to the Moon, establish a base, and continue onward to Mars. To accomplish this in a relatively short time frame and to avoid the high costs of transporting materials from the Earth, resources

on the Moon will need to be mined. Oxygen will be one of the most important resources, to be used as a rocket propellant and for life support. Ilmenite and lunar regolith have both been considered as ores for the production of oxygen. Resource production on the Moon will be a very important part of the U.S. space program. To produce resources we must explore to identify the location of ore or feedback and calculate the surface and underground reserves. Preliminary resource production tests will provide the information that can be used in final plant design. Bechtel Corporation's experience in terrestrial engineering and construction has led to an interest in lunar resource assessment leading to the construction of production facilities on the Moon. There is an intimate link between adequate resource assessment to define feedstock quantity and quality, material processing requirements, and the successful production of lunar oxygen. Although lunar resource assessment is often viewed as a research process, the engineering and production aspects are very important to consider. Resource production often requires the acquisition of different types, scales, or resolutions of data than that needed for research, and it is needed early in the exploration process. An adequate assessment of the grade, areal extent, and depth distribution of the resources is a prerequisite to mining. The need for a satisfactory resource exploration program using remote sensing techniques, field sampling, and chemical and physical analysis is emphasized. These data can be used to define the ore for oxygen production and the mining, processing facilities, and equipment required.
Author
Lunar Environment; Lunar Resources; Mining; Oxygen Production; Remote Sensing

19930008054 Chicago Univ., Chicago, IL, USA
An alpha-p-x analytical instrument for lunar resource investigations
Economou, T. E.; Turkevich, A. L.; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: Other Sources

An instrument using alpha backscattering, alpha-proton nuclear reactions, and x-ray production by alpha particles and other auxiliary sources can be used on lunar landers to provide detailed analytical information concerning the lunar surface material. This information is important scientifically and can be the basis for utilizing efficiently lunar resources to build lunar colonies in the future. This alpha particle instrument uses radioactive isotopes, silicon detectors for the alpha and proton modes, and mercuric iodide detectors operating at room temperature for the x-ray mode. The alpha and proton modes of the instrument can provide an analysis for all elements (except hydrogen) present in amounts greater than about 1 percent by atom. These modes have excellent sensitivity and accuracy for the lighter elements, in particular, directly determining the amount of oxygen in the lunar soil. This is an element of paramount significance for the lunar resource mission. The x-ray mode makes possible a determination of Ti, Fe, and other important metals with even greater accuracy. In general, the x-ray mode provides increased sensitivity for heavier elements, in many cases achieving a sensitivity of several hundred ppm.
Author
Alpha Particles; Backscattering; Lunar Resources; Lunar Surface; Nuclear Reactions; Protons; X Rays

19930008053 NASA Langley Research Center, Hampton, VA, USA
A remote laser mass spectrometer for lunar resource assessment
Deyoung, R. J.; Williams, M. D.; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: Other Sources

The use of lasers as a source of excitation for surface mass spectroscopy has been investigated for some time. Since the laser can be focused to a small spot with intensity, it can vaporize and accelerate atoms of material. Using this phenomenon with a time-of-flight mass spectrometer allows a surface elemental mass analysis of a small region with each laser pulse. While the technique has been well developed for Earth applications, space applications are less developed. NASA Langley recently began a research program to investigate the use of a laser to create ions from the lunar surface and to analyze the ions at an orbiting spacecraft. A multijoule, Q-switched Nd:YAG laser would be focused to a small spot on the lunar surface, creating a dense plasma. This plasma would eject high-energy ions, as well as neutrals, electrons, and photons. An experiment is being set up to determine the characteristics of such a laser mass spectrometer at long flight distances. This experiment will determine the character of a future flight instrument for lunar resource assessment.
Author
Laser Spectrometers; Lunar Composition; Lunar Resources; Lunar Surface; Mass Spectrometers; Surface Ionization

19930008052 POD Associates, Inc., Albuquerque, NM, USA
A ground-based search for lunar resources using high-resolution imaging in the infrared
Coombs, C. R.; Mckechnie, T. S.; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: Other Sources

When humans return to the Moon, lunar resources will play an important role in the successful deployment and maintenance of the lunar base. Previous studies have illustrated the abundance of resource materials available on the surface of the Moon, as well as their ready accessibility. Particularly worth considering are the lunar regional (2,000-30,000 sq km) pyroclastic deposits scattered about the lunar nearside. These 30-50-m-thick deposits are composed of fine-grained unconsolidated titanium- and iron-rich mafic glasses and may be used as bulk feedstock for the beneficiation of oxygen, iron, titanium, sulfur, and other solar wind gases, or simply used as is for construction and shielding purposes. A groundbased observing survey of the resource-rich regions on the lunar nearside using a new imaging technique designed to obtain much higher resolution images, and more precise compositional analyses than previously obtainable is proposed.
Author
High Resolution; Imaging Techniques; Infrared Radiation; Lunar Composition; Lunar Resources

19930008051 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Estimating lunar pyroclastic deposit depth from imaging radar data: Applications to lunar resource assessment
Campbell, B. A.; Stacy, N. J.; Campbell, D. B.; Zisk, S. H.; Thompson, T. W.; Hawke, B. R.; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: Other Sources

Lunar pyroclastic deposits represent one of the primary anticipated sources of raw materials for future human settlements. These deposits are fine-grained volcanic debris layers produced by explosive volcanism contemporaneous with the early stage of mare infilling. There are several large regional pyroclastic units on the Moon (for example, the Aristarchus Plateau, Rima Bode, and Sulpicius Gallus formations), and numerous localized examples, which often occur as dark-halo deposits around endogenic craters (such as in the floor of Alphonsus Crater). Several regional pyroclastic deposits were studied with spectral reflectance techniques: the Aristarchus Plateau materials were found to be a relatively homogeneous blanket of iron-rich glasses. One such deposit was sampled at the Apollo 17 landing site, and was found to have ferrous oxide and titanium dioxide contents of 12 percent and 5 percent, respectively. While the areal extent of these deposits is relatively well defined from orbital photographs, their depths have been constrained only by a few studies of partially filled impact craters and by imaging radar data. A model for radar backscatter from mantled units applicable to both 70-cm and 12.6-cm wavelength radar data is presented. Depth estimates from such radar observations may be useful in planning future utilization of lunar pyroclastic deposits.
Author
Backscattering; Deposits; Imaging Radar; Lunar Resources; Mathematical Models; Radar Data

19930008050 Arizona Univ., Tucson, AZ, USA
A lunar penetrator to determine solar-wind-implanted resources at depth in the lunar regolith
Boynton, W.; Feldman, W.; Swindle, T.; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: CASI; A01, Hardcopy

Several volatiles implanted into the lunar regolith by the solar wind are potentially important lunar resources. He-3 might be mined as a fuel for lunar nuclear fusion reactors. Even if the mining of He-3 turns out not to be feasible, several other elements commonly implanted by the solar wind (H,C, and N) could be important for life support and for propellant or fuel production for lunar bases. A simple penetrator-borne instrument package to measure the abundance of H at depth is proposed. Since solar-wind-implanted volatiles tend to correlate with one another, this can be used to estimate global inventories and to design extraction strategies for all of these species.
Author
Instrument Packages; Lunar Composition; Lunar Resources; Neutron Counters; Penetrometers

19930008049 Sandia National Labs., Albuquerque, NM, USA
Shock-treated lunar soil simulant: Preliminary assessment as a construction material
Boslough, Mark B.; Bernold, Leonhard E.; Horie, Yasuyuki; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: Other Sources

In an effort to examine the feasibility of applying dynamic compaction techniques to fabricate construction materials from lunar regolith, preliminary explosive shock-loading experiments on lunar soil simulants were carried out. Analysis of our shock-treated samples suggests that binding additives, such as metallic aluminum powder, may provide the necessary

characteristics to fabricate a strong and durable building material (lunar adobe) that takes advantage of a cheap base material available in abundance: lunar regolith.
L.R.R.
Compression Tests; Lunar Resources; Lunar Soil; Regolith; Shock Loads; Shock Tests

19930008048 Texas A&M Univ., College Station, TX, USA
Drilling and digging techniques for the early lunar outpost
Boles, Walter W.; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: Other Sources

The theme of this workshop is lunar resource assessment. Topics include identification, quantification, and location of useful elements on and below the lunar surface. The objective of this paper is to look at another side of the issue--how to remove soil from the stiff lunar-soil matrix once useful deposits are located. The goal of this paper is to cause those who think that digging or excavating on the Moon is a trivial problem to rethink the reasons for their opinions. Another goal is to encourage them to view total reliance upon terrestrial heuristics with suspicion. This paper will focus primarily upon digging.
Author
Drilling; Excavation; Lunar Environment; Lunar Resources; Lunar Soil; Lunar Surface

19930008047 Los Alamos National Lab., NM, USA
TOPLEX: Teleoperated Lunar Explorer. Instruments and operational concepts for an unmanned lunar rover
Blacic, James D.; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: Other Sources

A Teleoperated Lunar Explorer, or TOPLEX, consisting of a lunar lander payload in which a small, instrument-carrying lunar surface rover is robotically landed and teleoperated from Earth to perform extended lunar geoscience and resource evaluation traverses is proposed. The rover vehicle would mass about 100 kg and carry approximately 100 kg of analytic instruments. Four instruments are envisioned: (1) a Laser-Induced Breakdown Spectrometer (LIBS) for geochemical analysis at ranges up to 100 m, capable of operating in three different modes; (2) a combined x-ray fluorescence and x-ray diffraction (XRF/XRD) instrument for elemental and mineralogic analysis of acquired samples; (3) a mass spectrometer system for stepwise heating analysis of gases released from acquired samples; and (4) a geophysical instrument package for subsurface mapping of structures such as lava tubes.
Author
Instrument Packages; Laser Spectrometers; Lunar Resources; Lunar Roving Vehicles; Mass Spectrometers; Teleoperators; Unmanned Spacecraft; X Ray Diffraction; X Ray Fluorescence

19930008046 California Univ., Berkeley. Lawrence Berkeley Lab, CA, USA
Geophysical methods: An overview
Becker, A.; Goldstein, N. E.; Lee, K. H.; Majer, E. L.; Morrison, H. F.; Myer, L.; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: Other Sources

Geophysics is expected to have a major role in lunar resource assessment when manned systems return to the Moon. Geophysical measurements made from a lunar rover will contribute to a number of key studies: estimating regolith thickness, detection of possible large-diameter lava tubes within maria basalts, detection of possible subsurface ice in polar regions, detection of conductive minerals that formed directly from a melt (orthomagmatic sulfides of Cu, Ni, Co), and mapping lunar geology beneath the regolith. The techniques that can be used are dictated both by objectives and by our abilities to adapt current technology to lunar conditions. Instrument size, weight, power requirements, and freedom from orientation errors are factors we have considered. Among the geophysical methods we believe to be appropriate for a lunar resource assessment are magnetics, including gradiometry, time-domain magnetic induction, ground-penetrating radar, seismic reflection, and gravimetry.
Author
Geophysics; Lunar Geology; Lunar Magnetic Fields; Lunar Resources; Lunar Surface

19930008045 Schlumberger-Doll Research, Ridgefield, CT, USA
Application of nuclear well logging techniques to lunar resource assessment
Albats, P.; Groves, J.; Schweitzer, J.; Tombrello, T.; Lunar and Planetary Inst., Joint Workshop on New Technologies for Lunar Resource Assessment; JAN 1, 1992; In English; No Copyright; Avail: Other Sources

The use of neutron and gamma ray measurements for the analysis of material composition has become well established in the last 40 years. Schlumberger has pioneered the use of this technology for logging wells drilled to produce oil and gas, and for this purpose has developed neutron generators that allow measurements to be made in deep (5000 m) boreholes under adverse conditions. We also make ruggedized neutron and gamma ray detector packages that can be used to make reliable measurements on the drill collar of a rotating drill string while the well is being drilled, where the conditions are severe. Modern nuclear methods used in logging measure rock formation parameters like bulk density and porosity, fluid composition, and element abundances by weight including hydrogen concentration. The measurements are made with high precision and accuracy. These devices (well logging sondes) share many of the design criteria required for remote sensing in space; they must be small, light, rugged, and able to perform reliably under adverse conditions. We see a role for the adaptation of this technology to lunar or planetary resource assessment missions.
Author
Gamma Ray Spectrometers; Lunar Composition; Lunar Resources; Neutron Counters; Remote Sensing; Sondes

19930008044 Lunar and Planetary Inst., Houston, TX, USA
Joint Workshop on New Technologies for Lunar Resource Assessment
Elphic, Rick C., editor; Mckay, David S., editor; JAN 1, 1992; In English, 6-7 Apr. 1992, Santa Fe, NM, USA; See also N93-17234 through N93-17270
Contract(s)/Grant(s): NASW-4574
Report No.(s): NASA-CR-191918; NAS 1.26:191918; LPI-TR-92-06; No Copyright; Avail: CPIA, 10630 Little Patuxent Pkwy., Suite 202, Columbia, MD 21044-3320

The workshop included talks on NASA's and DOE's role in Space Exploration Initiative, lunar geology, lunar resources, the strategy for the first lunar outpost, and an industry perspective on lunar resources. The sessions focused on four major aspects of lunar resource assessment: (1) Earth-based remote sensing of the Moon; (2) lunar orbital remote sensing; (3) lunar lander and roving investigations; and (4) geophysical and engineering consideration. The workshop ended with a spirited discussion of a number of issues related to resource assessment.
Lunar Geology; Lunar Resources; Remote Sensing; Research and Development; Space Exploration

19930007725 Electromagnetic Launch Research, Inc., Cambridge, MA, USA
Electromagnetic launch of lunar material
Snow, William R.; Kolm, Henry H.; NASA. Johnson Space Center, Space Resources. Volume 2: Energy, Power, and Transport; JAN 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

Lunar soil can become a source of relatively inexpensive oxygen propellant for vehicles going from low Earth orbit (LEO) to geosynchronous Earth orbit (GEO) and beyond. This lunar oxygen could replace the oxygen propellant that, in current plans for these missions, is launched from the Earth's surface and amounts to approximately 75 percent of the total mass. The reason for considering the use of oxygen produced on the Moon is that the cost for the energy needed to transport things from the lunar surface to LEO is approximately 5 percent the cost from the surface of the Earth to LEO. Electromagnetic launchers, in particular the superconducting quenchgun, provide a method of getting this lunar oxygen off the lunar surface at minimal cost. This cost savings comes from the fact that the superconducting quenchgun gets its launch energy from locally supplied, solar- or nuclear-generated electrical power. We present a preliminary design to show the main features and components of a lunar-based superconducting quenchgun for use in launching 1-ton containers of liquid oxygen, one every 2 hours. At this rate, nearly 4400 tons of liquid oxygen would be launched into low lunar orbit in a year.
Author
Electromagnetic Propulsion; Liquid Oxygen; Lunar Orbits; Lunar Resources; Lunar Soil; Lunar Surface; Oxygen Production; Superconductivity

19930007723 General Dynamics Corp., San Diego, CA, USA
Utilization of space resources in the space transportation system
Simon, Michael C.; NASA. Johnson Space Center, Space Resources. Volume 2: Energy, Power, and Transport; JAN 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

Utilization of space resources (i.e., raw materials obtained from nonterrestrial sources) has often been cited as a prerequisite for large-scale industrialization and habitation of space. While transportation of extremely large quantities of material from Earth would be costly and potentially destructive to our environment, vast quantities of usable resources might be derived from the Moon, the asteroids, and other celestial objects in a cost-effective and environmentally benign manner.

The primary purpose of the parametric cost model developed as part of this study is to identify the factors that have the greatest influence on the economics of space resource utilization. In the near term, this information can be used to devise strategies for technology development so that capabilities developed will produce cost-effective results.
Author
Asteroids; Cost Analysis; Cost Effectiveness; Cost Estimates; Lunar Mining; Lunar Resources; Moon; Oxygen Production; Space Industrialization; Space Transportation System

19930007713 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Application of manufactured products
Sastri, Sankar; Duke, Michael B.; NASA. Johnson Space Center, Space Resources. Volume 3: Materials; JAN 1, 1992; In English; No Copyright; Avail: CASI; A02, Hardcopy

A wide range of products can be manufactured from the following materials: (1) lunar regolith or basalt; (2) regolith or rock beneficiated to concentrate plagioclase or other minerals; (3) iron, extracted from lunar soil or rocks by various means; (4) naturally occurring or easily obtained materials that have cementitious properties; and (5) byproducts of the above materials. Among the products that can be produced from these materials are the following: beams; plates and sheets; transparent plates (windows); bricks and blocks; pipes and tubes; low-density materials (foams); fiber, wire, and cables; foils and reflective coatings; hermetic seals (coatings); and formed objects. In addition to oxygen, which can be obtained by several processes, either from unbeneficiated regolith or by reduction of concentrated ilmenite, these materials make the simplest requirements of the lunar resource extraction system. A thorough analysis of the impact of these simplest products on the economics of space operations is not possible at this point. Research is necessary both to define optimum techniques and adapt them to space and to determine the probable market for the products so that the priority of various processes can be assessed. Discussions of the following products are presented: aerobraking heat shields; pressurized habitats; lunar photovoltaic farms; and agricultural systems.
Author
Basalt; By-Products; Ilmenite; Iron; Lunar Mining; Lunar Rocks; Lunar Soil; Oxygen Production; Regolith; Space Manufacturing

19930007712 Portland Cement Association, Skokie, IL, USA
Cement and concrete
Corley, Gene; Haskin, Larry A.; NASA. Johnson Space Center, Space Resources. Volume 3: Materials; JAN 1, 1992; In English; No Copyright; Avail: CASI; A01, Hardcopy

To produce lunar cement, high-temperature processing will be required. It may be possible to make calcium-rich silicate and aluminate for cement by solar heating of lunar pyroxene and feldspar, or chemical treatment may be required to enrich the calcium and aluminum in lunar soil. The effects of magnesium and ferrous iron present in the starting materials and products would need to be evaluated. So would the problems of grinding to produce cement, mixing, forming in vacuo and low gravity, and minimizing water loss.
Author
Cements; Concretes; Lunar Resources; Lunar Soil; Manufacturing

19930007711 Washington Univ., Saint Louis, MO, USA
Glass and ceramics
Haskin, Larry A.; NASA. Johnson Space Center, Space Resources. Volume 3: Materials; JAN 1, 1992; In English; No Copyright; Avail: CASI; A01, Hardcopy

A variety of glasses and ceramics can be produced from bulk lunar materials or from separated components. Glassy products include sintered regolith, quenched molten basalt, and transparent glass formed from fused plagioclase. No research has been carried out on lunar material or close simulants, so properties are not known in detail; however, common glass technologies such as molding and spinning seem feasible. Possible methods for producing glass and ceramic materials are discussed along with some potential uses of the resulting products.
Author
Ceramics; Glass; Lunar Resources; Manufacturing

19930007710 New York City Technical Coll., Brooklyn, NY, USA
Iron and alloys of iron
Sastri, Sankar; NASA. Johnson Space Center, Space Resources. Volume 3: Materials; JAN 1, 1992; In English; No Copyright; Avail: CASI; A02, Hardcopy

All lunar soil contains iron in the metallic form, mostly as an iron-nickel alloy in concentrations of a few tenths of 1 percent. Some of this free iron can be easily separated by magnetic means. It is estimated that the magnetic separation of 100,000 tons of lunar soil would yield 150-200 tons of iron. Agglutinates contain metallic iron which could be extracted by melting and made into powder metallurgy products. The characteristics and potential uses of the pure-iron and iron-alloy lunar products are discussed. Processes for working iron that might be used in a nonterrestrial facility are also addressed.
Author
Iron; Iron Alloys; Lunar Resources; Lunar Soil; Metallurgy

19930007709 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Manufacturing and fabrication, part 3
Sastri, Sankar; Duke, Michael B.; Haskin, Larry A.; Space Resources. Volume 3: Materials; JAN 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

The accessibility of material and energy off the Earth and the leverage that these nonterrestrial resources can exert on the space transportation system are important influences on the long-term goal of exploring the solar system. Research on separation of lunar materials and manufacturing of useful products from them is in its infancy. A few possible processes and products are described in this report. Specific attention is given to oxygen, metal, and silicate products.
Author
Fabrication; Lunar Resources; Manufacturing

19930007708 Lunar Industries, Inc., Houston, TX, USA
Lunar cement
Agosto, William N.; NASA. Johnson Space Center, Space Resources. Volume 3: Materials; JAN 1, 1992; In English; No Copyright; Avail: CASI; A01, Hardcopy

With the exception of water, the major oxide constituents of terrestrial cements are present at all nine lunar sites from which samples have been returned. However, with the exception of relatively rare cristobalite, the lunar oxides are not present as individual phases but are combined in silicates and in mixed oxides. Lime (CaO) is most abundant on the Moon in the plagioclase (CaAl2Si2O8) of highland anorthosites. It may be possible to enrich the lime content of anorthite to levels like those of Portland cement by pyrolyzing it with lunar-derived phosphate. The phosphate consumed in such a reaction can be regenerated by reacting the phosphorus product with lunar augite pyroxenes at elevated temperatures. Other possible sources of lunar phosphate and other oxides are discussed.
Author
Cements; Lunar Resources; Lunar Rocks; Lunar Soil; Minerals; Oxides

19930007706 Bechtel Power Corp., Houston, TX, USA
Processing of metal and oxygen from lunar deposits
Acton, Constance F.; NASA. Johnson Space Center, Space Resources. Volume 3: Materials; JAN 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

On the moon, some whole rocks may be ores for abundant elements, such as oxygen, but beneficiation will be important if metallic elements are sought from raw lunar dirt. In the extraction process, a beneficiated metallic ore, such as an oxide, sulfide, carbonate, or silicate mineral, is converted to reduced metal. A variety of plausible processing technologies, which includes recovery of meteoritic iron, and processing of lunar ilmenite, are described in this report.
I.I.C.
Deposits; Extraction; Lunar Resources; Lunar Rocks; Minerals; Oxygen

19930007705 State Univ. of North Texas, Denton, TX, USA
Bioprocessing of ores: Application to space resources
Johansson, Karl R.; NASA. Johnson Space Center, Space Resources. Volume 3: Materials; JAN 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

The role of microorganisms in the oxidation and leaching of various ores (especially those of copper, iron, and uranium) is well known. This role is increasingly being applied by the mining, metallurgy, and sewage industries in the bioconcentration of metal ions from natural receiving waters and from waste waters. It is concluded that bioprocessing using bacteria in closed reactors may be a variable option for the recovery of metals from the lunar regolith. Obviously, considerable research must

be done to define the process, specify the appropriate bacteria, determine the necessary conditions and limitations, and evaluate the overall feasibility.
Author
Bioprocessing; Extraction; Feasibility; Lunar Composition; Lunar Resources; Lunar Rocks; Minerals

19930007700 Carbotek, Inc., Houston, TX, USA
Processing lunar soils for oxygen and other materials
Knudsen, Christian W.; Gibson, Michael A.; NASA. Johnson Space Center, Space Resources. Volume 3: Materials; JAN 1, 1992; In English; No Copyright; Avail: CASI; A02, Hardcopy

Two types of lunar materials are excellent candidates for lunar oxygen production: ilmenite and silicates such as anorthite. Both are lunar surface minable, occurring in soils, breccias, and basalts. Because silicates are considerably more abundant than ilmenite, they may be preferred as source materials. Depending on the processing method chosen for oxygen production and the feedstock material, various useful metals and bulk materials can be produced as byproducts. Available processing techniques include hydrogen reduction of ilmenite and electrochemical and chemical reductions of silicates. Processes in these categories are generally in preliminary development stages and need significant research and development support to carry them to practical deployment, particularly as a lunar-based operation. The goal of beginning lunar processing operations by 2010 requires that planning and research and development emphasize the simplest processing schemes. However, more complex schemes that now appear to present difficult technical challenges may offer more valuable metal byproducts later. While they require more time and effort to perfect, the more complex or difficult schemes may provide important processing and product improvements with which to extend and elaborate the initial lunar processing facilities. A balanced R&D program should take this into account. The following topics are discussed: (1) ilmenite--semi-continuous process; (2) ilmenite--continuous fluid-bed reduction; (3) utilization of spent ilmenite to produce bulk materials; (4) silicates--electrochemical reduction; and (5) silicates--chemical reduction.
Author
By-Products; Ilmenite; Lunar Resources; Lunar Rocks; Lunar Soil; Lunar Surface; Oxygen; Oxygen Production; Silicates

19930007699 Aerojet TechSystems Co., Sacramento, CA, USA
The onsite manufacture of propellant oxygen from lunar resources
Rosenberg, Sanders D.; Beegle, Robert L., Jr.; Guter, Gerald A.; Miller, Frederick E.; Rothenberg, Michael; NASA. Johnson Space Center, Space Resources. Volume 3: Materials; JAN 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

The Aerojet carbothermal process for the manufacture of oxygen from lunar materials has three essential steps: the reduction of silicate with methane to form carbon monoxide and hydrogen; the reduction of carbon monoxide with hydrogen to form methane and water; and the electrolysis of water to form hydrogen and oxygen. The reactions and the overall process are shown. It is shown with laboratory experimentation that the carbothermal process is feasible. Natural silicates can be reduced with carbon or methane. The important products are carbon monoxide, metal, and slag. The carbon monoxide can be completely reduced to form methane and water. The water can be electrolyzed to produce hydrogen and oxygen. A preliminary engineering study shows that the operation of plants using this process for the manufacture of propellant oxygen has a large economic advantage when the cost of the plant and its operation is compared to the cost of delivering oxygen from Earth.
Author
Electrolysis; Hydrogen Production; Liquid Rocket Propellants; Lunar Bases; Lunar Resources; Lunar Rocks; Lunar Soil; Oxygen Production; Silicates; Space Processing; Water; Water Splitting

19930007698 Lunar Industries, Inc., Houston, TX, USA
Lunar beneficiation
Agosto, William N.; NASA. Johnson Space Center, Space Resources. Volume 3: Materials; JAN 1, 1992; In English; No Copyright; Avail: CASI; A02, Hardcopy

Natural concentrations of industrially valuable minerals are far less likely to be found on the Moon than on the Earth. But that is all the more reason for devising beneficiation processes to concentrate and extract the useful mineral components in lunar rocks and soils. As an example of a useful mineral that can be beneficiated, it has been estimated that ilmenite abundance accounts for 15 and 20 percent of the volume of the Apollo 11 and 17 basalts and 2 and 5 percent by volume in the Apollo 11 and 17 soils. Reduction of lunar ilmenite with hydrogen imported from Earth appears to one of the more practical schemes for obtaining lunar oxygen. While the reported concentrations are significant, a more highly concentrated ilmenite extract

would improve the efficiency of the reduction process. The topics covered include electrostatic concentration, magnetic concentration, lunar soil sizing, and electrical sizing.
Author
Beneficiation; Extraction; Ilmenite; Lunar Resources; Lunar Rocks; Lunar Soil; Minerals; Oxygen Production

19930007697 Lunar Industries, Inc., Houston, TX, USA
Beneficiation and extraction of nonterrestrial materials, part 2
Agosto, William N.; NASA. Johnson Space Center, Space Resources. Volume 3: Materials; JAN 1, 1992; In English; No Copyright; Avail: CASI; A02, Hardcopy

A review of options for processing extraterrestrial materials was dominated by industrial materials scientist who tried to identify which processes utilizing space materials could be implemented in the near term. The most practical process seem to us to be the extraction of lunar oxygen and the extraction of metals and ceramics from the residues of the reduction process. The growth of space activity will be accompanied by increased demand for liquid oxygen for each round trip to the Moon. The oxygen and the intermediary product water will be needed for the life support at the base. The reduced metals and ceramics may be considered byproducts or may develop into primary products. Some of the same processes would be directly applicable to recovery of products from asteroids. We also discussed other processes for directly utilizing asteroid metals. Some of the topics covered include beneficiation and oxygen extraction methods, metallurgy, and extraterrestrial cement.
Author
Asteroids; Beneficiation; Cements; Ceramics; Extraction; Extraterrestrial Resources; Liquid Oxygen; Lunar Resources; Oxygen Production; Reduction (Chemistry); Water

19930007696 Arizona Univ., Tucson, AZ, USA
Mining nonterrestrial resources: Information needs and research topics
Daemen, Jaak J. K.; NASA. Johnson Space Center, Space Resources. Volume 3: Materials; JAN 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

An outline of topics we need to understand better in order to apply mining technology to a nonterrestrial environment is presented. The proposed list is not intended to be complete. It aims to identify representative topics that suggest productive research. Such research will reduce the uncertainties associated with extrapolating from conventional earthbound practice to nonterrestrial applications. One objective is to propose projects that should put future discussions of nonterrestrial mining on a firmer, less speculative basis.
Author
Excavation; Extraterrestrial Resources; Mining; Technology Utilization

19930007695 Colorado School of Mines, Golden, CO, USA
Asteroid mining
Gertsch, Richard E.; NASA. Johnson Space Center, Space Resources. Volume 3: Materials; JAN 1, 1992; In English; No Copyright; Avail: CASI; A02, Hardcopy

The earliest studies of asteroid mining proposed retrieving a main belt asteroid. Because of the very long travel times to the main asteroid belt, attention has shifted to the asteroids whose orbits bring them fairly close to the Earth. In these schemes, the asteroids would be bagged and then processed during the return trip, with the asteroid itself providing the reaction mass to propel the mission homeward. A mission to one of these near-Earth asteroids would be shorter, involve less weight, and require a somewhat lower change in velocity. Since these asteroids apparently contain a wide range of potentially useful materials, our study group considered only them. The topics covered include asteroid materials and properties, asteroid mission selection, manned versus automated missions, mining in zero gravity, and a conceptual mining method.
Author
Asteroid Missions; Asteroids; Extraterrestrial Resources; Mining

19930007694 Colorado School of Mines, Golden, CO, USA
A baseline lunar mine
Gertsch, Richard E.; NASA. Johnson Space Center, Space Resources. Volume 3: Materials; JAN 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

A models lunar mining method is proposed that illustrates the problems to be expected in lunar mining and how they might be solved. While the method is quite feasible, it is, more importantly, a useful baseline system against which to test

other, possible better, methods. Our study group proposed the slusher to stimulate discussion of how a lunar mining operation might be successfully accomplished. Critics of the slusher system were invited to propose better methods. The group noted that while nonterrestrial mining has been a vital part of past space manufacturing proposals, no one has proposed a lunar mining system in any real detail. The group considered it essential that the design of actual, workable, and specific lunar mining methods begin immediately. Based on an earlier proposal, the method is a three-drum slusher, also known as a cable-operated drag scraper. Its terrestrial application is quite limited, as it is relatively inefficient and inflexible. The method usually finds use in underwater mining from the shore and in moving small amounts of ore underground. When lunar mining scales up, the lunarized slusher will be replaced by more efficient, high-volume methods. Other aspects of lunar mining are discussed.
Author
Lunar Excavation Equipment; Lunar Mining; Lunar Resources

19930007693 Arizona Univ., Tucson, AZ, USA
Lunar site characterization and mining
Glass, Charles E.; NASA. Johnson Space Center, Space Resources. Volume 3: Materials; JAN 1, 1992; In English; No Copyright; Avail: CASI; A02, Hardcopy; Original contains color illustrations

Lunar mining requirements do not appear to be excessively demanding in terms of volume of material processed. It seems clear, however, that the labor-intensive practices that characterize terrestrial mining will not suffice at the low-gravity, hard-vacuum, and inaccessible sites on the Moon. New research efforts are needed in three important areas: (1) to develop high-speed, high-resolution through-rock vision systems that will permit more detailed and efficient mine site investigation and characterization; (2) to investigate the impact of lunar conditions on our ability to convert conventional mining and exploration equipment to lunar prototypes; and (3) to develop telerobotic or fully robotic mining systems for operations on the Moon and other bodies in the inner solar system. Other aspects of lunar site characterization and mining are discussed.
Author
Landing Sites; Lunar Excavation Equipment; Lunar Exploration; Lunar Landing; Lunar Mining; Lunar Resources; Mineral Exploration; Site Selection

19930007692 Exxon Mineral Co., Houston, TX, USA
Lunar resource evaluation and mine site selection
Bence, A. Edward; NASA. Johnson Space Center, Space Resources. Volume 3: Materials; JAN 1, 1992; In English; No Copyright; Avail: CASI; A02, Hardcopy

Two scenarios in this evaluation of lunar mineral resources and the selection of possible mining and processing sites are considered. The first scenario assumes that no new surface or near-surface data will be available before site selection (presumably one of the Apollo sites). The second scenario assumes that additional surface geology data will have been obtained by a lunar orbiter mission, an unmanned sample return mission (or missions), and followup manned missions. Regardless of the scenario, once a potentially favorable mine site has been identified, a minimum amount of fundamental data is needed to assess the resources at that site and to evaluate its suitability for mining and downstream processing. Since much of the required data depends on the target mineral(s), information on the resource, its beneficiation, and the refining, smelting, and fabricating processes must be factored into the evaluation. The annual capacity and producing lifetime of the mine and its associated processing plant must be estimated before the resource reserves can be assessed. The available market for the product largely determines the capacity and lifetime of the mine. The Apollo 17 site is described as a possible mining site. The use of new sites is briefly addressed.
Author
Lunar Geology; Lunar Resources; Mineral Deposits; Mining; Site Selection

19930007691 Arizona Univ., Tucson, AZ, USA
Asteroid resources
Lewis, John S.; NASA. Johnson Space Center, Space Resources. Volume 3: Materials; JAN 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

There are three types of possible asteroidal materials that appear to be attractive for exploitation: (1) volatiles, (2) free metals, and (3) bulk dirt. Because some of the near-Earth asteroids are energetically more accessible than the Moon (require a round-trip total change in velocity less than 9 km/sec, though the trip time would be measured in years not days), such an asteroid might be chosen as the source of any useful material, even if that material was also available on the Moon. Provided

that the asteroid was minable, it might therefore be chosen as the source of bulk dirt needed for shielding in low Earth orbit (LEO) or elsewhere in near-Earth space. And the near-Earth asteroids may offer materials that are rare or absent on the surface of the Moon. The relationship between asteroids and meteorites is discussed. A brief overview of the entire range of meteorite compositions, with emphasis on the occurrence of interesting resources is presented. Focus is on materials useful in space, especially volatiles, metals, and raw dirt. Those few materials that may have sufficiently high market value to be worth returning to Earth will be mentioned.
Author
Asteroid Missions; Asteroids; Extraterrestrial Resources; Meteorites; Meteoritic Composition

19930007690 Rensselaer Polytechnic Inst., Troy, NY, USA
Ground-based observation of near-Earth asteroids
Gaffey, Michael J.; NASA. John Space Center, Space Resources. Volume 3: Materials; JAN 1, 1992; In English; No Copyright; Avail: CASI; A02, Hardcopy

An increased ground-based observation program is an essential component of any serious attempt to assess the resource potential of near-Earth asteroids. A vigorous search and characterization program could lead to the discovery and description of about 400 to 500 near-Earth asteroids in the next 20 years. This program, in conjunction with meteorite studies, would provide the data base to ensure that the results of a small number of asteroid-rendezvous and sample-return missions could be extrapolated with confidence into a geological base map of the Aten, Apollo, and Amor asteroids. Ground-based spectral studies of nearly 30 members of the Aten/Apollo/Amor population provide good evidence that this class includes bodies composed of silicates, metal-silicates, and carbonaceous assemblages similar to those found in meteorites. The instruments that are being used or could be used to search for near-Earth asteroids are listed. Techniques useful in characterizing asteroids and the types of information obtainable using these techniques are listed.
Author
Asteroid Missions; Asteroids; Extraterrestrial Resources; Schmidt Telescopes; Space Observations (From Earth)

19930007689 Texas Univ., Dallas, TX, USA
Lunar material resources: An overview
Carter, James L.; NASA. Johnson Space Center, Space Resources. Volume 3: Materials; JAN 1, 1992; In English
Contract(s)/Grant(s): NAG9-99; No Copyright; Avail: CASI; A03, Hardcopy

The analysis of returned lunar samples and a comparison of the physical and chemical processes operating on the Moon and on the Earth provide a basis for predicting both the possible types of material resources (especially minerals and rocks) and the physical characteristics of ore deposits potentially available on the Moon. The lack of free water on the Moon eliminates the classes of ore deposits that are most exploitable on Earth; namely, (1) hydrothermal, (2) secondary mobilization and enrichment, (3) precipitation from a body of water, and (4) placer. The types of lunar materials available for exploitation are whole rocks and their contained minerals, regolith, fumarolic and vapor deposits, and nonlunar materials, including solar wind implantations. Early exploitation of lunar material resources will be primarily the use of regolith materials for bulk shielding; the extraction from regolith fines of igneous minerals such as plagioclase feldspars and ilmenite for the production of oxygen, structural metals, and water; and possibly the separation from regolith fines of solar-wind-implanted volatiles. The only element, compound, or mineral, that by itself has been identified as having the economic potential for mining, processing, and return to Earth is helium-3.
Author
Lunar Geology; Lunar Resources; Lunar Rocks; Lunar Soil; Mineral Deposits; Mining

19930007688 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Lunar exploration for resource utilization
Duke, Michael B.; Space Resources. Volume 3: Materials; JAN 1, 1992; In English; No Copyright; Avail: CASI; A01, Hardcopy

The strategy for developing resources on the Moon depends on the stage of space industrialization. A case is made for first developing the resources needed to provide simple materials required in large quantities for space operations. Propellants, shielding, and structural materials fall into this category. As the enterprise grows, it will be feasible to develop additional sources - those more difficult to obtain or required in smaller quantities. Thus, the first materials processing on the Moon will probably take the abundant lunar regolith, extract from it major mineral or glass species, and do relatively simple chemical processing. We need to conduct a lunar remote sensing mission to determine the global distribution of features, geophysical

properties, and composition of the Moon, information which will serve as the basis for detailed models of and engineering decisions about a lunar mine.
Author
Lunar Exploration; Lunar Resources; Materials Recovery; Regolith; Remote Sensing; Space Industrialization

19930007687 Colorado School of Mines, Golden, CO, USA
To build a mine: Prospect to product
Gertsch, Richard E.; NASA. Johnson Space Center, Space Resources. Volume 3: Materials; JAN 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

The terrestrial definition of ore is a quantity of earth materials containing a mineral that can be extracted at a profit. While a space-based resource-gathering operation may well be driven by other motives, such an operation should have the most favorable cost-benefit ratio possible. To this end, principles and procedures already tested by the stringent requirements of the profit motive should guide the selection, design, construction, and operation of a space-based mine. Proceeding from project initiation to a fully operational mine requires several interacting and overlapping steps, which are designed to facilitate the decision process and insure economic viability. The steps to achieve a fully operational mine are outlined. Presuming that the approach to developing nonterrestrial resources will parallel that for developing mineral resources on Earth, we can speculate on some of the problems associated with developing lunar and asteroidal resources. The baseline for our study group was a small lunar mine and oxygen extraction facility. The development of this facility is described in accordance with the steps outlined.
Author
Economics; Lunar Exploration; Lunar Resources; Mineral Deposits; Mining

19930007686 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Space resources. Volume 3: Materials
Mckay, Mary Fae, editor; Mckay, David S., editor; Duke, Michael B., editor; JAN 1, 1992; In English; See also N93-16876 through N93-16904
Report No.(s): NASA-SP-509-VOL-3; S-689-VOL-3; NAS 1.21:509-VOL-3; LC-92-4468; No Copyright; Avail: CASI; A15, Hardcopy; Original contains color illustrations

Space Resources addresses the issues of using space resources to support life on the Moon and for exploration of Mars. This volume - Materials - covers a number of technical and policy issues regarding the materials in space (mainly lunar and asteroidal) which can be used to support space operations. In part 1, nature and location of these materials, exploration strategy, evaluation criteria, and the technical means to collect or mine these materials is discussed. A baseline lunar mine and the basics of asteroid mining are presented and critiqued. In part 2, the beneficiation of ores and the extraction of such materials as oxygen, metals, and the makings of concrete are discussed. In part 3, the manufacturing and fabrication of nonterrestrial products are discussed. The economic tradeoffs between bringing needed products from Earth and making these products on location in space is considered.
Extraterrestrial Resources; Materials; Minerals; Mining; Space Exploration

19930007685 Eagle Engineering, Inc., Houston, TX, USA
Issues for further study
Davis, Hubert P.; NASA. Johnson Space Center, Space Resources. Volume 1: Scenarios; JAN 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

The topics covered include the following: a lunar outpost map, lunar resource utilization, asteroid resource utilization, space energy utilization, and space ‘real estate’ utilization.
Author
Asteroids; Extraterrestrial Resources; Lunar Bases; Lunar Exploration; Lunar Mining; Lunar Resources; Mining

19930007683 NASA Langley Research Center, Hampton, VA, USA
Alternative scenarios utilizing nonterrestrial resources
Eldred, Charles H.; Roberts, Barney B.; NASA. Johnson Space Center, Space Resources. Volume 1: Scenarios; JAN 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

A collection of alternative scenarios that are enabled or substantially enhanced by the utilization of nonterrestrial resources is provided. We take a generalized approach to scenario building so that our report will have value in the context

of whatever goals are eventually chosen. Some of the topics covered include the following: lunar materials processing; asteroid mining; lunar resources; construction of a large solar power station; solar dynamic power for the space station; reduced gravity; mission characteristics and options; and tourism.
Author
Extraterrestrial Resources; Lunar Bases; Lunar Exploration; Mars (Planet); Mission Planning; NASA Space Programs; Space Bases; Space Exploration; Space Missions

19930007681 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Space resources. Volume 1: Scenarios
Mckay, Mary Fae, editor; Mckay, David S., editor; Duke, Michael B., editor; JAN 1, 1992; In English; See also N93-16871 through N93-16874
Report No.(s): NASA-SP-509-VOL-1; S-689-VOL-1; NAS 1.21:509-VOL-1; LC-92-4468; No Copyright; Avail: CASI; A04, Hardcopy; Original contains color illustrations

A number of possible future paths for space exploration and development are presented. The topics covered include the following: (1) the baseline program; (2) alternative scenarios utilizing nonterrestrial resources; (3) impacts of sociopolitical conditions; (4) common technologies; and issues for further study.
Asteroids; Extraterrestrial Resources; Lunar Bases; Lunar Resources; Mars (Planet); Mission Planning; NASA Space Programs; Social Factors; Space Bases; Space Exploration

19930007680 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Space resources. Overview
Mckay, Mary Fae, editor; Mckay, David S., editor; Duke, Michael B., editor; JAN 1, 1992; In English
Report No.(s): NASA-SP-509; S-689; NAS 1.21:509; LC-92-4468; No Copyright; Avail: CASI; A03, Hardcopy; Original contains color illustrations

Space resources must be used to support life on the Moon and in the exploration of Mars. Just as the pioneers applied the tools they brought with them to resources they found along the way rather than trying to haul all their needs over a long supply line, so too must space travelers apply their high technology tools to local resources. This overview describes the findings of a study on the use of space resources in the development of future space activities and defines the necessary research and development that must precede the practical utilization of these resources. Space resources considered included lunar soil, oxygen derived from lunar soil, material retrieved from near-Earth asteroids, abundant sunlight, low gravity, and high vacuum. The study participants analyzed the direct use of these resources, the potential demand for products from them, the techniques for retrieving and processing space resources, the necessary infrastructure, and the economic tradeoffs.
Author
Extraterrestrial Resources; Lunar Bases; Lunar Resources; Mars (Planet); Mission Planning; NASA Space Programs; Space Bases

19930007671 Texas Univ., Austin, TX, USA
Space law and space resources
Goldman, Nathan C.; NASA. Johnson Space Center, Space Resources. Volume 4: Social Concerns; JAN 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

Space industrialization is confronting space law with problems that are changing old and shaping new legal principles. The return to the Moon, the next logical step beyond the space station, will establish a permanent human presence there. Science and engineering, manufacturing and mining will involve the astronauts in the settlement of the solar system. These pioneers, from many nations, will need a legal, political, and social framework to structure their lives and interactions. International and even domestic space law are only the beginning of this framework. Dispute resolution and simple experience will be needed in order to develop, over time, a new social system for the new regime of space.
Author
Culture (Social Sciences); Extraterrestrial Resources; Solar System; Space Industrialization; Space Law; Space Stations

19930007668 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Space resources. Volume 4: Social concerns
Mckay, Mary Fae, editor; Mckay, David S., editor; Duke, Michael B., editor; JAN 1, 1992; In English; See also N93-16858 through N93-16868
Report No.(s): NASA-SP-509-VOL-4; S-689-VOL-4; NAS 1.21:509-VOL-4; LC-92-4468; No Copyright; Avail: CASI; A14, Hardcopy; Original contains color illustrations

Space resources must be used to support life on the Moon and exploration of Mars. This volume, Social Concerns, covers some of the most important issues which must be addressed in any major program for the human exploration of space. The volume begins with a consideration of the economics and management of large scale space activities. Then the legal aspects of these activities are discussed, particularly the interpretation of treaty law with respect to the Moon and asteroids. The social and cultural issues of moving people into space are considered in detail, and the eventual emergence of a space culture different from the existing culture is envisioned. The environmental issues raised by the development of space settlements are faced. Some innovative approaches are proposed to space communities and habitats and self-sufficiency is considered along with human safety at a lunar base or outpost.
Culture (Social Sciences); Extraterrestrial Resources; Lunar Bases; Moon; Social Factors; Space Habitats

19930004819 Wisconsin Univ., Madison, WI, USA
Lunar surface mining for automated acquisition of helium-3: Methods, processes, and equipment
Li, Y. T.; Wittenberg, L. J.; NASA. Johnson Space Center, The Second Conference on Lunar Bases and Space Activities of the 21st Century, Volume 2; Sep 1, 1992; In English; No Copyright; Avail: CASI; A02, Hardcopy

In this paper, several techniques considered for mining and processing the regolith on the lunar surface are presented. These techniques have been proposed and evaluated based primarily on the following criteria: (1) mining operations should be relatively simple; (2) procedures of mineral processing should be few and relatively easy; (3) transferring tonnages of regolith on the Moon should be minimized; (4) operations outside the lunar base should be readily automated; (5) all equipment should be maintainable; and (6) economic benefit should be sufficient for commercial exploitation. The economic benefits are not addressed in this paper; however, the energy benefits have been estimated to be between 250 and 350 times the mining energy. A mobile mining scheme is proposed that meets most of the mining objectives. This concept uses a bucket-wheel excavator for excavating the regolith, several mechanical electrostatic separators for beneficiation of the regolith, a fast-moving fluidized bed reactor to heat the particles, and a palladium diffuser to separate H2 from the other solar wind gases. At the final stage of the miner, the regolith 'tailings' are deposited directly into the ditch behind the miner and cylinders of the valuable solar wind gases are transported to a central gas processing facility. During the production of He-3, large quantities of valuable H2, H2O, CO, CO2, and N2 are produced for utilization at the lunar base. For larger production of He-3 the utilization of multiple-miners is recommended rather than increasing their size. Multiple miners permit operations at more sites and provide redundancy in case of equipment failure.
Author
Helium Isotopes; Lunar Bases; Lunar Excavation Equipment; Lunar Mining; Lunar Resources; Lunar Surface; Mineral Deposits; Regolith; Space Commercialization

19930004815 NASA Langley Research Center, Hampton, VA, USA
Conceptual design of a lunar base thermal control system
Simonsen, Lisa C.; Debarro, Marc J.; Farmer, Jeffery T.; NASA. Johnson Space Center, The Second Conference on Lunar Bases and Space Activities of the 21st Century, Volume 2; Sep 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

Space station and alternate thermal control technologies were evaluated for lunar base applications. The space station technologies consisted of single-phase, pumped water loops for sensible and latent heat removal from the cabin internal environment and two-phase ammonia loops for the transportation and rejection of these heat loads to the external environment. Alternate technologies were identified for those areas where space station technologies proved to be incompatible with the lunar environment. Areas were also identified where lunar resources could enhance the thermal control system. The internal acquisition subsystem essentially remained the same, while modifications were needed for the transport and rejection subsystems because of the extreme temperature variations on the lunar surface. The alternate technologies examined to accommodate the high daytime temperatures incorporated lunar surface insulating blankets, heat pump system, shading, and lunar soil. Other heat management techniques, such as louvers, were examined to prevent the radiators from freezing. The impact of the geographic location of the lunar base and the orientation of the radiators was also examined. A baseline design was generated that included weight, power, and volume estimates.
Author
Cabin Atmospheres; Closed Cycles; Latent Heat; Lunar Bases; Lunar Resources; Lunar Surface; Space Stations; Temperature Control; Water

19930004810 Wisconsin Univ., Madison, WI, USA

Potential of derived lunar volatiles for life support

Bula, R. J.; Wittenberg, L. J.; Tibbitts, T. W.; Kulcinski, G. L.; NASA. Johnson Space Center, The Second Conference on Lunar Bases and Space Activities of the 21st Century, Volume 2; Sep 1, 1992; In English; No Copyright; Avail: CASI; A01, Hardcopy

The lunar regolith contains small quantities of solar wind implanted volatile compounds that have vital, basic uses for maintaining life support systems of lunar or space settlements. Recent proposals to utilize the helium-3 isotope (He-3) derived from the lunar regolith as a fuel for fusion reactors would result in the availability of large quantities of other lunar volatile compounds. The quantities obtained would provide the annual life support replacement requirements of 1150 to 23,000 inhabitants per ton of He-3 recovered, depending on the volatile compound. Utilization of the lunar volatile compounds for life support depends on the costs, in terms of materials and energy, associated with their extraction from the lunar regolith as compared to the delivery costs of these compounds from Earth resources. Considering today's conservative estimated transportation costs ($10,000 dollars per kilogram) and regolith mining costs ($5 dollars per ton), the life support replacement requirements could be more economically supplied by recovering the lunar volatile compounds than transporting these materials from Earth resources, even before He-3 will be utilized as a fusion fuel. In addition, availability of lunar volatile compounds could have a significant cost impact on maintaining the life support systems of the space station and a Mars base.
Author

Helium Isotopes; Life Support Systems; Lunar Bases; Lunar Mining; Lunar Resources; Lunar Soil; Regolith

19930004805 Walt Disney World Co., Lake Buena Vista, FL, USA

Lunar base CELSS: A bioregenerative approach

Easterwood, G. W.; Street, J. J.; Sartain, J. B.; Hubbell, D. H.; Robitaille, H. A.; NASA. Johnson Space Center, The Second Conference on Lunar Bases and Space Activities of the 21st Century, Volume 2; Sep 1, 1992; In English; No Copyright; Avail: CASI; A01, Hardcopy

During the twenty-first century, human habitation of a self-sustaining lunar base could become a reality. To achieve this goal, the occupants will have to have food, water, and an adequate atmosphere within a carefully designed environment. Advanced technology will be employed to support terrestrial life-sustaining processes on the Moon. One approach to a life support system based on food production, waste management and utilization, and product synthesis is outlined. Inputs include an atmosphere, water, plants, biodegradable substrates, and manufacutured materials such as fiberglass containment vessels from lunar resources. Outputs include purification of air and water, food, and hydrogen (H2) generated from methane (CH4). Important criteria are as follows: (1) minimize resupply from Earth; and (2) recycle as efficiently as possible.
Author

Air Purification; Closed Ecological Systems; Food Production (In Space); Life Support Systems; Lunar Bases; Lunar Resources; Regeneration (Physiology); Waste Utilization; Water

19930004801

Concrete structure construction on the Moon

Matsumoto, Shinji; Namba, Haruyuki; Kai, Yoshiro; Yoshida, Tetsuji; NASA. Johnson Space Center, The Second Conference on Lunar Bases and Space Activities of the 21st Century, Volume 2; Sep 1, 1992; In English; No Copyright; Avail: CASI; A01, Hardcopy

This paper describes a precast prestressed concrete structure system on the Moon and erection methods for this system. The horizontal section of the structural module is hexagonal so that various layouts of the modules are possible by connecting the adjacent modules to each other. For erection of the modules, specially designed mobile cranes are used.
Author

Concrete Structures; Construction; Construction Materials; Lunar Bases; Lunar Resources; Space Habitats; Structural Design

19930004800

The possibility of concrete production on the Moon

Ishikawa, Noboru; Kanamori, Hiroshi; Okada, Takeji; NASA. Johnson Space Center, The Second Conference on Lunar Bases and Space Activities of the 21st Century, Volume 2; Sep 1, 1992; In English; No Copyright; Avail: CASI; A01, Hardcopy

When a long-term lunar base is constructed, most of the materials for the construction will be natural resources on the Moon, mainly for economic reasons. In terms of economy and exploiting natural resources, concrete would be the most

suitable material for construction. This paper describes the possibility of concrete production on the Moon. The possible production methods are derived from the results of a series of experiments that were carried out taking two main environmental features, low gravity acceleration and vacuum, into consideration.
Author
Concretes; Construction; Construction Materials; Lunar Bases; Lunar Resources; Lunar Soil; Microgravity; Moon; Vacuum

19930004798 Orbital Technologies Corp., Madison, WI, USA
Synergism of He-3 acquisition with lunar base evolution
Crabb, T. M.; Jacobs, M. K.; NASA. Johnson Space Center, The Second Conference on Lunar Bases and Space Activities of the 21st Century, Volume 2; Sep 1, 1992; In English; No Copyright; Avail: CASI; A02, Hardcopy

Researchers have discovered that the lunar surface contains a valuable fusion fuel element that is relatively scarce on Earth. This element, He-3, originates from the solar wind that has bombarded the surface of the Moon over geologic time. Mining operations to recover this resource would allow the by-product acquisition of hydrogen, water, carbon dioxide, carbon monoxide, methane, and nitrogen from the lunar surface with relatively minimal additional resource investment when compared to the costs to supply these resources from Earth. Two configurations for the He-3 mining system are discussed, and the impacts of these mining operations on a projected lunar base scenario are assessed. We conclude that the acquisition of He-3 is feasible with minimal advances in current state-of-the-art technologies and could support a terrestrial nuclear fusion power economy with the lowest hazard risk of any nuclear reaction known. Also, the availability of the by-products of He-3 acquisition from the Moon could significantly reduce the operational requirements of a lunar base and increase the commercialization potential of the base through consumable resupply of the lunar base itself, other components of the space infrastructure, and other space missions.
Author
By-Products; Cost Effectiveness; Helium Isotopes; Lunar Bases; Lunar Mining; Lunar Surface; Nuclear Fusion; Radiation Hazards; Solar Wind

19930004797 Wisconsin Univ., Madison, WI, USA
Fusion energy from the Moon for the twenty-first century
Kulcinski, G. L.; Cameron, E. N.; Santarius, J. F.; Sviatoslavsky, I. N.; Wittenberg, L. J.; Schmitt, Harrison H.; NASA. Johnson Space Center, The Second Conference on Lunar Bases and Space Activities of the 21st Century, Volume 2; Sep 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

It is shown in this paper that the D-He-3 fusion fuel cycle is not only credible from a physics standpoint, but that its breakeven and ignition characteristics could be developed on roughly the same time schedule as the DT cycle. It was also shown that the extremely low fraction of power in neutrons, the lack of significant radioactivity in the reactants, and the potential for very high conversion efficiencies, can result in definite advantages for the D-He-3 cycle with respect to DT fusion and fission reactors in the twenty-first century. More specifically, the D-He-3 cycle can accomplish the following: (1) eliminate the need for deep geologic waste burial facilities and the wastes can qualify for Class A, near-surface land burial; (2) allow 'inherently safe' reactors to be built that, under the worst conceivable accident, cannot cause a civilian fatality or result in a significant (greater than 100 mrem) exposure to a member of the public; (3) reduce the radiation damage levels to a point where no scheduled replacement of reactor structural components is required, i.e., full reactor lifetimes (approximately 30 FPY) can be credibly claimed; (4) increase the reliability and availability of fusion reactors compared to DT systems because of the greatly reduced radioactivity, the low neutron damage, and the elimination of T breeding; and (5) greatly reduce the capital costs of fusion power plants (compared to DT systems) by as much as 50 percent and present the potential for a significant reduction on the COE. The concepts presented in this paper tie together two of the most ambitious high-technology endeavors of the twentieth century: the development of controlled thermonuclear fusion for civilian power applications and the utilization of outer space for the benefit of mankind on Earth.
Author
Controlled Fusion; Deuterium; Energy Conversion Efficiency; Fusion Reactors; Helium Isotopes; Lunar Bases; Lunar Resources; Radiation Damage; Radiation Hazards

19930004796 Spectra Research Systems, Inc., Huntsville, AL, USA
Impact of lunar oxygen production on direct manned Mars missions
Young, Roy M., Jr.; Tucker, William B.; NASA. Johnson Space Center, The Second Conference on Lunar Bases and Space Activities of the 21st Century, Volume 2; Sep 1, 1992; In English; No Copyright; Avail: CASI; A02, Hardcopy

A manned Mars program made up of six missions is evaluated to determine the impact of using lunar liquid oxygen (LOX) as a propellant. Two departure and return nodes, low Earth orbit and low lunar orbit, are considered, as well as two return vehicle configurations, a full 70,000-kg vehicle and a 6800-kg capsule. The cost of lunar LOX delivered to orbit is expressed as a ratio of Earth launch cost.
Author
Cost Analysis; Liquid Oxygen; Liquid Rocket Propellants; Lunar Resources; Manned Mars Missions; Oxygen Production

19930004795 Technische Univ., Berlin, Germany
The influence of lunar propellant production on the cost-effectiveness of cislunar transportation systems
Koelle, H. H.; NASA. Johnson Space Center, The Second Conference on Lunar Bases and Space Activities of the 21st Century, Volume 2; Sep 1, 1992; In English; No Copyright; Avail: CASI; A02, Hardcopy

It is well known that propellants produced at the points of destination such as the Moon or Mars will help the economy of space transportation, particularly if round trips with a crew are involved. The construction and operation of a lunar base shortly after the turn of the century is one of the space programs under serious consideration at the present time. Space transportation is one of the major cost drivers. With present technology, if expendable launchers were employed, the specific transportation costs of one-way cargo flights would be approximately 10,000 dollars/kg (1985) at life-cycle cumulative 100,000 ton payload to the lunar surface. A fully reusable space transportation system using lunar oxygen and Earth-produced liquid hydrogen (LH2) would reduce the specific transportation costs by one order of magnitude to less than 1000 dollars/kg at the same payload volume. Another case of primary interest is the delivery of construction material and consumables from the lunar surface to the assembly site of space solar power plants in geostationary orbit (GEO). If such a system were technically and economically feasible, a cumulative payload of about 1 million tons or more would be required. At this level a space freighter system could deliver this material from Earth for about 300 dollars/kg (1985) to GEO. A lunar space transportation system using lunar oxygen and a fuel mixture of 50 percent Al and 50 percent LH2 (that has to come from Earth) could reduce the specific transportation costs to less than half, approximately 150 dollars/kg. If only lunar oxygen were available, these costs would come down to 200 dollars/kg. This analysis indicates a sizable reduction of the transportation burden on this type of mission. It should not be overlooked, however, that there are several uncertainties in such calculations. It is quite difficult at this point to calculate the cost of lunar-produced O and/or Al. This will be a function of production rate and life-cycle length. In quoting any cost of this nature, it is very important to state the cumulative transportation volume, since this is a very sensitive parameter. Nevertheless, cost models must be developed now to understand fully the interdependencies of a large number of parameters and to provide the best possible data for planning purposes. Without such data, mission modes and vehicle designs or sizes cannot be selected intelligently.
Author
Cislunar Space; Consumables (Spacecraft); Cost Effectiveness; Costs; Liquid Rocket Propellants; Lunar Bases; Lunar Resources; Payloads; Space Transportation System

19930004793 Los Alamos National Lab., NM, USA
Uses of lunar sulfur
Vaniman, D.; Pettit, D.; Heiken, G.; NASA. Johnson Space Center, The Second Conference on Lunar Bases and Space Activities of the 21st Century, Volume 2; Sep 1, 1992; In English; No Copyright; Avail: CASI; A02, Hardcopy

Sulfur and sulfur compounds have a wide range of applications for their fluid, electrical, chemical, and biochemical properties. Although known abundances on the Moon are limited (approximately 0.1 percent in mare soils), sulfur is relatively extractable by heating. Coproduction of sulfur during oxygen extraction from ilmenite-rich mare soils could yield sulfur in masses up to 10 percent of the mass of oxygen produced. Sulfur deserves serious consideration as a lunar resource.
Author
Lunar Maria; Lunar Resources; Lunar Soil; Sulfur; Sulfur Compounds

19930004792 Lunar and Planetary Inst., Houston, TX, USA
Lunar mining of oxygen using fluorine
Burt, Donald M.; NASA. Johnson Space Center, The Second Conference on Lunar Bases and Space Activities of the 21st Century, Volume 2; Sep 1, 1992; In English
Contract(s)/Grant(s): NASW-4066
Report No.(s): LPI-CONTRIB-748; No Copyright; Avail: CASI; A02, Hardcopy

An important aspect of lunar mining will be the extraction of volatiles, particularly oxygen, from lunar rocks.

Thermodynamic data show that oxygen could readily be recovered by fluorination of abundant lunar anorthite, CaAl2Si2O8. Fluorine is the most reactive element, and the only reagent able to extract 100 percent of the oxygen from any mineral, yet it can safely be stored or reacted in nickel or iron containers. The general fluorination reaction, mineral + 2F2 = mixed fluorides = O2, has been used for more than 30 years at a laboratory scale by stable-isotope geochemists. For anorthite, metallic Al and Si may be recovered from the mixed fluorides by Na-reduction, and CaO via exchange with Na2O; the resulting NaF may be recycled into F2 and Na by electrolysis, using lanthanide-doped CaF2 as the inert anode.
Author
Calcium Fluorides; Electrolysis; Extraction; Fluorination; Fluorine; Lunar Mining; Lunar Rocks; Oxygen

19930004790 Pennsylvania State Univ., University Park, PA, USA
Lunar resource recovery: A definition of requirements
Elsworth, D.; Kohler, J. L.; Alexander, S. S.; NASA. Johnson Space Center, The Second Conference on Lunar Bases and Space Activities of the 21st Century, Volume 2; Sep 1, 1992; In English; No Copyright; Avail: CASI; A01, Hardcopy

The capability to locate, mine, and process the natural resources of the Moon will be an essential requirement for lunar base development and operation. The list of materials that will be necessary is extensive and ranges from oxygen and hydrogen for fuel and life support to process tailings for emplacement over habitats. Despite the resources need, little is known about methodologies that might be suitable for utilizing lunar resources. This paper examines some of the requirements and constraints for resource recovery and identifies key areas of research needed to locate, mine, and process extraterrestrial natural resources.
Author
Habitats; Life Support Systems; Lunar Bases; Lunar Resources; Lunar Soil; Space Manufacturing

19930004789 Space Studies Inst., Princeton, NJ, USA
First steps to lunar manufacturing: Results of the 1988 Space Studies Institute Lunar Systems Workshop
Maryniak, Gregg E.; NASA. Johnson Space Center, The Second Conference on Lunar Bases and Space Activities of the 21st Century, Volume 2; Sep 1, 1992; In English; No Copyright; Avail: CASI; A02, Hardcopy

Prior studies by NASA and the Space Studies Institute have looked at the infrastructure required for the construction of solar power satellites (SPS) and other valuable large space systems from lunar materials. This paper discusses the results of a Lunar Systems Workshop conducted in January 1988. The workshop identified components of the infrastructure that could be implemented in the near future to create a revenue stream. These revenues could then be used to 'bootstrap' the additional elements required to begin the commercial use of nonterrestrial materials.
Author
Large Space Structures; Lunar Resources; Solar Power Satellites; Space Commercialization; Space Industrialization; Space Manufacturing; Technology Utilization

19930004788 Washington Univ., Saint Louis, MO, USA
Water and cheese from the lunar desert: Abundances and accessibility of H, C, and N on the Moon
Haskin, L. A.; NASA. Johnson Space Center, The Second Conference on Lunar Bases and Space Activities of the 21st Century, Volume 2; Sep 1, 1992; In English
Contract(s)/Grant(s): NAG9-56; No Copyright; Avail: CASI; A01, Hardcopy

The Moon has been underrated as a source of H, N, C, and other elements essential to support life and to provide fuel for rockets. There is enough of these elements in each cubic meter of typical lunar soil to provide a substantial lunch for two, if converted to edible forms. The average amount of C per square meter of the lunar surface to a depth of 2 m is some 35 percent of the average amount per square meter tied up in living organisms on Earth. The water equivalent of H in the upper 2 m of the regolith averages at least 1.3 million liters per square kilometer. Mining of H from a small fraction of the regolith would provide all the rocket fuel needed for thousands of years. These elements can be removed from the soil by heating it to high temperature. Some favor the unproven resources of Phobos, Deimos, or near-Earth asteroids instead of the Moon as a source of extraterrestrial material for use in space, or Mars over the Moon as a site for habitation, partly on the basis that the chemical elements needed for life support and propellant are readily abundant on those bodies, but not on the Moon. Well, the Moon is not as barren of H, C, and N as is commonly perceived. In fact, the elements needed for life support and for rocket fuel are plentiful there, although the ore grades are low. Furthermore, the proximity of the Moon and consequent lower cost

of transportation and shorter trip and communication times favor that body as the logical site for early acquisition of resources and extraterrestrial living.
Author
Chemical Composition; Deserts; Lunar Bases; Lunar Geology; Lunar Resources; Lunar Soil; Minerals; Mining; Water

19930004787 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Applications for special-purpose minerals at a lunar base
Ming, Douglas W.; The Second Conference on Lunar Bases and Space Activities of the 21st Century, Volume 2; Sep 1, 1992; In English; No Copyright; Avail: CASI; A02, Hardcopy

Maintaining a colony on the Moon will require the use of lunar resources to reduce the number of launches necessary to transport goods from the Earth. It may be possible to alter lunar materials to produce minerals or other materials that can be used for applications in life support systems at a lunar base. For example, mild hydrothermal alteration of lunar basaltic glasses can produce special-purpose minerals (e.g., zeolites, smectites, and tobermorites) that in turn may be used in life support, construction, waste renovation, and chemical processes. Zeolites, smectites, and tobermorites have a number of potential applications at a lunar base. Zeolites are hydrated aluminosilicates of alkali and alkaline earth cations that possess infinite, three-dimensional crystal structures. They are further characterized by an ability to hydrate and dehydrate reversibly and to exchange some of their constituent cations, both without major change of structure. Based on their unique absorption, cation exchange, molecular sieving, and catalytic properties, zeolites may be used as a solid support medium for the growth of plants, as an adsorption medium for separation of various gases (e.g., N2 from O2), as catalysts, as molecular sieves, and as a cation exchanger in sewage-effluent treatment, in radioactive waste disposal, and in pollution control. Smectites are crystalline, hydrated 2:1 layered aluminosilicates that also have the ability to exchange some of their constituent cations. Like zeolites, smectites may be used as an adsorption medium for waste renovation, as adsorption sites for important essential plant growth cations in solid support plant growth mediums (i.e., 'soils'), as cation exchangers, and in other important application. Tobermorites are cystalline, hydrated single-chained layered silicates that have cation-exchange and selectivity properties between those of smectites and most zeolites. Tobermorites may be used as a cement in building lunar base structures, as catalysts, as media for nuclear and hazardous waste disposal, as exchange media for waste-water treatment, and in other potential applications. Special-purpose minerals synthesized at a lunar base may also have important applications at a space station and for other planetary missions. New technologies will be required at a lunar base to develop life support systems that are self-sufficient, and the use of special-purpose minerals may help achieve this self-sufficiency.
Author
Aluminum Silicates; Catalysts; Chemical Reactions; Lunar Bases; Lunar Resources; Minerals; Zeolites

19920073980 NASA, Washington, DC, USA
Behavior of compacted lunar simulants using new vacuum triaxial device
Desai, Chandra S.; Saadatmanesh, Hamid; Allen, Thomas; Journal of Aerospace Engineering; Oct 1, 1992; ISSN 0893-1321; 5, 4, Oc; In English; Copyright; Avail: Other Sources

The objectives of this study are to create a lunar simulant locally from a basaltic rock and to design and develop a vacuum triaxial test device that can permit testing of compacted lunar simulant under cyclic loading with different levels of initial vacuum. Triaxial testing is performed in the device itself without removing the compacted specimen. Preliminary constrained compression and triaxial shear tests are performed to identify effects of initial confinements and vacuums. The results are used to define deformation and strength parameters. At this time, vacuum levels up to 0.0001 are possible. The research can aid in the development of compacted materials for various construction applications.
AIAA
Basalt; Environment Simulation; Load Testing Machines; Lunar Resources; Triaxial Stresses; Vacuum Tests

19920072994 NASA, Washington, DC, USA
In-situ resource utilization activities at the NASA Space Engineering Research Center
Ramohalli, Kumar; Aug 1, 1992; In English
Contract(s)/Grant(s): NAGW-1332
Report No.(s): IAF PAPER 92-0156; Copyright; Avail: Other Sources

The paper describes theoretical and experimental research activities at the NASA Space Engineering Research Center aimed at realizing significant cost savings in space missions through the use of locally available resources. The fundamental strategy involves idea generation, scientific screening, feasibility demonstrations, small-scale process plant design, extensive

testing, scale-up to realistic production rates, associated controls, and ‘packaging’, while maintaining sufficient flexibility to respond to national needs in terms of specific applications. Aside from training, the principal activities at the Center include development of a quantitative figure-of-merit to quickly assess the overall mission impact of individual components that constantly change with advancing technologies, extensive tests on a single-cell test bed to produce oxygen from carbon dioxide, and the use of this spent stream to produce methane.
AIAA
Extraterrestrial Resources; In Situ Measurement; NASA Space Programs; Research Facilities; Space Missions

19920071406 NASA Lewis Research Center, Cleveland, OH, USA
Engine system assessment study using Martian propellants
Pelaccio, D.; Jacobs, M.; Collins, J.; Scheil, C.; Meyer, M.; Jul 1, 1992; In English
Contract(s)/Grant(s): NAS3-25809
Report No.(s): AIAA PAPER 92-3446; Copyright; Avail: Other Sources

A feasibility study was performed that identified and characterized promising chemical propulsion system designs that utilize two or more of the propellant combinations: LOX/H2, LOX/CH4 and LOX/CO. The engine systems examined focused on the usage of common subsystem/component hardware where feasible. From the evaluation baseline employed, tripropellant MTV LOX cooled and bipropellant LEV and MEV engine systems are identified.
AIAA
Chemical Propulsion; Extraterrestrial Resources; Mars (Planet); Spacecraft Propulsion

19920067989 NASA Lewis Research Center, Cleveland, OH, USA
In-situ carbon dioxide fixation on Mars
Hepp, Aloysius F.; Landis, Geoffrey A.; Kubiak, Clifford P.; JAN 1, 1991; In English; 26th IECEC ‘91: Intersociety Energy Conversion Engineering Conference, Aug. 4-9, 1991, Boston, MA, USA; Copyright; Avail: Other Sources

The authors examine several novel proposals for CO2 fixation through chemical, photochemical, and photoelectrochemical means. For example, the reduction of CO2 to hydrocarbons such as acetylene (C2H2) can be accomplished with hydrogen. Acetylene has a theoretical vacuum specific impulse of about 375 s. The authors also examine potential uses of CO, as obtained or further reduced to carbon, as a reducing agent in metal oxide processing to form metals or metal carbides for use as structural or power materials. The CO2 can be recycled to generate O2 and CO. In this study, the authors examine reaction schemes for processing in situ resources. The authors highlight chemistry with hydrogen and carbon monoxide to produce propellants and other necessities of manned exploration.
AIAA
Carbon Dioxide; Extraterrestrial Resources; Mars (Planet)

19920067652 NASA, Washington, DC, USA
Full system engineering design and operation of an oxygen plant
Colvin, James; Schallhorn, Paul; Ramohalli, Kumar; Journal of Propulsion and Power; Oct 1, 1992; ISSN 0748-4658; 8, 5, Se; In English
Contract(s)/Grant(s): NAGW-1332; Copyright; Avail: Other Sources
Electrolytic Cells; Extraterrestrial Resources; Mars (Planet); Oxygen Production; Solid Electrolytes; Zirconium Oxides

19920065557 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Olivine in Antarctic micrometeorites - Comparison with other extraterrestrial olivine
Steele, Ian M.; Geochimica et Cosmochimica Acta; Jul 1, 1992; ISSN 0016-7037; 56, 7, Ju; In English
Contract(s)/Grant(s): NSF EAR-84-15791; NSF EAR-86-08299; NAG9-47; Copyright; Avail: Other Sources

The compositions of 5-micron or larger Mg-rich olivines from 26 Antarctic micrometeorite particles were examined and compared with those of other extraterrestrial olivine. The following differences were noted between the Antarctic meteorites and the generally recognized meteorite groups: (1) while refractory-rich (e.g., high Al2O3 or CaO) are common in C2, C3, and UOC meteorites, there are only rare, or possibly no refractory-rich olivines in Antarctic micrometeorites; (2) Mg-rich olivine compositions with FeO less than 1.9 wt pct are underrepresented in the Antarctic micrometeorites, relative to other

unequilibrated meteorites; and (3) no Mn-rich, high-Mg olivines were found similar to those described in interplanetary dust, C1, C2, C3, and UOC meteorites.
AIAA
Extraterrestrial Resources; Meteoritic Composition; Micrometeorites; Olivine

19920061903 NASA Ames Research Center, Moffett Field, CA, USA
Propellant production from the Martian atmosphere
Bowles, J. V.; Tauber, M. E.; Anagnost, A. J.; Whittaker, T.; Journal of Propulsion and Power; Aug 1, 1992; ISSN 0748-4658; 8, 4, Ju; In English; Copyright; Avail: Other Sources

Results are presented from a calculation of the specific impulses that can be generated through the combustion of cryogenic CO and O2 over a range of fuel/oxidizer ratios, chamber pressures, nozzle expansion ratios, freestream pressures representative of Mars, and the limiting conditions of equilibrium and frozen nozzle flow. For an expansion ratio of 80 and 100-atm. chamber pressure, a specific impulse of 298 sec was obtained; this is comparable to the best solid rocket propellants.
AIAA
Cryogenic Rocket Propellants; Extraterrestrial Resources; Manned Mars Missions; Mars Atmosphere; Propellant Combustion

19920061897 NASA, Washington, DC, USA
Lunar-derived titanium alloys for hydrogen storage
Love, S.; Hertzberg, A.; Woodcock, G.; Journal of Propulsion and Power; Aug 1, 1992; ISSN 0748-4658; 8, 4, Ju; In English; Copyright; Avail: Other Sources

Hydrogen gas, which plays an important role in many projected lunar power systems and industrial processes, can be stored in metallic titanium and in certain titanium alloys as an interstitial hydride compound. Storing and retrieving hydrogen with titanium-iron alloy requires substantially less energy investment than storage by liquefaction. Metal hydride storage systems can be designed to operate at a wide range of temperatures and pressures. A few such systems have been developed for terrestrial applications. A drawback of metal hydride storage for lunar applications is the system's large mass per mole of hydrogen stored, which rules out transporting it from earth. The transportation problem can be solved by using native lunar materials, which are rich in titanium and iron.
AIAA
Energy Storage; Hydrogen; Lunar Resources; Metal Hydrides; Titanium Alloys

19920057779 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Human exploration of space and power development
Cohen, Aaron; JAN 1, 1991; In English; 2nd International Symposium SPS 91 - Power from Space, Aug. 27-30, 1991, Gif-sur-Yvette, France; Copyright; Avail: Other Sources

The possible role of Solar Power Satellites (SPS) in advancing the goals of the Space Exploration Initiative is considered. Three approaches are examined: (1) the use of lunar raw materials to construct a large SPS in GEO, (2) the construction of a similar system on the lunar surface, and (3) a combination of (1) and (2). Emphasis is given to the mining of He-3 from the moon and its use by the SPS.
AIAA
Geosynchronous Orbits; Lunar Bases; Lunar Mining; Lunar Resources; Manned Space Flight; Solar Power Satellites

19920056102 NASA, Washington, DC, USA
Processing and properties of lunar ceramics
Fabes, B. D.; Poisl, W. H.; Beck, A.; Raymond, L. A.; Mar 1, 1992; In English
Contract(s)/Grant(s): NSF DMR-91-10062
Report No.(s): AIAA PAPER 92-1668; Copyright; Avail: Other Sources

Experiments are described in which monolithic glasses, short fibers, and glass ceramics were prepared by melt processing of simulated lunar regolith. The melt was formed by direct solar as well as resistive heating and was processed using a range of techniques. The processes used in making the three types of lunar ceramics are described together with physical properties of these ceramics and their potential uses.
AIAA
Ceramics; Lunar Resources; Melting; Space Manufacturing

19920056097 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Production of oxygen on the moon - Which processes are best and why
Taylor, Lawrence A.; Mar 1, 1992; In English
Contract(s)/Grant(s): NAG9-409
Report No.(s): AIAA PAPER 92-1662; Copyright; Avail: Other Sources

An evaluation of the 20 processes put forth for the liberation of oxygen from lunar materials has resulted in a ranking according to overall feasibility. At this time, the eight processes considered to be the most likely candidates for oxygen production on the moon are: ilmenite reduction with H2, CO, and CH4, glass reduction with H2, molten silicate electrolysis, fluxed molten silicate electrolysis, vapor pyrolysis, and ion plasma pyrolysis.
AIAA
Gas-Solid Interactions; Lunar Resources; Oxygen Production; Pyrolysis; Reduction (Chemistry)

19920055627 NASA Langley Research Center, Hampton, VA, USA
A lunar orbiting Node in support of missions to Mars
Butterfield, A.; Wrobel, J. R.; Garrett, L. B.; JAN 1, 1989; In English; 26th Space Congress, Apr. 25-28, 1989, Cocoa Beach, FL, USA; Copyright; Avail: Other Sources

A conceptual design study yielded an approximate size for the platform needed to support typical oxygen-transfer rates which were based upon NASA studies of Mars missions. The Node consists of a gravity gradient stabilized lunar orbiting tank-farm with a storage capacity of 100,000 kg of lunar oxygen, 3300 kg of lunar cargo, and 9300 kg of earth-supplied hydrogen. An emergency-habitat configuration accommodates 14 persons on-board for 110 days. The Node supports an annual lunar oxygen production of 10 exp 6 kg with 220,000 kg of oxygen delivered to earth orbit for an expenditure of 109,000 kg of earth-supplied hydrogen.
AIAA
Consumables (Spacecraft); Lunar Orbits; Lunar Resources; Manned Mars Missions

19920054351 NASA, Washington, DC, USA, NASA John F. Kennedy Space Center, Cocoa Beach, FL, USA
Extraterrestrial materials processing and related transport phenomena
Ramohalli, K. N. R.; Sridhar, K. R.; Journal of Propulsion and Power; Jun 1, 1992; ISSN 0748-4658; 8, 3, Ma; In English
Contract(s)/Grant(s): NAGW-3223; Copyright; Avail: Other Sources
Cost Reduction; Extraterrestrial Resources; Heat Transfer; Materials Science; Microgravity; Space Processing

19920051600 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
A strategy for investment in space resource utilization
Mendell, Wendell W.; Acta Astronautica; Jan 1, 1992; ISSN 0094-5765; 26; In English; Copyright; Avail: Other Sources

Considerations governing a strategy for investment in the utilization of space resources are discussed. It is suggested on the basis of an examination of current trends in terms of historical processes which operate on new frontiers that the limited markets and unfamiliar technologies associated with space commercialization today may change dramatically in 20 years when lunar resources are accessible. It is argued that the uncertainty of such projections discourages investment at a useful scale unless a strategy for technology development can be implemented which provides tangible and marketable benefits in the intermediate term. At present, technologies can be identified which will be required (and therefore valuable) at the time of lunar settlement, and whose development can be planned to yield marketable intermediate products on earth. It is concluded that the formation of precompetitive collaborative research consortia in the industrial sector could reduce technical and economic risk in the early stages and could promote a favorable political environment for the future growth of space activities.
AIAA
Earth Orbital Environments; Lunar Resources; Space Commercialization; Space Industrialization; Space Transportation

19920050586 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Why explore the moon?
Duke, Michael B.; Feb 1, 1992; In English
Report No.(s): AIAA PAPER 92-1029; Copyright; Avail: Other Sources

An overview is presented of reasons to pursue exploration of the moon, including the expansion of human settlements beyond earth, the scientific benefits from the exploration of the moon, the utilization of the moon as a research laboratory, and the opening of the resources of near-earth space. Consideration is also given to Mars exploration in which the moon is used

principally as a testbed. Attention is given to the current work by the Office of Exploration, whose effort is aimed at comprehending the first 'waypoint' in a long term strategy for moving toward the moon and Mars.
AIAA
Lunar Bases; Lunar Exploration; Lunar Resources; Space Commercialization

19920049575 NASA Lewis Research Center, Cleveland, OH, USA
Acetylene fuel from atmospheric CO2 on Mars
Landis, Geoffrey A.; Linne, Diane L.; Journal of Spacecraft and Rockets; Apr 1, 1992; ISSN 0022-4650; 29; In English; Copyright; Avail: Other Sources

The Mars mission scenario proposed by Baker and Zubrin (1990) intended for an unmanned preliminary mission is extended to maximize the total impulse of fuel produced with a minimum mass of hydrogen from Earth. The hydrogen along with atmospheric carbon dioxide is processed into methane and oxygen by the exothermic reaction in an atmospheric processing module. Use of simple chemical reactions to produce acetylene/oxygen rocket fuel on Mars from hydrogen makes it possible to produce an amount of fuel that is nearly 100 times the mass of hydrogen brought from earth. If such a process produces the return propellant for a manned Mars mission, the required mission mass in LEO is significantly reduced over a system using all earth-derived propellants.
AIAA
Acetylene; Atmospheric Energy Sources; Carbon Dioxide; Extraterrestrial Resources; Hydrocarbon Fuel Production; Mars Atmosphere

19920043692 NASA, Washington, DC, USA, NASA Ames Research Center, Moffett Field, CA, USA
Mars exploration advances: Missions to Mars - Mars base
Dejarnette, Fred R.; Mckay, Christopher P.; Jan 1, 1992; In English
Contract(s)/Grant(s): NAGW-1331
Report No.(s): AIAA PAPER 92-0485; Copyright; Avail: Other Sources

An overview is presented of Mars missions and related planning with attention given to four mission architectures in the light of significant limitations. Planned unpiloted missions are discussed including the Mars Orbital Mapping Mission, the Mars Rover Sample Return, the Mars Aeronomy Orbiter, and the Mars Environmental Survey. General features relevant to the missions are mentioned including launch opportunities, manned-mission phases, and propulsion options. The four mission architectures are set forth and are made up of: (1) the Mars-exploration infrastructures; (2) science emphasis for the moon and Mars; (3) the moon to stay and Mars exploration; and (4) space resource utilization. The possibility of robotic missions to the moon and Mars is touched upon and are concluded to be possible by the end of the century. The ramifications of a Mars base are discussed with specific reference to habitability and base activities, and the human missions are shown to require a heavy-lift launcher and either chemical/aerobrake or nuclear-thermal propulsion system.
AIAA
Extraterrestrial Resources; Lunar Exploration; Manned Mars Missions; Mars Bases; Mars Exploration; Mission Planning; Roving Vehicles

19920038459 Arizona Univ., Tucson, AZ, USA
Figure-of-merit approach to extraterrestrial resource utilization
Ramohalli, Kumar; Kirsch, Thomas; Preiss, Bruce; Journal of Propulsion and Power; Feb 1, 1992; ISSN 0748-4658; 8; In English
Contract(s)/Grant(s): NAG1-332; Copyright; Avail: Other Sources
Extraterrestrial Resources; Figure of Merit; Gaseous Fuels; Space Missions

19920038324 NASA Ames Research Center, Moffett Field, CA, USA
Analyses of exobiological and potential resource materials in the Martian soil
Mancinelli, Rocco L.; Marshall, John R.; White, Melisa R.; Advances in Space Research; JAN 1, 1992; ISSN 0273-1177; 12, 4, 19; In English; Copyright; Avail: Other Sources

Potential Martian soil components relevant to exobiology include water, organic matter, evaporites, clays, and oxides. These materials are also resources for human expeditions to Mars. When found in particular combinations, some of these materials constitute diagnostic paleobiomarker suites, allowing insight to be gained into the probability of life originating on Mars. Critically important to exobiology is the method of data analysis and data interpretation. To that end, methods of

analysis of potential biomarker and paleobiomarker compounds and resource materials in soils and rocks pertinent to Martian geology are investigated. Differential thermal analysis coupled with gas chromotography is shown to be a highly useful analytical technique for detecting this wide and complex variety of materials.
AIAA
Biological Evolution; Exobiology; Extraterrestrial Resources; Mars Surface; Soil Science

19920037988 NASA Lewis Research Center, Cleveland, OH, USA
Technical prospects for utilizing extraterrestrial propellants for space exploration
Linne, Diane L.; Meyer, Michael L.; Oct 1, 1991; In English
Report No.(s): IAF PAPER 91-669; Copyright; Avail: Other Sources

NASA's LeRC has supported several efforts to understand how lunar and Martian produced propellants can be used to their best advantage for space exploration propulsion. A discussion of these efforts and their results is presented. A Manned Mars Mission Analysis Study identified that a more thorough technology base for propellant production is required before the net economic benefits of in situ propellants can be determined. Evaluation of the materials available on the moon indicated metal/oxygen combinations are the most promising lunar propellants. A hazard analysis determined that several lunar metal/LOX monopropellants could be safely worked with in small quantities, and a characterization study was initiated to determine the physical and chemical properties of potential lunar monopropellant formulations. A bipropellant metal/oxygen subscale test engine which utilizes pneumatic injection of powdered metal is being pursued as an alternative to the monopropellant systems. The technology for utilizing carbon monoxide/oxygen, a potential Martian propellant, was studied in subscale ignition and rocket performance experiments.
AIAA
Extraterrestrial Resources; Fuel Production; Lunar Exploration; Lunar Resources; Manned Mars Missions; Rocket Propellants; Spacecraft Propulsion

19920037986 Eagle Engineering, Inc., Houston, TX, USA
Lunar hydrogen extraction
Snaufer, M. J.; Alred, J. W.; Oct 1, 1991; In English
Contract(s)/Grant(s): NAS9-17900
Report No.(s): IAF PAPER 91-667; Copyright; Avail: Other Sources

This paper examines the power and mass requirements of a lunar hydrogen extraction plant producing five metric tons of hydrogen per year. These power and mass requirements are based upon experimental work that determined gaseous hydrogen release rates from lunar samples at various heating rates and temperatures. An optimum heating temperature and rate can be selected to minimize the processing plant's power and mass requirements. The impact of thermal recovery on the power and mass requirements is studied, as is the use of nuclear waste heat for processing the regolith. In addition, the potential of using the extracted hydrogen in the form of methane as a propellant for a Lunar Excursion Vehicle is examined.
AIAA
Hydrogen Production; Lunar Bases; Lunar Resources; Space Technology Experiments

19920037984 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Advantages of the use of lunar and Mars propellant production
Roberts, Barney; Oct 1, 1991; In English
Report No.(s): IAF PAPER 91-661; Copyright; Avail: Other Sources

The use of nonterrestrial resources is discussed in the context of facilitating the transport of space-vehicle propellant to be used for lunar and/or Mars missions. A cost-benefit analysis is conducted to determine the feasibility and efficiency of developing propellant-production facilities in space for future mission support. The analysis suggests that after 2-3 years a break-even point is possible for return-on-investment mass, and technological hurdles are described that include systems for automation, mining, and processing.
AIAA
Extraterrestrial Resources; Lunar Resources; Mars (Planet); Oxygen Production; Rocket Propellants; Space Processing

19920037982 Arizona Univ., Tucson, AZ, USA
Technologies of ISRU/ISMU
Ramohalli, Kumar; Oct 1, 1991; In English
Contract(s)/Grant(s): NAGW-1332
Report No.(s): IAF PAPER 91-659; Copyright; Avail: Other Sources

The objectives of this paper are twofold. One is to unambiguously identify those in situ resource utilization (ISRU) in-situ materials utilization (ISMU) technologies that have matured past the stage of speculation, or uncertainty, and to present as much quantitative data as possible from working hardware. The second objective is to bring to the attention of the concerned authorities the important fact that many of the technologies are sufficiently advanced today to be seriously considered in the planning of space missions. The paper gives a brief overview of ISRU/ISMU from the literature. Next, results obtained from a well-planned set of research activities to promote ISRU/ISMU are quoted. These include some general technologies such as cryo coolers, power modules, and information systems followed by some very specific technologies such as oxygen production on the moon and Mars.
AIAA
Extraterrestrial Resources; Oxygen Production; Technology Assessment

19920037981 Science Applications International Corp., Schaumburg, IL, USA
Assessment of potential benefits from lunar/Mars propellant production for support of human exploration of the moon and Mars
Jacobs, Mark K.; Collins, John T.; Stancati, Michael L.; Oct 1, 1991; In English
Contract(s)/Grant(s): NAS3-25809
Report No.(s): IAF PAPER 91-658; Copyright; Avail: Other Sources
This paper describes an assessment of potential benefits offered through use of lunar/Mars in situ propellant production to support manned missions to the moon and Mars. Resources available at each location and processing options for their extraction are discussed. Key infrastructure and support systems needed to sustain the propellant production operation and to deliver the propellants from their point of origin to the point of application are defined. The analysis focuses on reductions of earth launched mass over the course of multiple missions to assess the potential savings offered. Initial results show the impact of requirements for sustaining in situ propellant production systems on benefits offered during steady-state operation.
AIAA
Extraterrestrial Resources; Lunar Resources; Rocket Propellants; Space Exploration; Space Manufacturing; Space Processing

19920037979 NASA Center for the Utilization of Local Planetary Resources, Arizona Univ., Tucson, AZ, USA, Arizona Univ., Tucson, AZ, USA
Non-terrestrial resources of economic importance to earth
Lewis, John S.; Oct 1, 1991; In English
Report No.(s): IAF PAPER 91-656; Copyright; Avail: Other Sources
The status of research on the importation of energy and nonterrestrial materials is reviewed, and certain specific directions for new research are proposed. New technologies which are to be developed include aerobraking, in situ propellant production, mining and beneficiation of extraterresrrial minerals, nuclear power systems, electromagnetic launch, and solar thermal propulsion. Topics discussed include the system architecture for solar power satellite constellations, the return of nonterrestrial He-3 to earth for use as a clean fusion fuel, and the return to earth of platinum-group metal byproducts from processing of nonterrestrial native ferrous metals.
AIAA
Economic Analysis; Energy Sources; Extraterrestrial Resources; Helium Isotopes; Solar Power Satellites; Spacecraft Propulsion

19920035167 EMEC Consultants, Export, PA, USA
Lunar production of oxygen by electrolysis
Keller, Rudolf; JAN 1, 1991; In English; 10th Princeton/AIAA/SSI Conference, May 15-18, 1991, Princeton, NJ, USA; Copyright; Avail: Other Sources
Two approaches to prepare oxygen from lunar resources by direct electrolysis are discussed. Silicates can be melted or dissolved in a fused salt and electrolyzed with oxygen evolved at the anode. Direct melting and electrolysis is potentially a very simple process, but high temperatures of 1400-1500 C are required, which aggravates materials problems. Operating temperatures can be lowered to about 1000 C by employing a molten salt flux. In this case, however, losses of electrolyte components must be avoided. Experimentation on both approaches is progressing.
AIAA
Electrolysis; Lunar Resources; Lunar Soil; Oxygen Production; Space Manufacturing

19920035166 Physical Sciences, Inc., Andover, MA, USA
Lunar oxygen production by pyrolysis of regolith
Senior, Constance L.; JAN 1, 1991; In English; 10th Princeton/AIAA/SSI Conference, May 15-18, 1991, Princeton, NJ, USA
Contract(s)/Grant(s): NAS9-18102; NAS9-19356; Copyright; Avail: Other Sources

Oxygen represents one of the most desirable products of lunar mining and manufacturing. Among the many processes which have been proposed for oxygen production, pyrolysis stands out as one which is uncomplicated and easy to bootstrap. Pyrolysis or vapor-phase reduction involves heating regolith to temperatures sufficient to allow partial decomposition and vaporization. Some metal oxides give up oxygen upon heating, either in the gas phase to form reduced gaseous species or in the condensed phase to form a metallic phase. Based on preliminary experiments and equilibrium calculations, the temperatures needed for pyrolysis are expected to be in the range of 2000 to 2200 K, giving total gas pressures of 0.001 to 0.1 torr. Bulk regolith can be used as a feedstock without beneficiation with concentrated solar radiation supplying most of energy needed. Further, selective condensation of metal-containing species from the gas phase may yield metallic iron and silicon as byproducts.
AIAA
Lunar Resources; Oxygen Production; Pyrolysis; Regolith; Solar Heating; Space Manufacturing

19920035145 NASA Lewis Research Center, Cleveland, OH, USA, Sverdrup Technology, Inc., Cleveland, OH, USA
Material processing with hydrogen and carbon monoxide on Mars
Hepp, Aloysius F.; Linne, Diane L.; Landis, Geoffrey A.; JAN 1, 1991; In English; 10th Princeton/AIAA/SSI Conference, May 15-18, 1991, Princeton, NJ, USA; Copyright; Avail: Other Sources

Several novel proposals are examined for propellant production from carbon dioxide and monoxide and hydrogen. Potential uses were also examined of CO as a fuel or as a reducing agent in metal oxide processing as obtained or further reduced to carbon. Hydrogen can be reacted with CO to produce a wide variety of hydrocarbons, alcohols, and other organic compounds. Methanol, produced by Fischer-Tropsch chemistry may be useful as a fuel; it is easy to store and handle because it is a liquid at Mars temperatures. The reduction of CO2 to hydrocarbons such as methane or acetylene can be accomplished with hydrocarbons. Carbon monoxide and hydrogen require cryogenic temperatures for storage as liquid. Noncryogenic storage of hydrogen may be accomplished using hydrocarbons, inorganic hydrides, or metal hydrides. Noncryogenic storage of CO may be accomplished in the form of iron carbonyl (FE(CO)5) or other metal carbonyls. Low hydrogen content fuels such as acetylene (C2H2) may be effective propellants with low requirements for earth derived resources. The impact on manned Mars missions of alternative propellant production and utilization is discussed.
AIAA
Carbon Dioxide; Carbon Monoxide; Extraterrestrial Resources; Hydrogen; Hydrogen Fuels; Mars (Planet); Photoelectrochemistry; Propellant Chemistry

19920035143 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Toward a global lunar resource survey - The Lunar Observer mission
Ridenoure, Rex W.; JAN 1, 1991; In English; 10th Princeton/AIAA/SSI Conference, May 15-18, 1991, Princeton, NJ, USA; Copyright; Avail: Other Sources

The present status of NASA's Lunar Observer study effort at JPL is discussed in the context of an ongoing 20-year series of studies focused on defining a robotic, low-altitude, polar-orbiting mission to the moon. The primary emphasis of the discussion is a review of the various systems-level factors that drive the overall mission plan. Selected top-level project and science requirements are summarized and the current mission and science objectives are presented. A brief description of the candidate science instrument complement is included. Several significant orbital effects caused by the lunar gravity field are explained and the variety of trajectory and maneuver options considered for both getting to the moon and orbiting there are described. The baseline mission scenario that results is a single-spacecraft, single-launch scenario which includes a small subsatellite for lunar gravity field determination.
AIAA
Lunar Flight; Lunar Probes; Lunar Resources; Mineral Exploration; Mission Planning

19920033574 PSI Technology Co., Andover, MA, USA
Solar heating of common lunar minerals for the production of oxygen
Senior, C. L.; British Interplanetary Society, Journal; Dec 1, 1991; ISSN 0007-094X; 44; In English
Contract(s)/Grant(s): NAS9-18102; Copyright; Avail: Other Sources

The purpose of this work was to demonstrate the feasibility of vapor-phase reduction (pyrolysis) of lunar materials to produce oxygen. Solar furnace experiments were conducted on two common lunar minerals, ilmenite and anorthite. Thermodynamic equilibrium calculations predicted that ilmenite should show a larger pressure increase than anorthite under conditions of the experiments and this was confirmed by the experiments. The measured mass loss of the ilmenite sample was consistent with loss of oxygen by reduction of iron in the liquid phase; this result was also predicted from equilibrium calculations. Based on preliminary experiments and equilibrium calculations, the temperatures needed for pyrolysis are expected to be in the range of 2000 to 2500 K, giving total gas pressures of 0.01 to 1 torr. Bulk regolith can be used as a feedstock without extensive beneficiation. Further, selective condensation of metal-containing species from the gas phase may yield metallic iron and silicon as byproducts from the process.
AIAA
Feasibility Analysis; Lunar Mining; Lunar Resources; Oxygen Production; Pyrolysis; Solar Heating

19920030339 Texas Univ., Dallas, TX, USA
Exospheric transport restrictions on water ice in lunar polar traps
Hodges, R. R., Jr.; Geophysical Research Letters; Nov 1, 1991; ISSN 0094-8276; 18; In English
Contract(s)/Grant(s): NAGW-1665; NAGW-2490; Copyright; Avail: Other Sources

There is little doubt that at least 10 exp 17 g of water has accreted on the moon as a result of the reduction of ferric iron at the regolith surface by solar wind protons, the vaporization of chondrites, and perhaps comet impacts. Lacking an efficient escape mechanism, most of this water (or its progeny) is probably on the moon now. If the water were to have migrated to permanently shaded cold traps near the lunar poles, ice deposts with densities greater than 1000 g/sq cm would cover the traps, providing accessible resources. However, exospheric transport considerations suggest that the actual amount of water ice in the cold traps is probably too small to be of practical interest. The alternative is global assimilation of most of the water into the regolith, a process that must account for about 30 micromoles of water per gram of soil.
AIAA
Lunar Resources; Selenology; Water

19920027999 NASA Center for the Utilization of Local Planetary Resources, Arizona Univ., Tucson, AZ, USA, Arizona Univ., Tucson, AZ, USA
Remote sensing of potential lunar resources. I - Near-side compositional properties
Johnson, Jeffrey R.; Larson, Stephen M.; Singer, Robert B.; Journal of Geophysical Research; Oct 25, 1991; ISSN 0148-0227; 96; In English
Contract(s)/Grant(s): NAGW-1332; NAGW-247; Copyright; Avail: Other Sources

Using telescopic CCD multispectral images of the lunar near side and the results of 330-870 nm spectroscopy of selected regions, the compositional differences relevant to the locations of potential lunar resources (such as ilmenite, FeTiO3, and solar-wind-implanted He-3 and H) are estimated. The 400/560 nm CCD ratio images were converted to weight percent TiO2, and the values were used to construct a new TiO2 abundance map which can be used to estimate the areas potentially rich in ilmenite. A 950/560 nm CCD ratio mosaic of the full moon provides estimates of relative surface maturity. Since high He-3 concentrations correlate with mature ilmenite-rich soils, a combination of relative surface maturity maps and the TiO2 abundance maps can be used to estimate distributions of He-3 (and possibly H) on local scales.
AIAA
Charge Coupled Devices; Lunar Resources; Lunar Surface; Multispectral Band Scanners; Remote Sensing

19920024072 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Science and In Situ Resources Utilization (ISRU): Design reference mission for the First Lunar Outpost
Mckay, David S.; Third SEI Technical Interchange: Proceedings; JAN 1, 1992; In English; No Copyright; Avail: CASI; A03, Hardcopy

Information is given in viewgraph form on the science and in situ resources utilization (ISRU) for the design reference mission for the First Lunar Outpost (FLO). Topics covered include requirements and themes, the general approach, science payloads, trade studies, science evolution, and present and future activities.
CASI
Extraterrestrial Resources; Lunar Bases; Lunar Exploration; Mission Planning; Moon; Payloads

19920024069 Lunar and Planetary Inst., Houston, TX, USA
Science themes for early robotic missions: LPI workshops
Spudis, Paul D.; NASA. Lyndon B. Johnson Space Center, Third SEI Technical Interchange: Proceedings; JAN 1, 1992; In English; No Copyright; Avail: CASI; A01, Hardcopy

Information is given in viewgraph form on science themes for early robotic missions that were developed during workshops. Topics covered include lunar resources, lunar terrain, lunar gravity, the lunar surface lander, and the Lunar Geoscience Explorer.
CASI
Extraterrestrial Resources; Geology; Geophysics; Lunar Gravitation; Lunar Resources; Lunar Surface; Mission Planning; Viking Lander Spacecraft

19920024067 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Lunar Resource Mapper/Lunar Geodetic Scout program status
Conley, Mike; Third SEI Technical Interchange: Proceedings; JAN 1, 1992; In English; No Copyright; Avail: CASI; A02, Hardcopy

Information is given in viewgraph form on the Lunar Resource Mapper/Lunar Geodetic Scout (LRM/LGS) program status. Topics covered include the LEXWG Lunar Observer science measurement priorities, space exploration initiative priorities, the question of why a lunar orbiting mission is attractive to the Space Exploration Initiative (SEI), instrument selection, major milestones, and the organization of the LRM/LGS Program Office.
CASI
Extraterrestrial Resources; Geodesy; Lunar Exploration; Lunar Gravitation; Mapping; Mission Planning; Moon; Space Exploration; Topography

19920024066 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
SEI reference mission
Weary, Dwayne; Third SEI Technical Interchange: Proceedings; JAN 1, 1992; In English; No Copyright; Avail: CASI; A02, Hardcopy

Information is given in viewgraph form on the Space Exploration Initiative (SEI). The goal of the reference mission is to expand the human presence to the moon and Mars in order to enhance our understanding of the universe, to seek terrestrial benefits from this exploration, and to establish the beginnings of a sustainable spacefaring civilization. Topics covered here include a phased definition of initial programmatic milestones and follow-on capabilities, near-term mission strategy, a lunar mission timeline, and a Mars mission timeline.
CASI
Extraterrestrial Resources; Lunar Exploration; Mission Planning; Moon; Space Exploration

19920022537 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Using space resources
Sullivan, Thomas A.; Mckay, David S.; JAN 1, 1991; In English
Report No.(s): NASA-TM-107966; NAS 1.15:107966; No Copyright; Avail: CASI; A03, Hardcopy; Original contains color illustrations

The topics covered include the following: reducing the cost of space exploration; the high cost of shipping; lunar raw materials; some useful space products; energy from the moon; ceramic, glass, and concrete construction materials; mars atmosphere resources; relationship to the Space Exploration Initiative (SEI); an evolutionary approach to using space resources; technology development; and oxygen and metal coproduction.
CASI
Extraterrestrial Resources; Mars (Planet); Materials Recovery; Metals; Moon; Space Exploration

19920010595 NASA Lewis Research Center, Cleveland, OH, USA
A compilation of lunar and Mars exploration strategies utilizing indigenous propellants
Linne, Diane L.; Meyer, Michael L.; Jan 1, 1992; In English
Contract(s)/Grant(s): RTOP 506-42-72
Report No.(s): NASA-TM-105262; E-6790; NAS 1.15:105262; No Copyright; Avail: CASI; A03, Hardcopy

The use of propellants manufactured from indigenous space materials has the potential to significantly reduce the amount

of mass required to be launched from the Earth's surface. The extent of the leverage, however, along with the cost for developing the infrastructure necessary to support such a process, is unclear. Many mission analyses have been performed that have attempted to quantify the potential benefits of in situ propellant utilization. Because the planning of future space missions includes many unknowns, the presentation of any single study on the use of in situ propellants is often met with critics' claims of the inaccuracy of assumptions or omission of infrastructure requirements. The results of many such mission analyses are presented in one format. Each summarized mission analysis used different assumptions and baseline mission scenarios. The conclusion from the studies is that the use of in situ produced propellants will provide significant reductions in Earth launch requirements. This result is consistent among all of the analyses regardless of the assumptions used to obtain the quantitative results. The determination of the best propellant combination and the amount of savings will become clearer and more apparent as the technology work progresses.
CASI
Extraterrestrial Resources; Lunar Exploration; Manned Mars Missions; Mars Exploration; Mission Planning; Rocket Propellants; Spacecraft Propulsion

19920010134 Texas Univ., Austin, TX, USA
Conceptual design of equipment to excavate and transport regolith from the lunar maria
Detwiler, Mark; Foong, Chee Seng; Stocklin, Catherine; JAN 1, 1990; In English
Contract(s)/Grant(s): NASW-4435
Report No.(s): NASA-CR-189972; NAS 1.26:189972; No Copyright; Avail: CASI; A07, Hardcopy

NASA hopes to have a manned lunar outpost completed by 2005. In order to establish the base, regolith must be excavated from the lunar surface. Regolith will be used as a source for life-supporting elements and as radiation shielding for the lunar outpost. The design team from the University of Texas at Austin designed excavation and transportation equipment for initial operations of the lunar base. The design team also characterized the elements to be found in the regolith and determined the power required to excavate regolith. The characterization of the soil was based on a literature review of lunar geography. Power requirements for excavation were developed by adapting terrestrial equations for excavation power requirements and adapting them to lunar soil conditions. The design of the excavation and transportation equipment was broken into three functions: loosing, collecting, and transporting. A scarifier was selected to loosen, a bucket was selected to collect, and a load-haul system was selected to transport. The functions are powered by a modular fuel cell powered vehicle that provides power for motion of the equipment.
CASI
Lunar Bases; Lunar Excavation Equipment; Lunar Rocks; Lunar Surface Vehicles; Regolith

19910073668 Massachusetts Inst. of Tech., Cambridge, MA, USA
Asteroids: A source of natural resources for terrestrial and extra-terrestrial applications
Gaffey, Michael J.; Mccord, Thomas B.; Lunar Science Inst., Abstracts of Papers Presented at a Special Session of the Seventh Annual Lunar Science Conference on Utilization of Lunar Materials and Expertise for Large Scale Operations in Space; JAN 1, 1976; In English; No Copyright; Avail: CASI; A01, Hardcopy
Asteroids; Economic Analysis; Extraterrestrial Resources; Feasibility Analysis; Mineral Exploration; Space Exploration

19910073666
Future geophysical techniques for probing beneath the regolith: Prospecting objectives
Strangway, David W.; Lunar Science Inst., Abstracts of Papers Presented at a Special Session of the Seventh Annual Lunar Science Conference on Utilization of Lunar Materials and Expertise for Large Scale Operations in Space; JAN 1, 1976; In English; No Copyright; Avail: CASI; A02, Hardcopy
Electromagnetic Fields; Iron; Lunar Exploration; Lunar Geology; Lunar Resources; Magnetic Surveys; Mineral Exploration; Regolith

19910073665 NASA Marshall Space Flight Center, Huntsville, AL, USA
Lightweight mobility systems for lunar operations utilizing elastic loop suspensions
Trautwein, Wolfgang; Costes, Nicholas C.; Lunar Science Inst., Abstracts of Papers Presented at a Special Session of the Seventh Annual Lunar Science Conference on Utilization of Lunar Materials and Expertise for Large Scale Operations in Space; JAN 1, 1976; In English; No Copyright; Avail: CASI; A01, Hardcopy
Lunar Construction Equipment; Lunar Excavation Equipment; Lunar Surface Vehicles; Suspension Systems (Vehicles); Vehicle Wheels; Vehicular Tracks

19910073663 Lehigh Univ., Bethlehem, PA, USA
Powder metallurgical components from lunar metal
Romig, A. D., Jr.; Goldstein, J. I.; Lunar Science Inst., Abstracts of Papers Presented at a Special Session of the Seventh Annual Lunar Science Conference on Utilization of Lunar Materials and Expertise for Large Scale Operations in Space; JAN 1, 1976; In English; No Copyright; Avail: CASI; A01, Hardcopy
Iron Alloys; Lunar Resources; Powder Metallurgy; Space Industrialization

19910073655 Rockwell International Corp., El Segundo, CA, USA
Large-scale processing of lunar materials
Ehricke, Krafft A.; Lunar Science Inst., Abstracts of Papers Presented at a Special Session of the Seventh Annual Lunar Science Conference on Utilization of Lunar Materials and Expertise for Large Scale Operations in Space; JAN 1, 1976; In English; No Copyright; Avail: CASI; A01, Hardcopy
Lunar Exploration; Lunar Resources; Lunar Rocks; Lunar Soil

19910073652 Lehigh Univ., Bethlehem, PA, USA
Metallic iron as a potential fuel for production of heat on the lunar surface
Sclar, Charles B.; Bauer, Jon F.; Lunar Science Inst., Abstracts of Papers Presented at a Special Session of the Seventh Annual Lunar Science Conference on Utilization of Lunar Materials and Expertise for Large Scale Operations in Space; JAN 1, 1976; In English; No Copyright; Avail: CASI; A01, Hardcopy
Fuel Production; Heat Generation; Heat of Combustion; Iron Alloys; Lunar Resources; Lunar Surface

19910073651 NASA Goddard Space Flight Center, Greenbelt, MD, USA
Lunar hydrogen sources
Okeefe, John A.; Lunar Science Inst., Abstracts of Papers Presented at a Special Session of the Seventh Annual Lunar Science Conference on Utilization of Lunar Materials and Expertise for Large Scale Operations in Space; JAN 1, 1976; In English; No Copyright; Avail: CASI; A01, Hardcopy
Hydrogen; Lunar Core; Lunar Craters; Lunar Resources; Lunar Surface; Lunar Temperature

19910073650 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Prospects for finding the most valuable potential resource of the moon: Water
Muller, P. M.; Lunar Science Inst., Abstracts of Papers Presented at a Special Session of the Seventh Annual Lunar Science Conference on Utilization of Lunar Materials and Expertise for Large Scale Operations in Space; JAN 1, 1976; In English Contract(s)/Grant(s): NAS7-100; No Copyright; Avail: CASI; A01, Hardcopy
Ice; Lunar Bases; Lunar Resources; Water

19910073649 California Univ., San Diego, La Jolla, CA, USA
Water on the moon
Arnold, James R.; Lunar Science Inst., Abstracts of Papers Presented at a Special Session of the Seventh Annual Lunar Science Conference on Utilization of Lunar Materials and Expertise for Large Scale Operations in Space; JAN 1, 1976; In English; No Copyright; Avail: CASI; A01, Hardcopy
Ice; Lunar Resources; Lunar Surface; Water

19910073648 NASA, Washington, DC, USA
Hydrogen resources for the moon
Williams, Richard J.; Lunar Science Inst., Abstracts of Papers Presented at a Special Session of the Seventh Annual Lunar Science Conference on Utilization of Lunar Materials and Expertise for Large Scale Operations in Space; JAN 1, 1976; In English; No Copyright; Avail: CASI; A02, Hardcopy
Economic Analysis; Hydrogen Production; Lunar Resources; Space Industrialization

19910073647 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
The regolith as a source of materials
Heiken, G.; Mckay, D. S.; Lunar Science Inst., Abstracts of Papers Presented at a Special Session of the Seventh Annual Lunar Science Conference on Utilization of Lunar Materials and Expertise for Large Scale Operations in Space; JAN 1, 1976; In English; No Copyright; Avail: CASI; A02, Hardcopy
Chemical Composition; Lunar Resources; Lunar Surface; Mining; Regolith

19910073645 Harvard Univ., Cambridge, MA, USA
A preliminary cost benefit analysis of space colonization: Abstract
Hopkins, Mark M.; Lunar Science Inst., Abstracts of Papers Presented at a Special Session of the Seventh Annual Lunar Science Conference on Utilization of Lunar Materials and Expertise for Large Scale Operations in Space; JAN 1, 1976; In English; No Copyright; Avail: CASI; A01, Hardcopy
Cost Effectiveness; Lunar Resources; Space Colonies; Space Industrialization

19910073643 Colgate Univ., Hamilton, NY, USA
Should we colonize the moon before space
Holbrow, C. H.; Lunar Science Inst., Abstracts of Papers Presented at a Special Session of the Seventh Annual Lunar Science Conference on Utilization of Lunar Materials and Expertise for Large Scale Operations in Space; JAN 1, 1976; In English; No Copyright; Avail: CASI; A01, Hardcopy
Buildings; Lunar Bases; Lunar Resources; Space Colonies

19910073642 Southern Research Inst., Birmingham, AL, USA
Some potential impacts of lunar oxygen availability on near-earth space transportation
Driggers, Gerald W.; Lunar Science Inst., Abstracts of Papers Presented at a Special Session of the Seventh Annual Lunar Science Conference on Utilization of Lunar Materials and Expertise for Large Scale Operations in Space; JAN 1, 1976; In English; No Copyright; Avail: CASI; A02, Hardcopy
Lunar Resources; Oxygen Production; Space Storage; Space Transportation

19910073641 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Long-range aspects of a large scale space program
Davis, Hubert P.; Lunar Science Inst., Abstracts of Papers Presented at a Special Session of the Seventh Annual Lunar Science Conference on Utilization of Lunar Materials and Expertise for Large Scale Operations in Space; JAN 1, 1976; In English; No Copyright; Avail: CASI; A03, Hardcopy
Long Term Effects; Lunar Resources; Product Development; Space Industrialization; Space Programs

19910073639 Lunar Science Inst., Houston, TX, USA
Abstracts of papers presented at a Special Session of the Seventh Annual Lunar Science Conference on Utilization of Lunar Materials and Expertise for Large Scale Operations in Space
Criswell, David R., editor; JAN 1, 1976; In English, 16 Mar. 1976, Houston, TX, USA
Report No.(s): NASA-CR-188129; NAS 1.26:188129; No Copyright; Avail: CASI; A10, Hardcopy
Conferences; Economic Development; Lunar Resources; Mineral Exploration; Product Development; Space Industrialization; Transportation

19910073583 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Evaluation of lunar resources
Mckay, David S.; Lunar Bases and Space Activities in the 21st Century; JAN 1, 1984; In English; No Copyright; Avail: Other Sources
Lunar Bases; Lunar Composition; Lunar Resources; Lunar Rocks; Lunar Soil

19910073581 NASA Ames Research Center, Moffett Field, CA, USA
The evoluation of CELSS for lunar bases
Macelroy, R. D.; Klein, Harold P.; Averner, M. M.; NASA, Lyndon B. Johnson Space Center, Lunar Bases and Space Activities in the 21st Century; JAN 1, 1984; In English; No Copyright; Avail: Other Sources
Closed Ecological Systems; Exobiology; Lunar Bases; Lunar Resources; Power Supplies

19910073567 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Lunar Bases and Space Activities in the 21st Century
JAN 1, 1984; In English, 29-31 Oct. 1984, Washington, DC, USA
Report No.(s): NASA-TM-89348; NAS 1.15:89348; No Copyright; Avail: CASI; A07, Hardcopy
Lunar Bases; Lunar Composition; Lunar Exploration; Lunar Resources; Moon

19910073102 Georgia Inst. of Tech., Atlanta, GA, USA
Design of a bulldozer for the lunar environment
Apostolides, Angelos; Mancuso, Martin; Mcray, Nelson; Parker, Johne; Thole, Patrick; Tomlinson, Charles; Mar 12, 1985; In English
Contract(s)/Grant(s): NGT-21-002-080
Report No.(s): NASA-CR-182768; NAS 1.26:182768; No Copyright; Avail: CASI; A06, Hardcopy
Lunar Environment; Lunar Excavation Equipment; Lunar Surface Vehicles; Tracked Vehicles

19910072751 Georgia Inst. of Tech., Atlanta, GA, USA
Lunar cargo transport vehicle
Betts, Douglas D.; Blankenship, Keith D.; Imhof, Philip G.; Linn, Thomas J.; Marchbanks, Timothy P.; Pillsbury, Charles S., IV; Mar 11, 1986; In English
Contract(s)/Grant(s): NGT-21-002-080
Report No.(s): NASA-CR-182582; NAS 1.25:182582; ME-4182; No Copyright; Avail: CASI; A05, Hardcopy
Cargo Spacecraft; Ferry Spacecraft; Lunar Mining; Lunar Orbits; Rendezvous Spacecraft; Spacecraft Design; Transport Vehicles

19910072748 Georgia Inst. of Tech., Atlanta, GA, USA
Automated regolith movement system
Crawford, Paul; Dimarco, Michael A.; Hagler, Ben L.; Kates, Andrew; Mcwhorter, Valerie L.; Porter, Timothy P.; Shaw, Christopher R.; Stevens, Anthony J.; Dec 1, 1987; In English
Contract(s)/Grant(s): NGT-21-002-080
Report No.(s): NASA-CR-180494; NAS 1.26:180494; ME-4182; No Copyright; Avail: CASI; A08, Hardcopy
Automatic Control; Lunar Excavation Equipment; Lunar Surface Vehicles

19910072744 Georgia Inst. of Tech., Atlanta, GA, USA
Lunar core drill
Adams, Matthew; Broom, James; French, Barry; Hajos, Mark; Monnig, Otto; Shaler, Nancy; Jun 3, 1985; In English
Contract(s)/Grant(s): NGT-21-002-080
Report No.(s): NASA-CR-183270; NAS 1.26:183270; ME-4182; No Copyright; Avail: CASI; A05, Hardcopy
Core Sampling; Drill Bits; Drills; Hydraulic Equipment; Lunar Based Equipment; Lunar Core; Lunar Excavation Equipment; Robot Arms

19910072743 Georgia Inst. of Tech., Atlanta, GA, USA
Lunar soil bagging implement
Gaines, Robert B.; House, Sarah J.; Impeduglia, John F.; Toledano, Yigal H.; Mar 1, 1987; In English
Contract(s)/Grant(s): NGT-21-002-080
Report No.(s): NASA-CR-182835; NAS 1.26:182835; ME-4182; No Copyright; Avail: CASI; A06, Hardcopy
Bags; Construction; Hydraulic Equipment; Lunar Bases; Lunar Excavation Equipment; Lunar Soil; Packaging

19910069088 NASA Lewis Research Center, Cleveland, OH, USA, Sverdrup Technology, Inc., Brook Park, OH, USA, Arizona Univ., Tucson, AZ, USA
Production and use of metals and oxygen for lunar propulsion
Hepp, Aloysius F.; Linne, Diane L.; Groth, Mary F.; Landis, Geoffrey A.; Colvin, James E.; Sep 1, 1991; In English
Report No.(s): AIAA PAPER 91-3481; Copyright; Avail: Other Sources

Production, power, and propulsion technologies for using oxygen and metals derived from lunar resources are discussed. The production process is described, and several of the more developed processes are discussed. Power requirements for chemical, thermal, and electrical production methods are compared. The discussion includes potential impact of ongoing power technology programs on lunar production requirements. The performance potential of several possible metal fuels including aluminum, silicon, iron, and titanium are compared. Space propulsion technology in the area of metal/oxygen rocket engines is discussed.
AIAA
Chemical Propulsion; Fuel Production; Lunar Resources; Metal Fuels; Metal Oxides; Metal Propellants; Oxygen Production; Production Engineering

19910057734 Hawaii Univ., Honolulu, HI, USA, NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Remote sensing of regional pyroclastic deposits on the north central portion of the lunar nearside
Hawke, B. R.; Campbell, B. A.; Lucey, P. G.; Peterson, C. A.; Coombs, C. R., et al.; JAN 1, 1991; In English; 21st Lunar and Planetary Science Conference, Mar. 12-16, 1990, Houston, TX, USA
Contract(s)/Grant(s): NAGW-237; NAGW-7323; NAGW-1385; Copyright; Avail: Other Sources

High-resolution 3.0-cm radar data for the Rima Bode regional pyroclastic deposit and a number of UV-visible reflectance spectra for regional pyroclastic deposits on the north-central portion of the lunar nearside are analyzed and compared to existing data. The data obtained indicate that small craters in this deposit excavated loose unwelded pyroclastic particles, suggesting that welded layers or lenses do not exist at depths within the deposit’s core area. The 70-cm radar data indicate that the Roma Bode deposit is thinner than the pyroclastic unit on the Aristarchus Plateau. The surfaces of all these regional pyroclastic deposits are dominated by ilmenite-rich black spheres, and contamination by low-Ti, nonpyroclastic debris appears to be minimal. The fine-grained block-free uncontaminated Rima Bode would be ideal for lunar mining operations and for rapidly covering lunar base modules with an adequate thickness of shielding material for protection from meteorite impact and space radiation.
AIAA
Lunar Bases; Lunar Geology; Lunar Mining; Lunar Surface; Remote Sensing

19910057160 Arizona Univ., Tucson, AZ, USA
Propellant production on Mars - Single cell oxygen production test bed
Colvin, James; Schallhorn, Paul; Ramohalli, Kumar; Jun 1, 1991; In English
Contract(s)/Grant(s): NAG1-332
Report No.(s): AIAA PAPER 91-2444; Copyright; Avail: Other Sources

A study focusing on oxygen production using resources indigenous to Mars is presented. A bank of solid zirconia electrolytic cells that will electrochemically separate oxygen from a high temperature stream of carbon dioxide is at the center of the oxygen production system. The experimental data are discussed with attention given to the cell operating temperature, the carbon dioxide flow rate, and the voltage applied across the cell.
AIAA
Electrolytic Cells; Extraterrestrial Resources; Mars (Planet); Oxygen Production; Solid Electrolytes; Zirconium Oxides

19910042998 Bionetics Corp., Hampton, VA, USA, NASA Langley Research Center, Hampton, VA, USA
A survey of surface structures and subsurface developments for lunar bases
Hypes, Warren D.; Wright, Robert L.; JAN 1, 1990; In English; Space 90: The Second International Conference, Apr. 22-26, 1990, Albuquerque, NM, USA; Copyright; Avail: Other Sources

Concepts proposed for lunar-base structures and shelters include those fabricated on earth, fabricated locally using lunar materials, and developed from subsurface features. Early bases may rely on evolutionary growth using Space Station modules and nodes covered with regolith for protection against thermal and radiative stresses. Expandable/inflatable shelters used alone on the surface or in conjunction with subselene (beneath the lunar surface) features and spent portions of the Space Shuttle’s fuel tanks offer early alternatives. More mature lunar bases may need larger volumes provided by erectable buildings, hybrid

inflatable/rigid spheres, modular concrete buildings using locally derived cement, or larger subselene developments.
AIAA
Lunar Bases; Lunar Logistics; Lunar Resources; Lunar Shelters; Spacecraft Modules; Structural Design

19910042974 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA, Arizona Univ., Tucson, AZ, USA
Automation and control of off-planet oxygen production processes
Marner, W. J.; Suitor, J. W.; Schooley, L. S.; Cellier, F. E.; JAN 1, 1990; In English; Space 90: The Second International Conference, Apr. 22-26, 1990, Albuquerque, NM, USA; Copyright; Avail: Other Sources

This paper addresses several aspects of the automation and control of off-planet production processes. First, a general approach to process automation and control is discussed from the viewpoint of translating human process control procedures into automated procedures. Second, the control issues for the automation and control of off-planet oxygen processes are discussed. Sensors, instruments, and components are defined and discussed in the context of off-planet applications, and the need for 'smart' components is clearly established.
AIAA
Automatic Control; Extraterrestrial Resources; Materials Handling; Oxygen Production; Production Engineering

19910042970 Washington Univ., Saint Louis, MO, USA
Lunar oxygen and metal for use in near-earth space - Magma electrolysis
Colson, Russell O.; Haskin, Larry A.; JAN 1, 1990; In English; Space 90: The Second International Conference, Apr. 22-26, 1990, Albuquerque, NM, USA; Copyright; Avail: Other Sources

The unique conditions on the moon, such as vacuum, absence of many reagents common on the earth, and presence of very nontraditional 'ores', suggest that a unique and nontraditional process for extracting materials from the ores may prove the most practical. An investigation has begun into unfluxed silicate electrolysis as a method for extracting oxygen, Fe, and Si from lunar regolith. The advantages of the process include simplicity of concept, absence of need to supply reagents from the earth, and low power and mass requirements for the processing plant. Disadvantages include the need for uninterrupted high temperature and the highly corrosive nature of the high-temperature silicate melts, which has made identifying suitable electrode and container materials difficult.
AIAA
Electrolysis; Iron; Lunar Mining; Lunar Resources; Magma; Oxygen Production; Silicates

19910042969 Michigan Technological Univ., Houghton, MI, USA
Separation of lunar ilmenite - Basalt vs. regolith
Dela'o, K. A.; Eisele, T. C.; Kasul, D. B.; Rose, W. I.; Kawatra, S. K.; JAN 1, 1990; In English; Space 90: The Second International Conference, Apr. 22-26, 1990, Albuquerque, NM, USA; Copyright; Avail: Other Sources

The paper presents the advantages and disadvantages of using lunar basalt or regolith as feedstock for an ilmenite extraction scheme. The ilmenite on the lunar surface is more reduced than ilmenite found on earth, hence, separation practices followed on earth cannot be used on the moon. The paper critically examines methods of ilmenite extraction on the lunar surface.
AIAA
Basalt; Ilmenite; Lunar Mining; Lunar Resources; Regolith

19910042965 Tennessee Univ., Knoxville, TN, USA, Exportech Co., Inc., New Kensington, PA, USA
Magnetic beneficiation of highland and hi-Ti mare soils - Rock, mineral, and glassy components
Taylor, Lawrence A.; Oder, Robin R.; JAN 1, 1990; In English; Space 90: The Second International Conference, Apr. 22-26, 1990, Albuquerque, NM, USA
Contract(s)/Grant(s): NAS9-18092; NAS9-17811; Copyright; Avail: Other Sources

The exploitation of lunar soil can provide valuable raw materials for in situ resource utilization at a lunar base. A study of magnetic characterization was undertaken of three mare and two highland soils obtained from NASA. Beneficiation of mare and highland soils by sizing and magnetic separation can effectively concentrate the important components of the soils (e.g., ilmenite, native Fe, plagioclase, and agglutinates). As a soil matures and the impact melts consume additional minerals and rocks, the modal percentage of the minerals will decrease. The 'normative' percentage will become much greater than the modal percentage. Therefore, greater efficiency of separation can be realized with the proper selection of maturity of the soil,

as well as by secondary grinding to further liberate specific minerals from lithic fragments (e.g., ilmenite and plagioclase).
AIAA
Beneficiation; Lunar Exploration; Lunar Resources; Lunar Rocks; Magnetic Materials; Titanium Oxides

19910042964 Exportech Co., Inc., New Kensington, PA, USA, Tennessee Univ., Knoxville, TN, USA
Magnetic beneficiation of highland and hi-Ti mare soils - Magnet requirements
Oder, R. R.; Taylor, L. A.; JAN 1, 1990; In English; Space 90: The Second International Conference, Apr. 22-26, 1990, Albuquerque, NM, USA
Contract(s)/Grant(s): NAS9-18092; NAS9-17811; Copyright; Avail: Other Sources

Magnetic beneficiation of immature highland soil 67511 recovered 22 wt pct of the sample with an iron oxide content of 0.6 pct. Magnetic isolates of immature highland soils are candidates for the manufacture of silicon, aluminum, and other metals. Fifty-seven percent of the ilmenite in immature mare soil 71061 was recovered in magnetic processing. Ilmenite can be recovered by magnetic separation but may be difficult to 'high'grade'. A parametric description is given of magnetic separators suitable for supplying ilmenite for the production of 22.7 metric tons per year oxygen.
AIAA
Beneficiation; Lunar Exploration; Lunar Resources; Lunar Soil; Magnetic Materials; Oxygen Production

19910042958 Hawaii Univ., Honolulu, HI, USA, NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Pyroclastic deposits as sites for lunar bases
Hawke, B. Ray; Clark, Beth; Coombs, C. R.; JAN 1, 1990; In English; Space 90: The Second International Conference, Apr. 22-26, 1990, Albuquerque, NM, USA
Contract(s)/Grant(s): NAGW-237; Copyright; Avail: Other Sources

Ilmenite-rich pyroclastic deposits may prove to be excellent sites for the establishment of a permanent lunar base for mining purposes. A wide variety of potentially useful by-products could be produced (e.g., Fe, Ti, H, N, C, S, Cu, Zn, Cd, Bi, and Pb). A number of ilmenite-rich pyroclastic deposits of regional extent has been studied. The physical properties of the regional pyroclastic units have important implications for lunar construction. These extensive, deep deposits of ilmenite-rich pyroclastic material are block-free and uncontaminated; they could be easily excavated and would be ideal for lunar mining operations. These deep, loose pyroclastic deposits would also be ideal for rapidly covering base modules with an adequate thickness of shielding.
AIAA
Lunar Bases; Lunar Composition; Lunar Mining; Lunar Resources; Mineral Deposits

19910041210 NASA Center for the Utilization of Local Planetary Resources, Arizona Univ., Tucson, AZ, USA, Arizona Univ., Tucson, AZ, USA
Mining the air - Resources of other worlds may reduce mission costs
Ramohalli, Kumar; Planetary Report; Feb 1, 1991; ISSN 0736-3680; 11; In English; Copyright; Avail: Other Sources

It is proposed that the mining of resources on another planet to support operations there and also to provide a means for the return trip to earth provides a less expensive way to send humans beyond low earth orbit to live on the moon and to explore Mars. Since a large fraction of any chemical propellant combination is the oxidizer that burns with the fuel to generate the rocket jet, and for life support, the generation of oxygen from any of its atmospheric or mineral compounds is a valuable capability. Such materials include the lunar minerals ilmenite and anorthite, Martian permafrost, water ice at the Martian poles, and atmospheric carbon dioxide on Mars. The possibilities of developing such technologies are discussed and the prospects of developing building materials for such facilities from local resources are considered. The role of the Space Engineering Research Center at the University of Arizona in exploring the use of local planetary resources is noted.
AIAA
Earth Orbital Environments; Lunar Resources; Mars Surface Samples; Space Exploration

19910036828 Arizona Univ., Tucson, AZ, USA
Extraterrestrial materials processing and related transport phenomena
Ramohalli, K. N. R.; Sridhar, K. R.; Jan 1, 1991; In English
Report No.(s): AIAA PAPER 91-0309; Copyright; Avail: Other Sources

Several concepts for significant cost reductions in extraterrestrial resource utilization are described. After an introduction of the desirability of in situ resource utilization, several candidate chemical processes are mentioned. It is brought out that

many of the key processes require fluid dynamics and heat transfer processes under reduced- and microgravity. These aspects are discussed within the broad framework of a two-phase thermal control systems. Another important aspect of space processing is that reliability and self-repairability are mandatory; automation aspects are discussed. In addition to these general considerations, the paper includes several specific processes that vary from solid electrolytic production of oxygen from carbon dioxide, to plasma-augmented reactions for reducing ilmenite on the moon.
AIAA
Cost Reduction; Extraterrestrial Resources; Fluid Dynamics; Heat Transfer; Microgravity; Space Processing

19910030105 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Strategies for a permanent lunar base
Duke, Michael B.; Mendell, Wendell W.; Roberts, Barney B.; JAN 1, 1989; In English; Copyright; Avail: Other Sources

Three objectives are stated for activities at a proposed manned lunar base. One objective is scientific investigation of the moon and its environment and the application of special properties of the moon to research problems. Another objective would be to produce the capability of using the materials of the moon for beneficial purposes throughout the earth-moon system. The third objective is to conduct research and development leading to a self-sufficient and self-supporting lunar base, the first extraterrestrial human colony. The potential benefits to earth deriving from these moon-based activities, such as technology development and realization, as well as growing industrialization of near-earth space, are addressed.
AIAA
Lunar Bases; Lunar Environment; Lunar Resources; Manned Space Flight

19910029468 NASA Center for the Utilization of Local Planetary Resources, Arizona Univ., Tucson, AZ, USA
Extraterrestrial resource utilization for economy in space missions
Lewis, J. S.; Ramohalli, K.; Triffet, T.; Oct 1, 1990; In English
Report No.(s): IAF PAPER 90-604; Copyright; Avail: Other Sources

The NASA/University of Arizona Space Engineering Research Center is dedicated to research on the discovery, characterization, mapping, beneficiation, extraction, processing, and fabrication of useful products from extraterrestrial material. Schemes for the automated production of low-technology products that are likely to be desired in large quantities in the early stages of any large-scale space activity are identified and developed. This paper summarizes the research program, concentrating upon the production of (1) propellants, both cryogenic and storable, (2) volatiles such as water, nitrogen, and carbon dioxide for use in life-support systems (3) structural metals, and (4) refractories for use in aerobrakes and furnace linings.
AIAA
Extraterrestrial Resources; Mission Planning; Space Manufacturing

19910027516 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Automation of materials processing
Suitor, Jerry; JAN 1, 1989; In English; Copyright; Avail: Other Sources

Sensors, instruments, and components which will be involved in automation of off-planet resource processing are discussed. The role of smart components in these activities is addressed. Process-specific control issues are briefly considered.
AIAA
Automatic Control; Extraterrestrial Resources; Planetary Environments; Process Control (Industry)

19910027505 Washington Univ., Saint Louis, MO, USA
Lunar resources - Toward living off the lunar land
Haskin, Larry A.; Colson, Russell O.; JAN 1, 1989; In English; Copyright; Avail: Other Sources

An overview is presented of possibilities for the exploitation of lunar materials already proven to exist by Apollo experience. It is noted that lunar soils contain various materials required for life support, construction, and transportation, but that the high cost of lifting material from the earth's surface suggests that, in the near term, lunar material should be considered for use both on the moon and in LEO. Lunar water production, farming, propellant production, and the production of glass, iron, aluminum, and silicon to be used in lunar construction are discussed. The role of solar power and the possibility of electrolysis of molten silicate as a means of producing oxygen and metals for use on the moon and in near-earth space are

examined. The benefits of immediate investment in developmental technology (given extensive project lead times) are stressed.
AIAA
Earth Orbital Environments; Lunar Bases; Lunar Resources; Lunar Soil

19910025573 NASA Ames Research Center, Moffett Field, CA, USA, Bionetics Corp., Moffett Field, CA, USA
The lunar outpost - Testbed for colonization and extraterrestrial evolution
Harper, Lynn D.; Connell, Kathleen M.; Sep 1, 1990; In English
Report No.(s): AIAA PAPER 90-3850; Copyright; Avail: Other Sources

Three aspects of extraterrestrial habitation are presented with primary focus on lunar habitation. An overview of human experience in low earth orbit (LEO) is given and the establishment of an experience base is discussed. Three primary conditions are listed as crucial requirements for extraterrestrial habitation. These include the construction of artificial environments (AEs); the improvement of AEs so that they are attractive enough for people to want to spend their lives nd eventually bear and raise children in such an environment; and finally, the achievement of self-sufficiency and growth by regenerating consumables and using in situ resources in order to be both cost effective and maximally independent. Regenerative life support, establishment and maintenance of productivity, and the importance of human reproduction in establishing a colony are all discussed in detail. Physiological issues and concerns are considered including hypogravity and radiation physiology.
AIAA
Earth Orbital Environments; Extraterrestrial Resources; Lunar Bases; Lunar Exploration

19910025503 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Process engineering concerns in the lunar environment
Sullivan, T. A.; Sep 1, 1990; In English
Report No.(s): AIAA PAPER 90-3753; Copyright; Avail: Other Sources

The paper discusses the constraints on a production process imposed by the lunar or Martian environment on the space transportation system. A proposed chemical route to produce oxygen from iron oxide bearing minerals (including ilmenite) is presented in three different configurations which vary in complexity. A design for thermal energy storage is presented that could both provide power during the lunar night and act as a blast protection barrier for the outpost. A process to release carbon from the lunar regolith as methane is proposed, capitalizing on the greater abundance and favorable physical properties of methane relative to hydrogen to benefit the entire system.
AIAA
Lunar Environment; Lunar Resources; Mars Surface; Oxygen Production; Planetary Environments; Space Transportation

19910023236 EMEC Consultants, Export, PA, USA
Electrolytic production of oxygen from lunar resources
Keller, Rudolf; NASA. Lewis Research Center, Space Electrochemical Research and Technology; Sep 1, 1991; In English; No Copyright; Avail: CASI; A02, Hardcopy

Some of the most promising approaches to extract oxygen from lunar resources involve electrochemical oxygen generation. In a concept called magma electrolysis, suitable oxides (silicates) which are molten at 1300 to 1500 C are then electrolyzed. Residual melt can be discarded after partial electrolysis. Alternatively, lunar soil may be dissolved in a molten salt and electrolyzed. In this approach, temperatures are lower and melt conductances higher, but electrolyte constituents need to be preserved. In a different approach ilmenite is reduced by hydrogen and the resulting water is electrolyzed.
CASI
Electrolysis; Lunar Resources; Lunar Soil; Oxygen Production

19910022004 NASA Lewis Research Center, Cleveland, OH, USA
Technical prospects for utilizing extraterrestrial propellants for space exploration
Linne, Diane L.; Meyer, Michael L.; JAN 1, 1991; In English; 42nd International Astronautical Congress, 5-11 Oct. 1991, Montreal, Quebec, Canada
Contract(s)/Grant(s): RTOP 506-42-72
Report No.(s): NASA-TM-105263; E-6594; NAS 1.15:105263; No Copyright; Avail: CASI; A03, Hardcopy

NASA's LeRC has supported several efforts to understand how lunar and Martian produced propellants can be used to

their best advantage for space exploration propulsion. A discussion of these efforts and their results is presented. A Manned Mars Mission Analysis Study identified that a more thorough technology base for propellant production is required before the the net economic benefits of in situ propellants can be determined. Evaluation of the materials available on the moon indicated metal/oxygen combinations are the most promising lunar propellants. A hazard analysis determined that several lunar metal/LOX monopropellants could be safely worked with in small quantities, and a characterization study was initiated to determine the physical and chemical properties of potential lunar monopropellant formulations. A bipropellant metal/oxygen subscale test engine which utilizes pneumatic injection of powdered metal is being pursued as an alternative to the monopropellant systems. The technology for utilizing carbon monoxide/oxygen, a potential Martian propellant, was studied in subscale ignition and rocket performance experiments.
CASI

Extraterrestrial Resources; Fuel Production; Lunar Exploration; Lunar Resources; Manned Mars Missions; Rocket Propellants; Spacecraft Propulsion

19910019908 NASA Lewis Research Center, Cleveland, OH, USA

Production and use of metals and oxygen for lunar propulsion

Hepp, Aloysius F.; Linne, Diane L.; Landis, Geoffrey A.; Groth, Mary F.; Colvin, James E.; JAN 1, 1991; In English; Conference on Advanced Space Exploration Initiative Technologies, 4-6 Sep. 1991, Cleveland, OH, USA

Contract(s)/Grant(s): RTOP 506-41-11

Report No.(s): NASA-TM-105195; E-6496; NAS 1.15:105195; AIAA PAPER 91-3481; No Copyright; Avail: CASI; A03, Hardcopy

Production, power, and propulsion technologies for using oxygen and metals derived from lunar resources are discussed. The production process is described, and several of the more developed processes are discussed. Power requirements for chemical, thermal, and electrical production methods are compared. The discussion includes potential impact of ongoing power technology programs on lunar production requirements. The performance potential of several possible metal fuels including aluminum, silicon, iron, and titanium are compared. Space propulsion technology in the area of metal/oxygen rocket engines is discussed.
CASI

Chemical Propulsion; Fuel Production; Lunar Resources; Metal Fuels; Metal Oxides; Metal Propellants; Oxygen Production; Production Engineering

19910017790 University of Northern Arizona, Flagstaff, AZ, USA

Evaluation of geophysical properties of the lunar regolith for the design of precursor scientific missions for the space exploration initiative

Morgan, Paul; Houston Univ., NASA(ASEE Summer Faculty Fellowship Program, 1990, Volume 2; Dec 1, 1990; In English

Contract(s)/Grant(s): NGT-44-005-803; No Copyright; Avail: CASI; A03, Hardcopy

The following topics are addressed: (1) the frequency of encountering boulders that represent hazards to lunar operations; (2) the ease of lunar soil excavation; (3) the use of explosives in excavation operation; (4) the trafficability of the regolith; (5) problems encountered in mining (probably strip mining) of the regolith; (6) the stable angle(s) of repose in excavation of the regolith; (7) the layering to be encountered in the subsurface; (8) knowledge of the regolith site and the possibility of its general application to any site on the lunar surface; (9) the data needed to characterize a site for a lunar base; (10) the influence of regolith properties on the design of geophysical experiments from the lunar base; and (11) terrestrial analogues for the geophysical properties of the lunar regolith.
CASI

Geophysics; Lunar Bases; Lunar Geology; Lunar Mining; Lunar Rocks; Lunar Surface; Regolith

19910016776 Nevada Univ., Reno, NV, USA

Some thoughts on Mercurian resources

Gillett, Stephen L.; Arizona Univ., Resources of Near-Earth Space: Abstracts; JAN 1, 1991; In English; No Copyright; Avail: Other Sources

Virtually all scenarios on Solar System development ignore Mercury, but such inattention is probably undeserved. Once viable lunar and (probably) asteroidal facilities are established in the next century, Mercury warrants further investigation. Mercury's high solar energy density is a major potential advantage for space-based industries. Indeed, despite its higher gravity, Mercury is roughly twice as easy to leave as the Moon if the additional solar flux is taken into account. Moreover,

with solar-driven technologies such as solar sails or electric propulsion, its depth in the Sun's gravity well is less important. Because Mercury is airless and almost certainly waterless, it will be an obvious place to export lunar technology, which will have been developed to deal with very similar conditions. Methods for extracting resources from anhydrous silicates will be particularly germane. Even without solar-powered propulsion, the discovery of low-delta-V access via multiple Venus and Earth encounters makes the planet easier to reach than had been thought. Technology developed for multi-year missions to asteroids and Mars should be readily adaptable to such Mercurian missions. Mercury will not be our first outpost in the Solar System. Nonetheless, as facilities are established in cis-Earth space, it probably merits attention as a next step for development.
CASI

Encounters; Extraterrestrial Resources; Mercury (Planet); Propulsion; Solar Energy

19910016774 Arizona Univ., Tucson, AZ, USA

Comparative economics of space resource utilization

Cutler, Andrew Hall; Resources of Near-Earth Space: Abstracts; JAN 1, 1991; In English; No Copyright; Avail: Other Sources

Physical economic factors such as mass payback ratio, total payback ratio, and capital payback time are discussed and used to compare the economics of using resources from the Moon, Mars and its moons, and near Earth asteroids to serve certain near term markets such as propellant in low Earth orbit or launched mass reduction for lunar and Martian exploration. Methods for accounting for the time cost of money in simple figures of merit such as MPRs are explored and applied to comparisons such as those between lunar, Martian, and asteroidal resources. Methods for trading off capital and operating costs to compare schemes with substantially different capital to operating cost ratio are presented and discussed. Areas where further research or engineering would be extremely useful in reducing economic uncertainty are identified, as are areas where economic merit is highly sensitive to engineering performance - as well as areas where such sensitivity is surprisingly low.
CASI

Asteroids; Economic Factors; Economics; Lunar Resources; Market Research; Mars (Planet); Moon; Operating Costs

19910016759 NASA Lewis Research Center, Cleveland, OH, USA

Chemical approaches to carbon dioxide utilization for manned Mars missions

Hepp, Aloysius F.; Landis, Geoffrey A.; Kubiak, Clifford P.; Arizona Univ., Resources of Near-Earth Space: Abstracts; JAN 1, 1991; In English; No Copyright; Avail: Other Sources

Utilization of resources available in situ is a critical enabling technology for permanent human presence in space. A permanent presence on Mars, for example, requires a tremendous infrastructure to sustain life under hostile conditions (low oxygen, partial pressure, ultraviolet radiation, low temperature, etc.). There are numerous studies on the most accessible of Martian resources: atmospheric carbon dioxide. As a resource on Mars, atmospheric CO2 is: (1) abundant; (2) available at all points on the surface; (3) of known presence, requiring no precursor mission to verify; (4) chemically simple; and (5) can be obtained by simple compression, with no requirements of mining or beneficiation equipment operation. Several novel proposals are presented for CO2 fixation through chemical, photochemical, and photoelectrochemical means.
CASI

Atmospheric Composition; Carbon Dioxide; Carbon Dioxide Concentration; Extraterrestrial Resources; Manned Mars Missions; Mars (Planet); Oxygen Production

19910016755 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA

Options for Martian propellant production

Dowler, Warren; French, James; Ramohalli, Kumar; Arizona Univ., Resources of Near-Earth Space: Abstracts; JAN 1, 1991; In English; No Copyright; Avail: Other Sources

A quantitative evaluation methodology for utilizing in-situ resources on Mars for the production of useful substances. The emphasis is on the chemical processes. Various options considering different feedstock (mostly, carbon dioxide, water, and iron oxides) are carefully examined for the product mix and the energy needs. Oxygen, carbon monoxide, alcohols, and other chemicals are the end products. The chemical processes involve electrolysis, methanation, and variations. It is shown that maximizing the product utility is more important than the production of oxygen, methane, or alcohols. An important factor is the storage of the chemicals produced. The product utility is dependent, to some extent, upon the mission. A combination of the stability, the enthalpy of formation, and the mass fraction of the products is seen to yield a fairly good quantitative feel for the overall utility and maximum mission impact.
CASI

Chemical Reactions; Electrolysis; Extraterrestrial Resources; Fuel Production; Mars (Planet); Methanation; Propellant Storage; Propellants

19910016754 General Dynamics Corp., San Diego, CA, USA

The potential for crustal resources on Mars

Cordell, Bruce M.; Gillett, Stephen L.; Arizona Univ., Resources of Near-Earth Space: Abstracts; JAN 1, 1991; In English; No Copyright; Avail: Other Sources

Martian resources pose not only an interesting scientific challenge but also have immense astronautical significance because of their ability to enhance mission efficiency, lower launch and program costs, and stimulate the development of large Mars surface facilities. Although much terrestrial mineralization is associated with plate tectonics and Mars apparently possesses a thick, stationary lithosphere, the presence of crustal swells, rifting, volcanism, and abundant volatiles indicates that a number of sedimentary, hydrothermal, dry-magma mineral concentration processes may have operated on Mars. For example, in Colorado Plateau-style (roll-front) deposits, uranium precipitation is localized by redox variations in groundwater. Also, evaporites (either in salt pans or even interstitially in pore spaces) might concentrate Cl, Li, and K. Many Martian impact craters have been modified by volcanism and probably have been affected by rising magma bodies interacting with ground ice or water. Such conditions might produce hydrothermal circulations and element concentrations. If the high sulfur content found by the Viking landers typifies Martian abundances, sulfide ore bodies may have been formed locally. Mineral-rich Africa seems to share many volcanic and tectonic characteristics with portions of Mars and may suggest Mars' potential mineral wealth. For example, the rifts of Valles Marineris are similar to the rifts in east Africa, and may both result from a large mantle plume rising from the interior and disrupting the surface. The gigantic Bushveld complex of South Africa, an ancient layered igneous intrusion that contains ores of chromium and Pt-group metals, illustrates the sort of dry-magma processes that also could have formed local element concentrations on Mars, especially early in the planet's history when heat flow was higher.
CASI

Extraterrestrial Resources; Mars (Planet); Minerals; Planetary Composition; Planetary Crusts; Planetary Geology; Structural Properties (Geology)

19910016753 Massachusetts Inst. of Tech., Cambridge, MA, USA

Evolution of ore deposits on terrestrial planets

Burns, R. G.; Arizona Univ., Resources of Near-Earth Space: Abstracts; JAN 1, 1991; In English; No Copyright; Avail: Other Sources

Ore deposits on terrestrial planets materialized after core formation, mantle evolution, crustal development, interactions of surface rocks with the hydrosphere and atmosphere, and, where life exists on a planet, the involvement of biological activity. Core formation removed most of the siderophilic and chalcophilic elements, leaving mantles depleted in many of the strategic and noble metals relative to their chondritic abundances. Basaltic magma derived from partial melting of the mantle transported to the surface several metals contained in immiscible silicate and sulfide melts. Magmatic ore deposits were formed during cooling, fractional crystallization and density stratification from the basaltic melts. Such ore deposits found in earth's Archean rocks were probably generated during early histories of all terrestrial planets and may be the only types of igneous ores on Mars. Where plate tectonic activity was prevalent on a terrestrial planet, temporal evolution of ore deposits took place. Repetitive episodes of subduction modified the chemical compositions of the crust and upper mantles, leading to porphyry copper and molybdenum ores in calc-alkaline igneous rocks and granite-hosted tin and tungsten deposits. Such plate tectonic-induced mineralization in relatively young igneous rocks on earth may also have produced hydrothermal ore deposits on Venus in addition to the massive sulfide and cumulate chromite ores associated with Venusian mafic igneous rock. Sedimentary ore deposits resulting from mechanical and chemical weathering in reducing atmospheres in Archean earth included placer deposits (e.g., uraninite, gold, pyrite ores). Chromite, ilmenite, and other dense unreactive minerals could also be present on channel floors and in valley networks on Mars, while banded iron formations might underlie the Martian northern plains regions. As oxygen evolved in earth's atmosphere, so too did oxide ores. By analogy, gossans above sulfide ores probably occur on Mars, but not submarine ferromanganese nodules and crusts which have precipitated in oxygenated seawater on earth.
CASI

Chemical Composition; Extraterrestrial Resources; Mineral Deposits; Planetary Crusts; Planetary Evolution; Planetary Geology; Planetary Mantles; Terrestrial Planets

19910016752 NASA Lyndon B. Johnson Space Center, Houston, TX, USA

Martian impact crater ejecta morphologies and their potential as indicators of subsurface volatile distribution

Barlow, Nadine G.; Arizona Univ., Resources of Near-Earth Space: Abstracts; JAN 1, 1991; In English; No Copyright; Avail: Other Sources

Many martian impact craters ejecta morphologies suggestive of fluidization during ejecta emplacement. Impact into

subsurface volatile reservoirs (i.e., water, ice, CO2, etc.) is the mechanism favored by many scientists, although acceptance of this mechanism is not unanimous. In recent years, a number of studies were undertaken to better understand possible relationships between ejecta morphology and latitude, longitude, crater diameter, and terrain. These results suggest that subsurface volatiles do influence the formation of specific ejecta morphologies and may provide clues to the vertical and horizontal distribution of volatiles in more localized regions of Mars. The location of these volatile reservoirs will be important to humans exploring and settling Mars in the future. Qualitative descriptions of ejecta morphology and quantitative analyses of ejecta sinuosity and ejecta lobe areal extent from the basis of the studies. Ejecta morphology studies indicate that morphology is correlated with crater diameter and latitude, and, using depth-diameter relationships, these correlations strongly suggest that changes in morphology are related to transition among subsurface layers with varying amounts of volatiles. Ejecta sinuosity studies reveal correlations between degree of sinuosity (lobateness) and crater morphology, diameter, latitude, and terrain. Lobateness, together with variations in areal extent of the lobate ejecta blanket with morphology and latitude, probably depends most directly on the ejecta emplacement process. The physical parameters measured here can be compared with those predicted by existing ejecta emplacement models. Some of these parameters are best reproduced by models requiring incorporation of volatiles within the ejecta. However, inconsistencies between other parameters and the models indicate that more detailed modeling is necessary before the location of volatile reservoirs can be confidently predicted based on ejecta morphology studies alone.
CASI
Ejecta; Extraterrestrial Resources; Geomorphology; Mars (Planet); Mars Craters; Mars Surface

19910016751 Arizona Univ., Tucson, AZ, USA
Water resources and hydrology of Mars
Baker, V. R.; Gulick, V. C.; Kargel, J. S.; Strom, R. G.; Resources of Near-Earth Space: Abstracts; JAN 1, 1991; In English; No Copyright; Avail: Other Sources

The surface of Mars has been extensively modified by a large variety of water erosional and depositional processes. Although liquid water is presently unstable on the planet's surface, in its cold, hyperarid climate, there is abundant geomorphological evidence of past fluvial valley development multiple episodes of catastrophic flooding, periglacial landforms, ice-related permafrost, lake deposits, eroded impact craters and possible glacial landforms throughout much of Mars' geological history. The amount of water required to form such features is estimated to be equivalent to a planet-wide layer approximately 50 meters deep. Some of this water undoubtedly was removed from the planet by atmospheric escape processes, but much probably remains in the subsurface of Mars. Jakosky summarized the present partitioning of water on Mars, expressed as an average global depth, as follows: in the polar caps, 30 meters; in the megaregolith, 500 to 1000 meters; structurally bound in clays, 10 meters; and in high latitude regolith, a few meters. However, most of this water is probably in the form of ice, except in anomalous areas of possible near surface liquid water, and in regions where hydrothermal systems are still active. The best locations for prospecting are those areas where water or ice is sufficiently concentrated at shallow enough depths to make it feasible to pump out or mine.
CASI
Extraterrestrial Resources; Hydrology; Ice; Mars (Planet); Mars Surface; Planetary Geology; Polar Caps; Water Resources

19910016750 General Dynamics Corp., San Diego, CA, USA
Optimum rocket propulsion for energy-limited transfer
Zuppero, Anthony; Landis, Geoffrey A.; Arizona Univ., Resources of Near-Earth Space: Abstracts; JAN 1, 1991; In English; No Copyright; Avail: Other Sources

In order to effect large-scale return of extraterrestrial resources to Earth orbit, it is desirable to optimize the propulsion system to maximize the mass of payload returned per unit energy expended. This optimization problem is different from the conventional rocket propulsion optimization. A rocket propulsion system consists of an energy source plus reaction mass. In a conventional chemical rocket, the energy source and the reaction mass are the same. For the transportation system required, however, the best system performance is achieved if the reaction mass used is from a locally available source. In general, the energy source and the reaction mass will be separate. One such rocket system is the nuclear thermal rocket, in which the energy source is a reactor and the reaction mass a fluid which is heated by the reactor and exhausted. Another energy-limited rocket system is the hydrogen/oxygen rocket where H2/O2 fuel is produced by electrolysis of water using a solar array or a nuclear reactor. The problem is to choose the optimum specific impulse (or equivalently exhaust velocity) to minimize the amount of energy required to produce a given mission delta-v in the payload. The somewhat surprising result is that the optimum specific impulse is not the maximum possible value, but is proportional to the mission delta-v. In general terms, at the beginning of the mission it is optimum to use a very low specific impulse and expend a lot of reaction mass, since this is the most energy

efficient way to transfer momentum. However, as the mission progresses, it becomes important to minimize the amount of reaction mass expelled, since energy is wasted moving the reaction mass. Thus, the optimum specific impulse will increase with the mission delta-v. Optimum I(sub sp) is derived for maximum payload return per energy expended for both the case of fixed and variable I(sub sp) engines. Sample missions analyzed include return of water payloads from the moons of Mars and of Saturn.
CASI
Extraterrestrial Resources; Hydrogen Oxygen Engines; Momentum Transfer; Nuclear Propulsion; Spacecraft Propulsion; Specific Impulse

19910016749 General Dynamics Corp., San Diego, CA, USA
Mass budget for mining the moons of Mars
Zuppero, Anthony; Landis, Geoffrey A.; Arizona Univ., Resources of Near-Earth Space: Abstracts; JAN 1, 1991; In English; No Copyright; Avail: Other Sources

The mass budget is detailed for system architectures that use rocket fuels of propellants derived from Deimos and Phobos to transport 10000 ton payloads of exofuel (exoatmospheric fuels) or exomass (exoatmospheric mass) to earth orbits. A point design for the system architecture is used that includes a self-sustaining cycle, which requires no materials from earth, and an infrastructure, which must be emplaced to start the cycle. Both the use of steam rockets and the use of liquid oxygen and liquid hydrogen is examined. It is shown that a system delivering 10000 tons of payload to a highly elliptical earth orbit requires approximately 23000 tons of water for use by nuclear heated steam rockets to effect completely propulsive, round trip maneuvers. It is also shown that about 8000 tons will be available for sale at low earth orbit, each cycle, and that the number of cycles can number in the tens before critical components are replaced.
CASI
Deimos; Extraterrestrial Resources; Mining; Phobos; Rocket Propellants; Space Commercialization; Water Resources

19910016748 Martin Marietta Corp., Denver, CO, USA
Survey of resource opportunities and critical evaluation of economic requirements
Clark, Benton C.; Arizona Univ., Resources of Near-Earth Space: Abstracts; JAN 1, 1991; In English; No Copyright; Avail: Other Sources

A series of mission analyses were performed to evaluate human mission to Mars and the moon with and without the aid of planetary resource utilization. The types of trade studies that are considered include the use of resources to manufacture propellant, food, habitat atmospheric gases, and lander habitat structure. Also, the potential for export of resources from the moon, Mars, Phobos, Deimos, and selected asteroids is also examined. In all cases, mass leveraging is evaluated. For certain cases, economic factors are evaluated as well. It is concluded that some uses are highly leveraging on the mission, whereas others have lesser impact and, therefore, should be afforded lesser priority in resource utilization studies. This survey is made with a consistent set of scaling laws for spacecraft propulsion and habitation systems and subsystems, and therefore, provides a rational basis for comparing different resource locations and use strategies.
CASI
Asteroids; Economic Analysis; Extraterrestrial Resources; Lunar Exploration; Lunar Resources; Manned Mars Missions; Mars (Planet); Mission Planning

19910016746 Analex Corp., Cleveland, OH, USA
Stacking the odds in favor of a space propulsion jackpot
Willoughby, Alan J.; Arizona Univ., Resources of Near-Earth Space: Abstracts; JAN 1, 1991; In English; No Copyright; Avail: Other Sources

When faced with a variety of technical options to solve a problem, program planners often try to identify one potential winner, then channel their resources into this option. The more scarce their resources are perceived to be, the more likely they are to fall into this trap of illogic. The real ideal solution could well be an optimum combination of options, not just one. Many propulsion opportunities are tantalizing solutions to the potentially high cost of travelling to other planets. Among these opportunities, nuclear thermal rockets (NTR), nuclear electric propulsion (NEP), and asteroid derived propellants stand out as high-payoff modest-challenge options, as near term as they are resolved to be made. But which to choose? Or should higher risk higher payoff technology be opted for, such as fusion? The approach advocated here, technoflex, is one that addresses NTR, NEP, and asteroid propellants in harmony rather than in isolation. Technoflex is technology rich, and option flexible. Technoflex should cost roughly the same as a classic phased technology elimination approach. The synergistic benefits

amongst these three options, how they can be efficiently pursued together, and how they can fit with longer range technologies are stressed. Even if no single option reaches its highest expectations, the combinations of any two partial winners would still give big dividends. These combinations are cheap propellants in space, dual mode high thrust/low thrust, or versatile propellant NTR. The triple payoff is excellent, even if all three options would pan out below expectations. If only one option reaches its potential, it could make the other two still worth their investment. If all three options meet full expectations, the triple payoff is a space propulsion jackpot which makes concern about the initial investment ludicrous as well as open up the solar system to expedient exploration.
CASI

Asteroids; Extraterrestrial Resources; Nuclear Electric Propulsion; Nuclear Rocket Engines; Propellants; Spacecraft Propulsion

19910016745 Analex Corp., Cleveland, OH, USA

Momentum harvesting techniques for solar system travel

Willoughby, Alan J.; Arizona Univ., Resources of Near-Earth Space: Abstracts; JAN 1, 1991; In English; No Copyright; Avail: Other Sources

Astronomers are lately estimating there are 400,000 earth visiting asteroids larger than 100 meters in diameter. These asteroids are uniquely accessible sources of building materials, propellants, oxygen, water, and minerals. They also constitute a huge momentum reserve, potentially usable for travel throughout the solar system. To use this momentum, these stealthy objects must be tracked and the ability to extract the desired momentum obtained. Momentum harvesting by momentum transfer from asteroid to spacecraft, and by using the momentum of the extraterrestrial material to help deliver itself to its destination is discussed. The purpose is neither to quantify nor justify the momentum exchange processes, but to stimulate collective imaginations with some intriguing possibilities which emerge when momentum as well as material is considered. A net and tether concept is the suggested means of asteroid capture, the basic momentum exchange process. The energy damping characteristics of the tether determines the velocity mismatch that can be tolerated, and hence the amount of momentum that can be harvested per capture. As the tether plays out of its reel, drag on the tether steadily accelerates the spacecraft and dilutes, in time, the would-be collision. A variety of concepts for riding and using asteroids after capture are introduced. The hitchhiker uses momentum transfer only. The beachcomber, the caveman, the swinger, the prospector, and the rock wrecker also take advantage of raw asteroid materials. The chemist and the hijacker go further, they process the asteroid into propellants. Or, an asteroid railway system could be constructed with each hijacked asteroid becoming a scheduled train. Travelers could board this space railway system assured that water, oxygen propellants, and shielding await them. Austere space travel could give way to comforts, with a speed and economy impossible without nature's gift of earth visiting asteroids.
CASI

Asteroid Capture; Asteroids; Extraterrestrial Resources; Mission Planning; Momentum Transfer; Spacecraft Propulsion; Tethering

19910016744 NASA Lewis Research Center, Cleveland, OH, USA

Near-Earth asteroids: Metals occurrence, extraction, and fabrication

Westfall, Richard; Arizona Univ., Resources of Near-Earth Space: Abstracts; JAN 1, 1991; In English; No Copyright; Avail: Other Sources

Near-earth asteroids occur in three principle types of orbits: Amor, Apollo, and Aten. Amor asteroids make relatively close (within 0.3 AU) approaches to the earth's orbit, but do not actually overlap it. Apollo asteroids spend most of their time outside the earth's orbital path, but at some point of close approach to the sun, they cross the orbit of the earth. Aten asteroids are those whose orbits remain inside the earth's path for the majority of their time, with semi-major axes less than 0.1 AU. Near-earth orbit asteroids include: stones, stony-irons, irons, carbonaceous, and super-carbonaceous. Metals within these asteroids include: iron, nickel, cobalt, the platinum group, aluminum, titanium, and others. Focus is on the extraction of ferrous and platinum group metals from the stony-iron asteroids, and the iron asteroids. Extraction of the metal fraction can be accomplished through the use of tunnel-boring-machines (TBM) in the case of the stony-irons. The metals within the story-iron asteroids occur as dispersed granules, which can be separated from the stony fraction through magnetic and gaseous digestion separation techniques. The metal asteroids are processes by drilling and gaseous digestion or by gaseous digestion alone. Manufacturing of structures, housings, framing networks, pressure vessels, mirrors, and other products is accomplished through the chemical vapor deposition (CVD) of metal coating on advanced composites and on the inside of contour-defining inflatables (CDI). Metal coatings on advanced composites provide: resistance to degradation in the hostile environments of space; superior optical properties; superior heat dissipation; service as wear coatings; and service as evidential coatings. Metal coatings on the inside of CDI produce metal load-bearing products. Fibers such as graphite, kevlar, glass, ceramic, metal, etc.,

can be incorporated in the metal coatings on the inside of CDI producing metal matrix products which exhibit high strength and resist crack propagation.
CASI
Asteroids; Extraction; Extraterrestrial Resources; Iron Compounds; Materials Recovery; Metals; Platinum Compounds

19910016743 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Short-period comets
Weissman, Paul R.; Campins, Humberto; Arizona Univ., Resources of Near-Earth Space: Abstracts; JAN 1, 1991; In English; No Copyright; Avail: Other Sources

The spacecraft flybys of Comet Halley in 1986 confirmed Whipple's icy conglomerate hypothesis for cometary nuclei and showed that comets are far richer in volatiles than any other class of solar system bodies. Water is the most abundant volatile, comprising roughly 80 percent of the gas flowing out from the nucleus. Carbon monoxide is next with a content of 15 percent relative to water, though with approximately half of that coming from an extended source in the cometary coma, i.e., hydrocarbon dust grains. The detection of large numbers of hydrocarbon CHON grains was one of the more significant discoveries of the Halley flybys, as was the ground-based observation that CN occurs in jets, again indicating an extended source. Evidence was also found for more complex hydrocarbons. Estimates of the total dust-to-gas ratio for Halley range as high as 2:1, indicating that a substantial fraction of the volatile material may be tied up in solid hydrocarbons rather than ices. The role of clathrates in trapping more volatile ices is not yet understood. If Halley can be taken to be representative of all short-period comets, then the short-period comets may provide a significant source of volatiles in near-earth space. This resource is more difficult to reach dynamically than the near-earth asteriods, but the high volatile content may justify the additional effort necessary. In addition, there is considerable evidence that at least some fraction of the near-earth asteriods are extinct cometary nuclei which have evolved into asteroid orbits, and which may contain significant volatiles buried beneath an insulating lag-deposit crust of nonvolatiles. Knowledge of comets will be greatly enhanced in the near future by the Comet Rendezvous Flyby mission now under development by NASA, and by the proposed Rosetta mission.
CASI
Carbon Monoxide; Chemical Composition; Extraterrestrial Resources; Halley's Comet; Hydrocarbons; Water Resources

19910016742 Arizona Univ., Tucson, AZ, USA
Enstatite chondrites and achondrites as asteroidal resources
Hutson, M. L.; Lewis, John S.; Resources of Near-Earth Space: Abstracts; JAN 1, 1991; In English; No Copyright; Avail: Other Sources

The highly reduced nature of the enstatite meteorites (chondrites and achondrites) differs from that of all other types of stony meteorites. The silicates in the enstatite meteorites contain almost no FeO. In addition, many normally lithophile elements such as Na, Ca, Mg, Cr, and Ti display chalcophilic behavior. A study of the chemistry and mineralogy of the enstatite meteorites was undertaken to determine their resource potential. On average, about 99 percent of the volume of an enstatite achondrite, or aubrite, consists of only four silicate minerals: enstatite, Na-rich plagioclase, diopside, and forsterite, with enstatite being by far the most abundant mineral. The remaining one percent of the volume consists of troilite, kamacite, and trace amounts of oldhamite, daubreelite, ferromagnesian albandite, and schreibersite. Thus, the aubrites can be considered as a possible source for large quantities of Mg, Si, and O, but are of little interest as a source of anything else. The enstatite chondrites appear to be more promising candidates for resource utilization. The chondrites are generally divided into two groups: EH (high iron, fine-grained, with abundant chondrules); and EL (low iron, coarse-grained, with little or no evidence of chondrules). Metallic Ni-Fe makes up roughly 20-25 weight percent of each type of enstatite chondrite. These meteorites are also a good source of nitrogen. This is due in part to the presence of osbornite and sinoite. The latter mineral is restricted to EL chondrites, which typically have a higher bulk nitrogen content than the EH chondrites. Three valuable metals, Cr, Mn, and Ti, are concentrated in a few distinct sulfide phases in the enstatite chondrites. These sulfide phases are troilite and niningerite in EH chondrites and troilite, daubreelite, and ferroan alabandite in EL chondrites.
CASI
Achondrites; Asteroids; Chemical Composition; Chondrites; Enstatite; Extraterrestrial Resources; Meteoritic Composition; Minerals

19910016740 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
An ISU study of asteroid mining
Burke, J. D.; Arizona Univ., Resources of Near-Earth Space: Abstracts; JAN 1, 1991; In English; No Copyright; Avail: Other Sources

During the 1990 summer session of the International Space University, 59 graduate students from 16 countries carried out a design project on using the resources of near-earth asteroids. The results of the project, whose full report is now available from ISU, are summarized. The student team included people in these fields: architecture, business and management, engineering, life sciences, physical sciences, policy and law, resources and manufacturing, and satellite applications. They designed a project for transporting equipment and personnel to a near-earth asteroid, setting up a mining base there, and hauling products back for use in cislunar space. In addition, they outlined the needed precursor steps, beginning with expansion of present ground-based programs for finding and characterizing near-earth asteroids and continuing with automated flight missions to candidate bodies. (To limit the summer project's scope the actual design of these flight-mission precursors was excluded.) The main conclusions were that asteroid mining may provide an important complement to the future use of lunar resources, with the potential to provide large amounts of water and carbonaceous materials for use off earth. However, the recovery of such materials from presently known asteroids did not show an economic gain under the study assumptions; therefore, asteroid mining cannot yet be considered a prospective business.
CASI
Asteroids; Extraterrestrial Resources; Mining; Project Planning; Space Bases

19910016739 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Lunar base siting
Staehle, Robert L.; Dowling, Richard; Arizona Univ., Resources of Near-Earth Space: Abstracts; JAN 1, 1991; In English; No Copyright; Avail: Other Sources

As with any planetary body, the lunar surface is quite heterogeneous. There are widely dispersed sites of particular interest for known and potential resource availability, selenology, and lunar observatories. Discriminating characteristics include solar illumination, view of earth, local topography, engineering properties of the regolith and certain geological features, and local mineralogy and petrology. Space vehicle arrival and departure trajectories constitute a minor consideration. Over time, a variety of base sites will be developed serving different purposes. Resource-driven sites may see the fastest growth during the first decades of lunar development, but selection of the most favorable sites is likely to be driven by suitability for a combination of activities. As on earth, later development may be driven by geographical advantages of surface transportation routes. With the availability of near-constant sunlight for power generation, as well as permanently shadowed areas at cryogenic temperatures, polar sites are attractive because they require substantially less earth-launched mass and lower equipment complexity for an initial permanent base. Discovery of accessible volatiles reservoirs, either in the form of polar permafrost or gas reservoirs at other locations, would dramatically increase the attractiveness of any site from a logistical support and selenological point of view. Amid such speculation, no reliable evidence of such volatiles exist. More reliable evidence exists for areas of certain mineral concentrations, such as ilmenite, which could form a feedstock for some proposed resource extraction schemes. While tentative selections of advantageous base sites are made, new data from lunar polar orbiters and the Galileo polar flybys would be very helpful.
CASI
Lunar Bases; Lunar Observatories; Lunar Resources; Lunar Surface; Selenology; Site Selection

19910016733 Houston Univ., TX, USA
Solar cells for lunar applications by vacuum evaporation of lunar regolith materials
Ignatiev, Alex; Arizona Univ., Resources of Near-Earth Space: Abstracts; JAN 1, 1991; In English; No Copyright; Avail: Other Sources

The National Space Exploration Initiative, specifically the Lunar component, has major requirements for technology development of critical systems, one of which is electrical power. The availability of significant electrical power on the surface of the Moon is a principal driver defining the complexity of the lunar base. Proposals to generate power on the Moon include both nuclear and solar (photovoltaic) systems. A more efficient approach is to attempt utilization of the existing lunar resources to generate the power systems. Synergism may occur from the fact that there have already been lunar materials processing techniques proposed for the extraction of oxygen that would have, as by-products, materials that could be specifically used to generate solar cells. The lunar environment is a vacuum with pressures generally in the 1 x 10(exp -10) torr range. Such conditions provide an ideal environment for direct vacuum deposition of thin film solar cells using the waste silicon, iron, and TiO2 available from the lunar regolith processing meant to extract oxygen. It is proposed, therefore, to grow by vacuum deposition, thin film silicon solar cells from the improved regolith processing by-products.
CASI
Evaporation; Lunar Resources; Lunar Rocks; Oxygen Production; Regolith; Solar Cells

19910016717 Kuck (David L.), Oracle, AZ, USA

Extraterrestrial resources: Implications from terrestrial experience

Kuck, David L.; Gillett, Stephen L.; Arizona Univ., Resources of Near-Earth Space: Abstracts; JAN 1, 1991; In English; No Copyright; Avail: Other Sources

Terrestrial mining experience indicates that the overwhelming criterion of a potentially economic deposit is its recoverable concentration of the desired mineral or element. Recovery can be based on contrast in physical and/or chemical properties, but processes based on physical properties are typically less expensive. As several processes generally are used in sequence, they have a profound effect on extraction costs. These criteria will also apply to extraterrestrial resources. Although the extreme cost of access to space makes even ordinary materials extremely valuable, this inaccessibility also makes capital and maintenance costs extremely high. The following four development stages will apply, especially with the additional unknowns of an extraterrestrial environment: (1) Exploration for the highest grade of the mineral or element desired (because the extraction plant must be simple, cheap, and rugged to minimize capital and maintenance costs, high grade is extremely important); (2) Laboratory testing of various physical and/or chemical separation techniques on the possible ore to determine if the material can indeed be recovered economically; (3) a pilot plant test, in which a large sample is dug from the deposit to determine excavation rates, power requirements, and equipment wear. (This sample is then run through a pilot mill designed on the basis of the laboratory testing. Pilot plant testing must be carried out at increasing scales, but several trials are generally necessary at each scale before the size of operations can be increased. Moreover, pilot testing is necessary for each new mineral deposit); and (4) Last is the full-scale mine and plant start-up. (New problems invariably occur at this point, but they can be kept to a minimum if the pilot plant tests were realistic). If such a development plan is followed rigorously, major cost overruns, with their potentially disastrous effects on resource developments, can be avoided.

CASI

Costs; Criteria; Excavation; Extraction; Extraterrestrial Resources; Maintenance; Mineral Deposits; Mining; Pilot Plants

19910016716 Michigan Technological Univ., Houghton, MI, USA

Utilization of lunar ilmenite: Basalt or regolith?

Kawatra, S. K.; Delao, K. L.; Arizona Univ., Resources of Near-Earth Space: Abstracts; JAN 1, 1991; In English; No Copyright; Avail: Other Sources

A critical discussion of whether lunar basalt or regolith should be used as a resource for mineral processing schemes on the lunar surface, with pros and cons for each argument is presented. A literature review has shown that the majority of authors feel that mining the lunar basalt, crushing it, and then processing to remove the desired minerals, would be the route to take. The argument that this method would not be a sound mineral processing practice is presented. Mining and crushing are difficult propositions even on Earth; to attempt such processes in the hostile lunar environment would be a phenomenal task. It would be better to start with a simpler scheme, such as processing the regolith, which can be adapted to the multitude of unknowns facing the first lunar production plant. If, however, the lunar mining trend is followed, it must be kept in mind that mining and processing technology which is radically different from what is currently available and used on Earth will have to be developed. Podnieks and Roepke (1987) and Lindroth and Podnieks (1987) have summarized the new technology that may be applicable, but this technology is very similar to the current, 99 percent inefficient technology used on Earth. One such possible technique is sodium vapor fragmentation of basalt. Initial testwork was conducted at Michigan Technological University on terrestrial basalt with extremely promising results, though much time and effort will be needed to fully develop this process.

CASI

Basalt; Crushing; Ilmenite; Lunar Mining; Lunar Rocks; Regolith

19910016712 Nevada Univ., Reno, NV, USA

Possible lunar ores

Gillett, Stephen L.; Arizona Univ., Resources of Near-Earth Space: Abstracts; JAN 1, 1991; In English; No Copyright; Avail: Other Sources

Despite the conventional wisdom that there are no lunar ores, geochemical considerations suggest that local concentrations of useful rare elements exist on the Moon in spite of its extreme dryness. The Moon underwent protracted igneous activity in its history, and certain magmatic processes can concentrate incompatible elements even if anhydrous. Such processes include: (1) separation of a magma into immiscible liquid phases (depending on composition, these could be silicate-silicate, silicate-oxide, silicate-sulfide, or silicate-salt); (2) cumulate deposits in layered igneous intrusions; and (3) concentrations of rare, refractory, lithophile elements (e.g., Be, Li, Zr) in highly differentiated, silica-rich magmas, as in the lunar granites. Terrestrial mining experience indicates that the single most important characteristic of a potential ore is its

concentration of the desire element. The utility of a planet as a resource base is that the welter of interacting processes over geologic time can concentrate rare element automatically. This advantage is squandered if adequate exploration for ores is not first carried out.
CASI
Geochemistry; Geochronology; Liquid Phases; Lunar Resources; Lunar Surface; Magma; Mining; Moisture Content; Refractories

19910016711 Arizona Univ., Tucson, AZ, USA
Refractory materials from lunar resources
Fabes, B. D.; Poisl, W. H.; Resources of Near-Earth Space: Abstracts; JAN 1, 1991; In English; No Copyright; Avail: Other Sources

Refractories - materials which are able to withstand extremely high temperatures - are sure to be an important part of any processing facility or human outpost which is built on Mars. Containers for processing lunar oxygen will need high temperature components. Fabrication of structural material from lunar resources need both containment vessels to hold high temperature melts and molds in which to form the final shapes. Certainly, it would be desirable to fabricate such vessels and molds on the Moon, rather than carrying them up from the Earth. At first glance, this might appear to be a trivial task, since the Moon's surface consists of a variety of refractory compositions. To turn the regolith into a useful fire brick or mold, however, will require water or other binders and additives which are likely to be in extremely short supply on the Moon. The steps needed to make fire bricks and molds for lunar-derived structural materials are examined, pointing out the critical steps and resources which will be needed. While these processes and applications may seem somewhat mundane, it is emphasized that it is precisely these rudimentary processes which must be mastered before discussing making aerobrakes, and other fancier refractories from lunar resources.
CASI
Bricks; Containment; Fabrication; Lunar Resources; Refractories; Refractory Materials; Regolith

19910016708 Bureau of Mines, Minneapolis, MN, USA
Mining and beneficiation: A review of possible lunar applications
Chamberlain, Peter G.; Arizona Univ., Resources of Near-Earth Space: Abstracts; JAN 1, 1991; In English; No Copyright; Avail: Other Sources

Successful exploration of Mars and outer space may require base stations strategically located on the Moon. Such bases must develop a certain self-sufficiency, particularly in the critical life support materials, fuel components, and construction materials. Technology is reviewed for the first steps in lunar resource recovery-mining and beneficiation. The topic is covered in three main categories: site selection; mining; and beneficiation. It will also include (in less detail) in-situ processes. The text described mining technology ranging from simple diggings and hauling vehicles (the strawman) to more specialized technology including underground excavation methods. The section of beneficiation emphasizes dry separation techniques and methods of sorting the ore by particle size. In-situ processes, chemical and thermal, are identified to stimulate further thinking by future researchers.
CASI
Beneficiation; Lunar Bases; Lunar Resources; Mining; Moon

19910016707 Worcester Polytechnic Inst., MA, USA
Mechanisms of ilmenite reduction and their impact on the design of effective reactor systems
Briggs, R. A.; Sacco, A.; Arizona Univ., Resources of Near-Earth Space: Abstracts; JAN 1, 1991; In English; No Copyright; Avail: Other Sources

One of the first activities at a lunar base could be oxygen recovery from ilmenite (FeTiO3). Oxygen produced from lunar soils could be used to fuel transportation vehicles operating in near-earth space. The first step in developing a suitable reactor system for lunar operation is to determine the mechanisms and rates of oxygen removal from ilmenite. In-situ gravimetric measurements and microscopic examinations were used to determine the hydrogen reduction mechanisms of synthetic ilmenite discs between 823 to 1353 K. A shrinking core reaction model, modified to account for the growth of an iron film on the surface of discs, was capable of predicting experimentally observed conversion-time relationships. The observed reduction mechanism, kinetic rates, and associated activation energy established a base line from which comparisons could be made to improve oxygen yield and removal rates. One proposed technique to improve the rate and extent of oxygen removal was to preoxidize ilmenite. Preoxidation is commonly used during the reduction of ilmenite ores in the iron industry

and has been employed for many years to lower operating temperatures and increase reduction rates. This technology could prove beneficial for oxygen production facilities on the Moon as less massive reactor vessels and/or less energy could be associated with a process including preoxidation. X ray diffraction and energy dispersive spectroscopy were utilized to follow the progression of ilmenite oxidation at 1123 and 1140 K and the reduction of pseudobrookite (Fe_2TiO_5) at 873 and 973 K. Structures formed during the progress of oxidation were related to the system's phase diagrams. Results indicated that after initially producing ilmenite-hematite solutions and rutile (TiO_2), pseudobrookite was the end product of oxidation at all temperatures examined (1049 to 1273 K). Initial results from the reduction of pseudobrookite indicate a series of phases are produced including ferropseudobrookite ($FeTi_2O_5$), ulvospinel (Fe_2TiO_4), and ilmenite. Rates of pseudobrookite reduction were typically 50 to 200 times that of ilmenite.
CASI
Activation Energy; Chemical Reactions; Ilmenite; Lunar Resources; Lunar Soil; Minerals; Oxidation; Oxygen Production; Predictions

19910016706 Space Data Resources and Information, Washington, DC, USA
Utilization of space resources: A historical view
David, Leonard W.; Arizona Univ., Resources of Near-Earth Space: Abstracts; JAN 1, 1991; In English; No Copyright; Avail: Other Sources

While widely accepted today, the use of non-Earth resources in official space planning circles has been long in coming. Popular and governmental acceptance of using extraterrestrial resources, be they asteroids, comets, or other celestial bodies are highlighted. Particular emphasis is placed on those individuals, such as the late Dandridge Cole, who pioneered early discussion and thought on the topic over a period of several decades. The evolution of using extraterrestrial resources in governmental space policy, such as NASA's Outlook for Space (1976) and Pioneering the Space Frontier (1986) is reviewed. Put forward is the view that a redefinition of resources of near-Earth space may be warranted, particularly in consideration of using high vacuum, solar radiation, and magnetospheric phenomenon for experimentation and application purposes. Lastly, a prospective look at public reaction to utilizing space resources is presented.
CASI
Extraterrestrial Resources; Histories; Materials Handling; Space Commercialization; Space Law; Utilization

19910016705 Arizona Univ., Tucson, AZ, USA
Resources of Near-Earth Space: Abstracts
JAN 1, 1991; In English; 2nd Annual Symposium of the Univ. of Arizona/NASA Space Engineering Research Center for Utilization of Local Planetary Resources, 7-10 Jan. 1991, Tucson, AZ, USA; See also N91-26020 through N91-26097
Report No.(s): NASA-CR-188219; NAS 1.26:188219; No Copyright; Avail: CASI; A04, Hardcopy

The objectives are by theory, experiment, and bench-level testing of small systems, to develop scientifically-sound engineering processes and facility specifications for producing propellants and fuels, construction and shielding materials, and life support substances from the lithospheres and atmospheres of lunar, planetary, and asteroidal bodies. Current emphasis is on the production of oxygen, other usefull gases, metallic, ceramic/composite, and related byproducts from lunar regolith, carbonaceous chrondritic asteroids, and the carbon dioxide rich Martian atmosphere.
Abstracts; Asteroids; Carbon Dioxide; Life Support Systems; Lunar Resources; Lunar Rocks; Mars Atmosphere; Oxygen Production; Regolith

19910015935 Washington Univ., Saint Louis, MO, USA
Lunar resources: Toward living off the lunar land
Haskin, Larry A.; Colson, Russell O.; Arizona Univ., NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1990; In English; No Copyright; Avail: CASI; A03, Hardcopy

The following topics are addressed: (1) lunar resources and surface conditions; (2) guidelines for early lunar technologies; (3) the lunar farm; (4) the lunar filling station; (5) lunar construction materials; (6) the lunar power company; (7) the electrolysis of molten silicate as a means of producing oxygen and metals for use on the Moon and in near-Earth space.
K.S.
Lunar Bases; Lunar Resources

19910015934 Washington Univ., Saint Louis, MO, USA
Lunar oxygen and metal for use in near-Earth space: Magma electrolysis
Colson, Russell O.; Haskin, Larry A.; Arizona Univ., NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1990; In English; No Copyright; Avail: CASI; A02, Hardcopy

Because it is energetically easier to get material from the Moon to Earth orbit than from the Earth itself, the Moon is a potentially valuable source of materials for use in space. The unique conditions on the Moon, such as vacuum, absence of many reagents common on the Earth, and the presence of very nontraditional ores suggest that a unique and nontraditional process for extracting materials from the ores may prove the most practical. With this in mind, an investigation of unfluxed silicate electrolysis as a method for extracting oxygen, iron, and silicon from lunar regolith was initiated and is discussed. The advantages of the process include simplicity of concept, absence of need to supply reagents from Earth, and low power and mass requirements for the processing plant. Disadvantages include the need for uninterrupted high temperature and the highly corrosive nature of the high-temperature silicate melts which has made identifying suitable electrode and container materials difficult.
CASI
Electrolysis; Iron; Lunar Resources; Lunar Rocks; Minerals; Oxygen Production; Silicon

19910015933 BDM International, Inc., Albuquerque, NM, USA, Bechtel International Corp., San Francisco, CA, USA, Lovelace Scientific Resources, Inc., Albuquerque, NM, USA
Engineering, construction, and operations in space
Johnson, Stewart W., editor; Wetzel, John P., editor; Arizona Univ., NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1990; In English, 29-31 Aug. 1988, Albuquerque, NM, USA; No Copyright; Avail: CASI; A03, Hardcopy

The century-old Mond process for carbonyl extraction of metals from ore shows great promise as an efficient low energy scheme for producing high-purity Fe, Ni, Cr, Mn, and Co from lunar or asteroidal feedstocks. Scenarios for winning oxygen from the lunar regolith can be enhanced by carbonyl processing of the metallic alloy by-products of such operations. The native metal content of asteroidal regoliths is even more suitable to carbonyl processing. High-purity, corrosion resistant Fe and Ni can be extracted from asteroidial feedstocks along with a Co-rich residue containing 0.5 percent platinum-group metals. The resulting gaseous metal carbonyl can produce a variety of end products using efficient vapor forming techniques.
CASI
Asteroids; Carbonyl Compounds; Extraction; Extraterrestrial Resources; Lunar Rocks; Metals; Minerals; Oxygen Production

19910015932 Arizona Univ., Tucson, AZ, USA
Data base on physical observations of near-Earth asteroids and establishment of a network to coordinate observations of newly discovered near-Earth asteroids
Davis, D. R.; Chapman, C. R.; Campins, H.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1990; In English; No Copyright; Avail: CASI; A01, Hardcopy

This program consists of two tasks: (1) development of a data base of physical observations of near-earth asteroids and establishment of a network to coordinate observations of newly discovered earth-approaching asteroids; and (2) a simulation of the surface of low-activity comets. Significant progress was made on task one and, and task two was completed during the period covered by this progress report.
CASI
Asteroids; Comets; Data Bases; Extraterrestrial Resources; Surface Properties; Visual Observation

19910015931 Arizona Univ., Tucson, AZ, USA
Energy management analysis of lunar oxygen production
Fazzolari, R.; Wong-Swanson, B. G.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1990; In English; No Copyright; Avail: CASI; A02, Hardcopy

Energy load models in the process of hydrogen reduction of ilmenite for lunar oxygen production are being developed. The load models will be used as a first step to ultimately determine the optimal energy system needed to supply the power requirements for the process. The goal is to determine the energy requirements in the process of hydrogen reduction of ilmenite to produce oxygen. The general approach is shown, and the objectives are to determine the energy loads of the processes in the system. Subsequent energy management studies will be made to minimize the system losses (irreversibilities) and to design optimal energy system power requirements. A number of processes are being proposed as possible candidates for lunar application and some detailed experimental efforts are being conducted within this project at the University of Arizona. Priorities are directed toward developing the energy models for each of the proposed processes being considered. The

immediate goals are to identify the variables that would impact energy requirements and energy sources of supply.
CASI
Energy Requirements; Hydrogen; Ilmenite; Lunar Resources; Mathematical Models; Oxygen Production; Reduction (Chemistry)

19910015930 Arizona Univ., Tucson, AZ, USA
A figure-of-merit approach to extraterrestrial resource utilization
Ramohalli, K.; Kirsch, T.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1990; In English; No Copyright; Avail: CASI; A03, Hardcopy

A concept is developed for interrelated optimizations in space missions that utilize extraterrestrial resources. It is shown that isolated (component) optimizations may not result in the best mission. It is shown that substantial benefits can be had through less than the best propellants, propellant combinations, propulsion hardware, and actually, some waste in the traditional sense. One ready example is the possibility of discarding hydrogen produced extraterrestrially by water splitting and using only the oxygen to burn storable fuels. The gains in refrigeration and leak-proof equipment mass (elimination) outweigh the loss in specific impulse. After a brief discussion of this concept, the synthesis of the four major components of any future space mission is developed. The four components are: orbital mechanics of the transportation; performance of the rocket motor; support systems that include power; thermal and process controls, and instruments; and in situ resource utilization plant equipment. This paper's main aim is to develop the concept of a figure-of-merit for the mission. The Mars Sample Return Mission is used to illustrate the new concept. At this time, a popular spreadsheet is used to quantitatively indicate the interdependent nature of the mission optimization. Future prospects are outlined that promise great economy through extraterrestrial resource utilization and a technique for quickly evaluating the same.
CASI
Extraterrestrial Resources; Figure of Merit; Mission Planning; Space Missions

19910015927 Arizona Univ., Tucson, AZ, USA
Determination of lunar ilmentite abundances from remotely sensed data
Johnson, J. R.; Larson, S. M.; Singer, Robert B.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1990; In English; No Copyright; Avail: CASI; A03, Hardcopy

The mapping of ilmenite on the surface of the moon is a necessary precursor to the investigation of prospective lunar base sites. Telescopic observations of the moon using a variety of narrow bandpass optical interference filters are being performed as a preliminary means of achieving this goal. Specifically, ratios of images obtained using filters centered at 0.40 and 0.56 microns provide quantitative estimates of TiO_2 abundances. Analysis of preliminary distribution maps of TiO_2 concentrations allows identification of specific high-Ti areas. Investigations of these areas using slit spectra in the range 0.03 to 0.85 microns are underway to search for discrete spectral signatures attributable to ilmenite.
CASI
Abundance; Ilmenite; Lunar Composition; Lunar Maps; Lunar Resources; Mapping; Spectral Signatures; Titanium Oxides

19910015922 Science Applications International Corp., San Diego, CA, USA
The feasibility of solar reflector production from lunar materials for solar power in space
Arizona Univ., NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1990; In English; No Copyright; Avail: CASI; A03, Hardcopy

Science Applications International Corporation (SAIC) investigated the feasibility of producing solar reflectors from indigenous lunar materials for solar power production on the moon. First, lunar construction materials and production processes were reviewed, and candidate materials for reflector production were identified. At the same time, lunar environmental conditions were reviewed for their effect on production of concentrators. Next, conceptual designs and fabrication methods were proposed and studied for production of dish concentrators and heliostats. Finally, fabrication testing was performed on small-scale models using earth analogs of lunar materials. Findings from this initial investigation indicate that production of concentrators from lunar materials may be an attractive approach for solar energy production on the moon. Further design and testing are required to determine the best techniques and approaches to optimize this concept. Four materials were identified as having high potential for solar reflector manufacture. These baseline materials were foamed glass, concrete with glass-fiber reinforcement, a glass-fiber/glass-melt composite, and an iron-glass sintered material.
CASI
Concentrators; Fabrication; Heliostats; Lunar Based Equipment; Lunar Resources; Parabolic Reflectors; Solar Generators; Solar Reflectors

19910015921 Arizona Univ., Tucson, AZ, USA

Helium-3 in the lunar regolith

Swindle, T.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1990; In English; No Copyright; Avail: Other Sources

A preliminary assessment of He-3 distribution in lunar soils was completed, including variations with soil location, depth, composition, grain size, and other parameters that might be useful in developing mining scenarios. One of the primary tools was a compilation of available analyses of He-3 in lunar samples. The compilation includes analyses of more than 250 numbered samples (plus duplicates and subsamples in many cases) from the American and Russian lunar programs, reported in nearly 100 publications. In addition, average abundances for soils from each of the Apollo landing sites were computed. These were coupled with models and measurements of other pertinent parameters.

CASI

Helium Isotopes; Lunar Composition; Lunar Mining; Lunar Rocks; Lunar Soil; Regolith

19910015919 Arizona Univ., Tucson, AZ, USA

Innovative techniques for the production of energetic radicals for lunar materials processing including photogeneration via concentrated solar energy

Osborn, D. E.; Lynch, D. C.; Fazzolari, R.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1990; In English; No Copyright; Avail: CASI; A02, Hardcopy

The Department of Materials Science and Engineering (MSE) is investigating the use of monatomic chlorine produced in a cold plasma to recover oxygen and metallurgically significant metals from lunar materials. Development of techniques for the production of the chlorine radical (and other energetic radicals for these processes) using local planetary resources is a key step for a successful approach. It was demonstrated terrestrially that the use of UV light to energize the photogeneration of OH radicals from ozone or hydrogen peroxide in aqueous solutions can lead to rapid reaction rates for the breakdown of toxic organic compounds in water. A key question is how to use the expanded solar resource at the lunar surface to generate process-useful radicals. This project is aimed at investigating that question.

CASI

Chlorination; Cold Plasmas; Free Radicals; Lunar Resources; Materials Recovery; Metals; Photochemical Reactions; Solar Energy

19910015916 Arizona Univ., Tucson, AZ, USA

Volatile-bearing phases in carbonaceous chondrites: Compositions, modal abundance, and reaction kinetics

Ganguly, Jibamitra; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1990; In English; No Copyright; Avail: CASI; A01, Hardcopy

The spectral and density characteristics of Phobos and Deimos (the two small natural satellites of Mars) strongly suggest that a significant fraction of the near-earth asteroids are made of carbonaceous chondrites, which are rich in volatile components and, thus, could serve as potential resources for propellants and life supporting systems in future planetary missions. However, in order to develop energy efficient engineering designs for the extraction of volatiles, knowledge of the nature and modal abundance of the minerals in which the volatiles are structurally bound and appropriate kinetic data on the rates of the devolatilization reactions is required. Theoretical calculations to predict the modal abundances and compositions of the major volatile-bearing and other mineral phases that could develop in the bulk compositions of C1 and C2 classes (the most volatile rich classes among the carbonaceous chondrites) were performed as functions of pressure and temperature. The rates of dehydration of talc at 585, 600, 637, and 670 C at P(total) = 1 bar were determine for the reaction: Talc = 3 enstatite + quartz + water. A scanning electron microscopic study was conducted to see if the relative abundance of phases can be determined on the basis of the spectral identification and x ray mapping. The results of this study and the other studies within the project are discussed.

CASI

Abundance; Carbonaceous Chondrites; Dehydration; Extraterrestrial Resources; Meteoritic Composition; Reaction Kinetics; Talc

19910015915 Arizona Univ., Tucson, AZ, USA

Production of oxygen from lunar ilmenite

Zhao, Y.; Shadman, F.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1990; In English; No Copyright; Avail: CASI; A01, Hardcopy

The following subjects are addressed: (1) the mechanism and kinetics of carbothermal reduction of simulated lunar ilmenite using carbon and, particularly, CO as reducing agents; (2) the determination of the rate-limiting steps; (3) the investigation of the effect of impurities, particularly magnesium; (4) the search for catalysts suitable for enhancement of the rate-limiting step; (5) the comparison of the kinetics of carbothermal reduction with those of hydrogen reduction; (6) the study of the combined use of CO and hydrogen as products of gasification of carbonaceous solids; (7) the development of reduction methods based on the use of waste carbonaceous compounds for the process; (8) the development of a carbothermal reaction path that utilizes gasification of carbonaceous solids to reducing gaseous species (hydrocarbons and carbon monoxide) to facilitate the reduction reaction kinetics and make the process more flexible in using various forms of carbonaceous feeds; (9) the development of advanced gas separation techniques, including the use of high-temperature ceramic membranes; (10) the development of an optimum process flow sheet for carbothermal reduction, and comparison of this process with the hydrogen reduction scheme, as well as a general comparison with other leading oxygen production schemes; and (11) the use of new and advanced material processing and separation techniques.
CASI
Ilmenite; Lunar Resources; Oxygen Production; Reaction Kinetics; Reduction (Chemistry)

19910015914 Arizona Univ., Tucson, AZ, USA
Ilmenite beneficiation and high-precision analyses of extraterrestrial material
Ruiz, J.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1990; In English; No Copyright; Avail: Other Sources

During the past year, work on characterizing lunar material that has the potential of becoming ilmenite lunar ore was performed. The important aspects of any such material are that it has abundant ilmenite and that the ilmenite be easily separated. The final result sought is a pure (greater than 99 percent ilmenite) concentrate that will be used as feed for the ilmenite reduction process. There are two types of starting material available on the moon. Solid rock (basalt or anorthosite) and regolith. Extensive literature reviews of ilmenite separation experiments were performed, and simulants (meteorites) were separated. It was concluded that, because of the large amounts of agglomerates, regolith may not be the best starting material for ilmenite beneficiation and that either basalts or anorthosites may be better. This is because no matter how finely the regolith is ground, it would not be possible to efficiently separate all the ilmenite. This hypotheses, however, needs to be tested with lunar material.
CASI
Beneficiation; Ilmenite; Lunar Resources; Lunar Rocks; Minerals; Reduction (Chemistry); Separation

19910015913 Arizona Univ., Tucson, AZ, USA
Extraction of volatile and metals from extraterrestrial materials
Lewis, John S.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1990; In English; No Copyright; Avail: CASI; A02, Hardcopy

Since March 1, 1989, attention was concentrated on the extraction of ilmenite from extraterrestrial materials and on the planning and development of laboratory facilities for carbonyl extraction of ferrous metal alloys. Work under three subcontracts was administered by this project: (1) electrolytic production of oxygen from molten lunar materials; (2) microwave processing of lunar materials; and (3) production of a resource-oriented space science data base.
CASI
Carbonyl Compounds; Data Bases; Extraction; Ilmenite; Iron Alloys; Lunar Resources; Microwaves; Oxygen Production

19910015912 Arizona Univ., Tucson, AZ, USA
Autonomous production of propellants
Ramohalli, Kumar; Schallhorn, P. A.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1990; In English; No Copyright; Avail: CASI; A01, Hardcopy

The autonomous production of propellants is addressed. Since 80 to 90 percent of a spacecraft's mass is typically propellants, it is advantageous to produce propellants in strategic locations en route to, and at, the desired mission destination. This reduces the weight of the spacecraft and the cost of each mission. Since one of the primary goals of the space program is safety, a totally automated propellant production system is desirable. This system would remove, from hostile, high-risk extraterrestrial environments, the constant human intervention currently required in the production of many propellants. This enables the exploration of space to be more than the search for and production of fuel. As a proof-of-concept demonstration, one specific case was chosen for this study. That case was a composite propellant processor (the principle is more important

than the application), and the specific processor used saved SERC the considerable cost of acquiring a new liquid propellant processor that would also have required similar automation.
CASI
Automatic Control; Composite Propellants; Control Systems Design; Extraterrestrial Resources; Fuel Production; Space Exploration

19910015911 Arizona Univ., Tucson, AZ, USA
Cold plasma processing of local planetary ores for oxygen and metallurgically important metals
Lynch, D. C.; Bullard, D.; Ortega, R.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1990; In English; No Copyright; Avail: CASI; A01, Hardcopy; Original contains color illustrations

The utilization of a cold plasma in chlorination processing is described. Essential equipment and instruments were received, the experimental apparatus assembled and tested, and preliminary experiments conducted. The results of the latter lend support to the original hypothesis: a cold plasma can both significantly enhance and bias chemical reactions. In two separate experiments, a cold plasma was used to reduce $TiCl_4$ vapor and chlorinate ilmenite. The latter, reacted in an argon-chlorine plasma, yielded oxygen. The former experiment reveals that chlorine can be recovered as HCl vapor from metal chlorides in a hydrogen plasma. Furthermore, the success of the hydrogen experiments has lead to an analysis of the feasibility of direct hydrogen reduction of metal oxides in a cold plasma. That process would produce water vapor and numerous metal by-products.
CASI
Chemical Reactions; Cold Plasmas; Extraterrestrial Resources; Metals; Minerals; Oxygen Production; Reduction (Chemistry)

19910015910 Arizona Univ., Tucson, AZ, USA
Performance of unconventional propellants
Rascon, Mario; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1990; In English; No Copyright; Avail: CASI; A01, Hardcopy

This research involves the theoretical calculations of rocket performance for exotic propellants at various operating conditions, such as chamber pressure, pressure ratios, and oxidizer-to-fuel ratios. Exotic propellants are materials that may not normally be used as propellants on earth due to their low performance characteristics or other factors. The majority of the work was done using the Gordon and McBride CET 86 Program in both a mainframe version and personal computer versions. In addition, the Lockheed/Air Force Solid Propellant Theoretical Performance Program for the IBM PS/2, which handles condensed product species better, was also used.
CASI
Combustion Efficiency; Extraterrestrial Resources; Performance Prediction; Propellant Combustion; Propulsion System Performance; Rocket Propellants

19910015909 Arizona Univ., Tucson, AZ, USA
NASA Space Engineering Research Center for utilization of local planetary resources
Ramohalli, Kumar; Lewis, John S.; JAN 1, 1990; In English; See also N91-25224 through N91-25249
Report No.(s): NASA-CR-188220; NAS 1.26:188220; No Copyright; Avail: CASI; A13, Hardcopy; Original contains color illustrations

The University of Arizona and NASA have joined to form the UA/NASA Space Engineering Research Center. The purpose of the Center is to discover, characterize, extract, process, and fabricate useful products from the extraterrestrial resources available in the inner solar system (the moon, Mars, and nearby asteroids). Individual progress reports covering the center's research projects are presented and emphasis is placed on the following topics: propellant production, oxygen production, ilmenite, lunar resources, asteroid resources, Mars resources, space-based materials processing, extraterrestrial construction materials processing, resource discovery and characterization, mission planning, and resource utilization.
Asteroids; Extraterrestrial Resources; Fuel Production; Lunar Resources; Mars (Planet); Materials Handling; Moon; Oxygen Production; Propellants

19910015908 Arizona Univ., Tucson, AZ, USA
Theoretical predictions of volatile bearing phases and volatile resources in some carbonaceous chondrites
Ganguly, Jibamitra; Saxena, Surendra K.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1989; In English; No Copyright; Avail: CASI; A02, Hardcopy

Carbonaceous chondrites are usually believed to be the primary constituents of near-Earth asteroids and Phobos and Diemos, and are potential resources of fuels which may be exploited for future planetary missions. The nature and abundances are calculated of the major volatile bearing and other phases, including the vapor phase that should form in C1 and C2 type carbonaceous chondrites as functions of pressure and temperature. The results suggest that talc, antigorite plus or minus magnesite are the major volatile bearing phases and are stable below 400 C at 1 bar in these chondritic compositions. Simulated heating of a kilogram of C2 chondrite at fixed bulk composition between 400 and 800 C at 1 bar yields about 135 gm of volatile, which is made primarily of H2O, H2, CH4, CO2 and CO. The relative abundances of these volatile species change as functions of temperature, and on a molar basis, H2 becomes the most dominant species above 500 C. In contrast, Cl chondrites yield about 306 gm of volatile under the same condition, which consist almost completely of 60 wt percent H2O and 40 wt percent CO2. Preliminary kinetic considerations suggest that equilibrium dehydration of hydrous phyllosilicates should be attainable within a few hours at 600 C. These results provide the framework for further analyses of the volatile and economic resource potentials of carbonaceous chondrites.
CASI
Carbonaceous Chondrites; Extraterrestrial Resources; Rocket Propellants; Space Processing; Vapor Phases

19910015907 Arizona Univ., Tucson, AZ, USA
Notes on lunar ilmenite
Hutson, M. L.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1989; In English; No Copyright; Avail: CASI; A02, Hardcopy

Opaques (mostly ilmenite) make up 0 to 5 percent of highland rocks, 1 to 11 percent of low-Ti mare basalts, and 10 to 34 percent of high-Ti mare basalts (Carter 1988). Apollos 11 and 17 sampled high-Ti basalts. Apollos 12 and 14 sampled low-Ti basalts. Apollo 15 sampled a complex mixture of mare and highland material. Apollo 16 sampled mainly highland material (Taylor 1975).
CASI
Ilmenite; Lunar Resources

19910015905 Arizona Univ., Tucson, AZ, USA
An annotated bibliography of propellant processing methods
Cutler, A. H.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1989; In English; No Copyright; Avail: CASI; A01, Hardcopy

The author has specialized in space resources research for many years, with special emphasis on oxygen reduction methods. He has been retained to write a comprehensive review of these methods, detailing advantages and disadvantages, listing by-products and presenting recommendations. As the first step, an extensive outline was prepared, and the portion of this outline covering product manufacture was selected as the initial goal. A working version is presented.
CASI
Annotations; Extraterrestrial Resources; Fuel Production; Rocket Propellants

19910015904 California Univ., San Diego, CA, USA
Bibliographic search of the literature on lunar processing
Criswell, D. R.; Arizona Univ., NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1989; In English; No Copyright; Avail: Other Sources

The Lunar and Planetary Institute (LPI) search produced approximately 80 references. Most of these are available at the LPI. The product includes only the author, title, date, and reference. The earliest (Cooper et al., Certain ecological aspects of a closed lunar base, Rand Corp.) is dated 6 March 1958. The latest is a semi-popular article (Cole and Majdacic, Astronomy, vol. 16) produced last year. The early references tend to be reports of government sponsored engineering studies. The later are generally semi-popular and science press articles. These references will be obtained on disk from the LPI and can be converted into an ASCII file for access via IBM-compatible PCs.
CASI
Lunar Resources; Space Processing; Surveys

19910015903 Planetary Science Inst., Tucson, AZ, USA
Development of the data base for near-Earth resources
Davis, D. R.; Arizona Univ., NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1989; In English; No Copyright; Avail: Other Sources

Development of the data base for near-Earth resources was begun. Specific items accomplished were: (1) Definition of data base contents via discussions among the PSI staff and outside scientist such as Lucy McFadden and Mark Skyes; (2) Discussion/demonstration of dBase capabilities and possible organization of file(s) with L. Alvarez, Steward Observatory; (3) Data base entries for near-Earth asteroids consisting of data from the Russian ephemeris, a forthcoming review chapter for the Asteroids 2 book, and other literature; and (4) Development of a list of asteroid observers worldwide to be contacted during the coordinated phase of the project. A copy of the data base as it now exists is included.
CASI
Data Base Management Systems; Data Bases; Extraterrestrial Resources

19910015902 Arizona Univ., Tucson, AZ, USA
Energy management study for lunar oxygen production
Fazzolare, R. A.; Wong-Swanson, B. G.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1989; In English; No Copyright; Avail: CASI; A01, Hardcopy

Energy management opportunities in the process of hydrogen reduction of ilmenite for lunar oxygen production are being investigated. An optimal energy system to supply the power requirements for the process will be determined.
CASI
Electricity; Energy Requirements; Ilmenite; Lunar Resources; Oxygen Production; Space Processing; Thermal Energy

19910015897 Arizona Univ., Tucson, AZ, USA
Beneficiation of lunar ilmenite feedstock
Ruiz, J.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1989; In English; No Copyright; Avail: Other Sources

The chemical and physical characteristics are reviewed of ilmenite in lunar material and high precision, low abundance analyses were developed for platinoids and other possibly important elements in space materials using an induced coupled plasma mass spectrometer.
CASI
Beneficiation; Chemical Analysis; Ilmenite; Lunar Resources; Space Processing

19910015893 Arizona Univ., Tucson, AZ, USA
Chlorination processing of local planetary ores for oxygen and metallurgically important metals
Lynch, D. C.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1989; In English; No Copyright; Avail: CASI; A03, Hardcopy

The use of chlorine to extract, reclaim, and purify metals has attractive possibilities for extraterrestrial processing of local planetary resources. While a complete cyclic process has been proposed for the recovery of metallurgically significant metals and oxygen, herein the chlorination step of the cycle is examined. An experimental apparatus for reacting refractory materials, such as ilmenite, in a microwave induced plasma is being built. Complex equilibria calculations reveal that stable refractory materials can, under the influence of a plasma, undergo chlorination and yield oxygen as a by-product. These issues and the potential advantages for plasma processing in space are reviewed. Also presented is a discussion of the complex equilibria program used in the analysis.
CASI
Chlorination; Extraterrestrial Resources; Metal Vapors; Minerals; Oxygen Production; Space Processing

19910015892 Arizona Univ., Tucson, AZ, USA
Production of oxygen from lunar ilmenite
Shadman, F.; Zhao, Y.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; JAN 1, 1989; In English; No Copyright; Avail: CASI; A03, Hardcopy

The overall objective of this project was to develop a novel carbothermal reduction process for production of oxygen from lunar ilmenite. The specific objective was to use a reaction sequence in which a wide variety of carbonaceous compounds (including carbonaceous wastes) can be used as reducing agents. During the first phase, two reactor systems were designed, constructed, and operated to study the reaction fundamental important in this process. One system is a small fluidized bed, and the other is a thermo-gravimetric reactor system. Preliminary experiments on synthetic ilmenite are conducted to study the effect of carbon type, carbon loading, temperature, and gas flow rate. Results indicate that a reaction path based on carbon

gasification can be used to promote the overall kinetics. A unique temperature and concentration-programmed reaction procedure was being developed for rapid parametric study of the process.
CASI
Gasification; Ilmenite; Lunar Resources; Oxygen Production; Reduction (Chemistry)

19910015889 Arizona Univ., Tucson, AZ, USA
NASA Space Engineering Research Center for Utilization of Local Planetary Resources
Ramohalli, Kumar; Lewis, John S.; JAN 1, 1989; In English; See also N91-25204 through N91-25222
Report No.(s): NASA-CR-188221; NAS 1.26:188221; No Copyright; Avail: CASI; A08, Hardcopy

Progress toward the goal of exploiting extraterrestrial resources for space missions is documented. Some areas of research included are as follows: Propellant and propulsion optimization; Automation of propellant processing with quantitative simulation; Ore reduction through chlorination and free radical production; Characterization of lunar ilmenite and its simulants; Carbothermal reduction of ilmenite with special reference to microgravity chemical reactor design; Gaseous carbonyl extraction and purification of ferrous metals; Overall energy management; and Information management for space processing.
Chemical Reactors; Extraterrestrial Resources; Ilmenite; Information Management; Minerals; Rocket Propellants; Space Processing

19910015077 Planetary Science Inst., Tucson, AZ, USA
Near-Earth asteroids: Observer alert network and database analysis
Davis, Donald R.; Chapman, Clark R.; Arizona Univ., NASA Space Engineering Research Center for Utilization of Local Planetary Resources; Apr 1, 1991; In English; No Copyright; Avail: CASI; A02, Hardcopy

The Planetary Science Institute (PSI) was funded by SERCulpr to develop a communication network to alert observers of newly discovered near-earth asteroids (NEA's). This network is intended to encourage observers to obtain physical observations of NEA's, which are needed in order to characterize and assess the resource potential of these bodies. This network was declared operational in October 1990 via an announcement to the asteroid observing community. The PSI is also supported to develop the Near-Earth Asteroid Database (NEAD), a comprehensive database of physical and dynamical data on NEA's. In the past year, the database was updated on newly discovered NEA's during 1990, and new data on radar observations and dynamical classifications were added.
CASI
Asteroids; Communication Networks; Data Bases; Extraterrestrial Resources

19910015076 Arizona Univ., Tucson, AZ, USA
Modeling, simulation, and control of an extraterrestrial oxygen production plant
Schooley, L.; Cellier, F.; Zeigler, B.; Doser, A.; Farrenkopf, G.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; Apr 1, 1991; In English; No Copyright; Avail: CASI; A02, Hardcopy

The immediate objective is the development of a new methodology for simulation of process plants used to produce oxygen and/or other useful materials from local planetary resources. Computer communication, artificial intelligence, smart sensors, and distributed control algorithms are being developed and implemented so that the simulation or an actual plant can be controlled from a remote location. The ultimate result of this research will provide the capability for teleoperation of such process plants which may be located on Mars, Luna, an asteroid, or other objects in space. A very useful near-term result will be the creation of an interactive design tool, which can be used to create and optimize the process/plant design and the control strategy. This will also provide a vivid, graphic demonstration mechanism to convey the results of other researchers to the sponsor.
CASI
Computerized Simulation; Extraterrestrial Resources; Industrial Plants; Oxygen Production; Plant Design; Process Control (Industry); Remote Control; Space Bases; Teleoperators

19910015073 Arizona Univ., Tucson, AZ, USA
Compositions of near-Earth asteroids
Lebofsky, L. A.; Nelson, M. L.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; Apr 1, 1991; In English; No Copyright; Avail: CASI; A02, Hardcopy

The goal is to determine whether any of the near-earth asteroids contain water-bearing phyllosilicate (clay) minerals. If

these minerals are present, they would provide a readily available source of water for propellant generation and use in life support systems. Telescopic detection of water on the near-earth asteroids is complicated because thermal emission from the asteroid itself masks the diagnostic absorption features for objects this close to the sun. Sophisticated thermal models are necessary to determine whether the absorption features are present. This year, development of these models was continued and more telescopic data to test the models was obtained.
CASI
Asteroids; Astronomical Models; Clays; Extraterrestrial Resources; Minerals; Water

19910015067 Arizona Univ., Tucson, AZ, USA
Processing of glass-ceramics from lunar resources
Fabes, B. D.; Poisl, W. H.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; Apr 1, 1991; In English; No Copyright; Avail: CASI; A02, Hardcopy

The goal is to fabricate useful ceramic materials from the by-products of lunar oxygen production processes. Specifically, the crystal nucleation and growth kinetics of ilmenite-extracted lunar regolith were studied in order to produce glass-ceramics with optimal mechanical, thermal, and abrasion resistant properties. In the initial year of the program, construction and calibration of a high temperature viscometer, used for determining the viscosity of simulated lunar glasses was finished. A series of lunar simulants were also prepared, and the viscosity of each was determined over a range of temperatures. It was found that an increase in the concentration of Fe2O3 decreases the viscosity of the glass. While this may be helpful in processing the glass, Fe2O3 concentrations greater than approximately 10 wt percent resulted in uncontrolled crystallization during viscosity measurements. Impurities (such as Na2O, MnO, and K2O) in the regolith appeared to decrease the viscosity of the parent glass. These effects, as well as those of TiO2 and SiO2 on the processability of the glass, however, remain to be quantified.
CASI
By-Products; Ceramics; Crystal Growth; Glass; Ilmenite; Lunar Resources; Nucleation; Oxygen Production

19910015066 Arizona Univ., Tucson, AZ, USA
Recovery of precious metals from space
Freiser, Henry; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; Apr 1, 1991; In English; No Copyright; Avail: CASI; A03, Hardcopy

The overall objective is to develop efficient and economical separation and recovery methods for the platinum group and other precious metals. The separation of Pd(II) from Pt(II), Ir(III), and Rh(III) with trioctylphosphine oxide (TOPO) in heptane using centrifugal partition chromatography (CPC) was investigated. Activities to achieve this objective focussed on selection and evaluation of extraction systems for the PGM and modification of selected systems for multistage operation with a view to scaling up to desired macro levels. On the basis of preliminary evaluation of a series of simple metal complexing agents and chelating agents, the TOPO in heptane was selected as a likely system for isolating of Pd(II) and Pt(II) from the other PGM. A multistage apparatus capable of configuration as a simple rugged device, a centrifugal partition chromatograph (CPC), was shown to be effective. The extraction of Pd(II) was studied by CPC and batch solvent extraction. The distribution ratios for Pd(II) determined by both methods agree well. In low HCl concentrations (less than 0.1 M), the extracted species was PdCl2.(TOPO)2, irrespective of the chloride concentration, while at acid concentrations above 0.1 M, the Pd was extracted as the ion pair, 2(TOPO.H+).(PdCl4)2-. Base line separation of Pd(II) and Pt(II) in CPC was obtained under a variety of chloride and HCl concentration. It was demonstrated that the efficiency of CPC for metal separation was limited by chemical kinetic factors rather than instrumental factors, strongly suggesting that dramatic improvements can be achieved by studying reaction kinetics of formation and dissociation of the extractable metal complex.
CASI
Centrifugal Force; Chromatography; Extraterrestrial Resources; Materials Recovery; Noble Metals; Palladium; Platinum; Solvent Extraction

19910015065 Arizona Univ., Tucson, AZ, USA
Dehydration kinetics of talc at 1 bar
Ganguly, J.; Bose, K.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; Apr 1, 1991; In English; No Copyright; Avail: CASI; A03, Hardcopy

Experimental results on the dehydration kinetics of talc, which is likely to be a major potential resource for water and hydrogen in carbonaceous chondrites, is presented. The rate of dehydration of an essentially pure Mg-end member natural talc,

(Mg(.99)Fe(.01))3Si4O10(OH)2, was studied by measuring in situ weight change under isothermal condition at 1 bar as a function of time in the temperature range 775 to 985 C. The grain size of the starting material was 0.7 to 1 micron. It was found that the data up to 50 to 60 percent dehydration can be fitted by an equation of the form alpha = exp(-Kt(exp n)), where alpha is the weight fraction of talc remaining, K is a rate constant and n is a numerical constant for a given temperature. For any set of isothermal data, there is a major change in the value of n for larger dehydration. For up to approximately 50 percent dehydration, all rate constants can be described by an Arrheniun relation with an activation energy of 432 (+/- 30) kJ/mol; n has a nearly constant value of 0.54 between 775 and 875 C, but increases almost linearly according to n = -10.77 + 0.012T C at T greater than or equal to 875 C.
CASI

Carbonaceous Chondrites; Dehydration; Extraterrestrial Resources; Hydrogen; Reaction Kinetics; Talc; Water

19910015061 Arizona Univ., Tucson, AZ, USA

Oxygen plant breadboard design, and techniques for improving mission figure-of-merit

Ramohalli, Kumar; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; Apr 1, 1991; In English; No Copyright; Avail: CASI; A02, Hardcopy; Original contains color illustrations

A breadboard oxygen plant to process anaerobic carbon dioxide is designed and constructed; the objective is not only to produce a key propellant component extraterrestrially, but also to develop the important technologies that are necessary for a successful operation of in-situ materials utilization hardware. The solid electrolytic cells are supplied to specifications by an established vendor. The cell thermal control, electrical control, and flow control are installed after detailed designs. Extensive data are obtained that characterize the operation of the plant as the input parameters are varied. The initial mass, energy, and volume-needs provide the input to a figure-of-merit software program to calculate the impact of various candidate technologies upon the overall mission. The desirability of studies on storage and high-density propellants is shown. This task dovetails into other tasks that are evaluating alternative cell materials, catalysis for compactness, and smart sensors for effective control.
CASI

Breadboard Models; Carbon Dioxide; Extraterrestrial Resources; Figure of Merit; Fuel Production; Industrial Plants; Oxygen Production; Plant Design; Propellants

19910015059 EMEC Consultants, Export, PA, USA

Experimental study of the electrolysis of silicate melts

Keller, R.; Larimer, K. T.; Arizona Univ., NASA Space Engineering Research Center for Utilization of Local Planetary Resources; Apr 1, 1991; In English; No Copyright; Avail: CASI; A02, Hardcopy

To produce oxygen from lunar resources, it may be feasible to melt and electrolyze local silicate ores. This possibility was explored experimentally with synthesized melts of appropriate compositions. Platinum electrodes were employed at a melt temperature of 1425 C. When silicon components of the melt were reduced, the platinum cathode degraded rapidly, which prompted the substitution of a graphite cathode substrate. Discrete particles containing iron or titanium were found in the solidified electrolyte after three hours of electrolysis. Electrolyte conductivities did not decrease substantially, but the escape of gas bubbles, in some cases, appeared to be hindered by high viscosity of the melt.
CASI

Electrolysis; Iron; Lunar Resources; Melts (Crystal Growth); Minerals; Oxygen Production; Silicates; Titanium

19910015057 Arizona Univ., Tucson, AZ, USA

Innovative techniques for the production of energetic radicals for lunar materials processing including photogeneration via concentrated solar energy

Osborn, D. E.; Lynch, D. C.; Fozzolari, R.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; Apr 1, 1991; In English; No Copyright; Avail: CASI; A01, Hardcopy

A technique for photo generation of radicals is discussed that can be used in the recovery of oxygen and metals from extraterrestrial resources. The concept behind this work was to examine methods whereby radicals can be generated and used in the processing of refractory materials. In that regard, the focus is on the use of sunlight. Sunlight provides useful energy for processing in the forms of both thermal and quantum energy. A number of experiments were conducted in the chlorination of metals with and without the aid of UV and near UV light. The results of some of those experiments are discussed.
CASI

Chlorination; Lunar Resources; Materials Recovery; Metals; Oxygen Production; Photochemical Reactions; Radicals; Solar Energy

19910015056 Arizona Univ., Tucson, AZ, USA

Cold plasma processing of local planetary ores for oxygen and metallurgically important metals

Lynch, D. C.; Bullard, D.; Ortega, R.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; Apr 1, 1991; In English; No Copyright; Avail: CASI; A03, Hardcopy

The utilization of a cold or nonequilibrium plasma in chlorination processing is discussed. Titanium dioxide (TiO2) was successfully chlorinated at temperatures between 700 and 900 C without the aid of carbon. In addition to these initial experiments, a technique was developed for determining the temperature of a specimen in a plasma. Development of that technique has required evaluating the emissivity of TiO2, ZrO2, and FeOTiO2 and analyzing the specimen temperature in a plasma as a function of both power absorbed by the plasma and the pressure of the plasma. The mass spectrometer was also calibrated with TiCl4 and CCl4 vapor.

CASI

Chlorination; Cold Plasmas; Extraterrestrial Resources; Metallurgy; Minerals; Nonequilibrium Plasmas; Reaction Kinetics

19910015055 Arizona Univ., Tucson, AZ, USA

Beneficiation of lunar ilmenite

Ruiz, Joaquin; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; Apr 1, 1991; In English; No Copyright; Avail: CASI; A01, Hardcopy

One of the most important commodities lacking in the moon is free oxygen which is required for life and used extensively for propellent. Free oxygen, however, can be obtained by liberating it from the oxides and silicates that form the lunar rocks and regolith. Ilmenite (FeTiO3) is considered one of the leading candidates for production of oxygen because it can be reduced with a reasonable amount of energy and it is an abundant mineral in the lunar regolith and many mare basalts. In order to obtain oxygen from ilmenite, a method must be developed to beneficiate ilmenite from lunar material. Two possible techniques are electrostatic or magnetic methods. Both methods have complications because lunar ilmenite completely lacks Fe(3+). Magnetic methods were tested on eucrite meteorites, which are a good chemical simulant for low Ti mare basalts. The ilmenite yields in the experiments were always very low and the eucrite had to be crushed to xxxx. These data suggest that magnetic separation of ilmenite from fine grain lunar basalts would not be cost effective. Presently, experiments are being performed with electrostatic separators, and lunar regolith is being waited for so that simulants do not have to be employed.

CASI

Beneficiation; Ilmenite; Lunar Resources; Lunar Rocks; Oxygen Production; Regolith

19910015054 Arizona Univ., Tucson, AZ, USA

Production of oxygen from lunar ilmenite

Shadman, F.; Zhao, Y.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; Apr 1, 1991; In English; No Copyright; Avail: CASI; A03, Hardcopy

The kinetics and the mechanism of reduction of synthetic ilmenite by hydrogen in the temperature range of 807 to 1014 C were investigated. At temperatures below 876 C, the temporal profiles of conversion have a sigmoidal shape and indicate the presence of three different stages (induction, acceleration, and deceleration) during the reduction reaction. The apparent activation energy for the reaction is 22.3 kcal/mole, whereas the intrinsic activation energy is 16.9 kcal/mole. Scanning electron microscopy and energy dispersive x-ray analyses show that the diffusion of Fe product away from the reaction front and through the TiO2 phase, followed by the nucleation and growth of a separate Fe phase is an important step affecting the process kinetics. X-ray diffraction and wavelength dispersive x-ray results indicate that the TiO2 can be reduced to lower oxides of titanium at temperatures higher than 876 C.

CASI

Ilmenite; Iron; Lunar Resources; Nucleation; Oxygen Production; Reaction Kinetics; Reduction (Chemistry); Titanium Oxides

19910015053 Arizona Univ., Tucson, AZ, USA

Coproduction of volatiles and metals from extraterrestrial materials

Lewis, John S.; NASA Space Engineering Research Center for Utilization of Local Planetary Resources; Apr 1, 1991; In English; No Copyright; Avail: CASI; A01, Hardcopy

Two main efforts in support of the general goals of SERC/culpr are presented. Investigations of processes for the coproduction of metals from extra-terrestrial materials in conjunction with plausible schemes for oxygen extraction continue. The principal emphasis was on the extraction and purification of iron from the ilmenite reduction process for oxygen, from the cathode metal deposits made in the magma electrolysis process for oxygen, and from native ferrous metal alloys on the

moon and asteroids. All work on the separation and purification of ferrous metals was focussed upon the gaseous carbonyl process, a scheme that involves only temperatures attainable by passive thermal control. The exploration of a variety of schemes was initiated, involving the use of several different propulsion options and both propulsive and aerobraking capture at earth, for return of extraterrestrial resources to earth orbits. In addition, the search for new opportunities in space resource utilization continues. Examples include the continuation of work underway on: (1) the feasibility of locating solar power satellites in highly eccentric earth orbit; (2) the energetics of extracting the potential clean fusion fuel He-3 from the atmosphere for return to earth; and (3) the utility of a nuclear steam rocket (using non-terrestrial water as the working fluid) for transportation in the inner solar system.
CASI
Extraction; Extraterrestrial Resources; Ilmenite; Iron; Iron Alloys; Lunar Resources; Oxygen Production; Purification

19910015052 Arizona Univ., Tucson, AZ, USA
NASA Space Engineering Research Center for Utilization of Local Planetary Resources
Ramohalli, Kumar; Lewis, John S.; Apr 1, 1991; In English; See also N91-24366 through N91-24391
Report No.(s): NASA-CR-188222; NAS 1.26:188222; No Copyright; Avail: CASI; A12, Hardcopy; Original contains color illustrations

In the processing of propellants, volatiles, and metals subject area, the following topics are discussed: reduction of lunar regolith; reduction of carbon dioxide; and reduction of carbonaceous materials. Other areas addressed include: (1) production of structural and refractory materials; (2) resource discovery and characterization; (3) system automation and optimization; and (4) database development. The majority of these topics are discussed with respect to the development of lunar and mars bases. Some main topics of interest include: asteroid resources, lunar resources, mars resources, materials processing, construction materials, propellant production, oxygen production, and space-based oxygen production plants.
Asteroids; Carbon Dioxide; Extraterrestrial Resources; Lunar Resources; Mars (Planet); Oxygen Production; Propellants; Reduction (Chemistry); Space Bases

19910014303 NASA Lewis Research Center, Cleveland, OH, USA
Material processing with hydrogen and carbon monoxide on Mars
Hepp, Aloysius F.; Landis, Geoffrey A.; Linne, Diane L.; JAN 1, 1991; In English; 10th Biennial Conference on Space Manufacturing, 15-19 May 1991, Princeton, NJ, USA
Contract(s)/Grant(s): RTOP 506-41-11
Report No.(s): NASA-TM-104405; E-6230; NAS 1.15:104405; No Copyright; Avail: CASI; A03, Hardcopy

Several novel proposals are examined for propellant production from carbon dioxide and monoxide and hydrogen. Potential uses were also examined of CO as a fuel or as a reducing agent in metal oxide processing as obtained or further reduced to carbon. Hydrogen can be reacted with CO to produce a wide variety of hydrocarbons, alcohols, and other organic compounds. Methanol, produced by Fischer-Tropsch chemistry may be useful as a fuel; it is easy to store and handle because it is a liquid at Mars temperatures. The reduction of CO2 to hydrocarbons such as methane or acetylene can be accomplished with hydrogen. Carbon monoxide and hydrogen require cryogenic temperatures for storage as liquids. Noncryogenic storage of hydrogen may be accomplished using hydrocarbons, inorganic hydrides, or metal hydrides. Noncryogenic storage of CO may be accomplished in the form of iron carbonyl (FE(CO)5) or other metal carbonyls. Low hydrogen content fuels such as acetylene (C2H2) may be effective propellants with low requirements for earth derived resources. The impact on manned Mars missions of alternative propellant production and utilization is discussed.
CASI
Carbon Dioxide; Carbon Monoxide; Extraterrestrial Resources; Hydrogen; Hydrogen Fuels; Mars (Planet); Photoelectrochemistry; Propellant Chemistry

19910012867 Michigan Technological Univ., Houghton, MI, USA
Planetary materials and resource utilization: An interdisciplinary engineering design course at Michigan Technological University
Rose, W. I.; Paces, J. B.; Chesner, C. A.; Pletka, B. J.; Hellawell, A.; Kawatra, S. K.; Pilling, J. E.; NASA. Lewis Research Center, Vision-21: Space Travel for the Next Millennium; Apr 1, 1990; In English; No Copyright; Avail: CASI; A02, Hardcopy

A new course was developed and instituted in the spring quarter of 1989 dealing with topics related to space resource utilization and related engineering. The course development required a concerted, coordinated effort, because a similar course which might be used as a guide could not be identified anywhere and the interdisciplinary perspective that was required was

not identified anywhere on the university campus. Students in the class worked on interdisciplinary design projects which culminated in papers and oral presentations. Each of the six design groups consisted of several engineers with different disciplinary roots. The entire course lecture sequence, about 50 hours in all, was videotaped. Discussed here are the authors' experiences in developing the course, including the course syllabus and speaker list.
CASI
Education; Extraterrestrial Resources; Lunar Bases; Lunar Soil; Mechanical Engineering; Space Manufacturing; Students

19910012833 Martin Marietta Aerospace, Denver, CO, USA
Nuclear thermal rockets using indigenous extraterrestrial propellants
Zubrin, Robert M.; NASA. Lewis Research Center, Vision-21: Space Travel for the Next Millennium; Apr 1, 1990; In English; No Copyright; Avail: CASI; A03, Hardcopy

A preliminary examination of a concept for a Mars and outer solar system exploratory vehicle is presented. Propulsion is provided by utilizing a nuclear thermal reactor to heat a propellant volatile indigenous to the destination world to form a high thrust rocket exhaust. Candidate propellants, whose performance, materials compatibility, and ease of acquisition are examined and include carbon dioxide, water, methane, nitrogen, carbon monoxide, and argon. Ballistics and winged supersonic configurations are discussed. It is shown that the use of this method of propulsion potentially offers high payoff to a manned Mars mission. This is accomplished by sharply reducing the initial mission mass required in low earth orbit, and by providing Mars explorers with greatly enhanced mobility in traveling about the planet through the use of a vehicle that can refuel itself each time it lands. Thus, the nuclear landing craft is utilized in combination with a hydrogen-fueled nuclear-thermal interplanetary launch. By utilizing such a system in the outer solar system, a low level aerial reconnaissance of Titan combined with a multiple sample return from nearly every satellite of Saturn can be accomplished in a single launch of a Titan 4 or the Space Transportation System (STS). Similarly a multiple sample return from Callisto, Ganymede, and Europa can also be accomplished in one launch of a Titan 4 or the STS.
CASI
Extraterrestrial Resources; Gaseous Rocket Propellants; Interplanetary Flight; Manned Mars Missions; Mars (Planet); Mission Planning; Nuclear Fuels; Spacecraft Propulsion

19910012828 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Industrializing the near-earth asteroids: Speculations on human activities in space in the latter half of the 21st century
Sercel, Joel C.; NASA. Lewis Research Center, Vision-21: Space Travel for the Next Millennium; Apr 1, 1990; In English; No Copyright; Avail: CASI; A03, Hardcopy

The use of solar system resources for human industry can be viewed as a natural extension of the continual growth of our species' habitat. Motivations for human activities in space can be discussed in terms of five distinct areas: (1) information processing and collection; (2) materials processing; (3) energy production to meet terrestrial power needs; (4) the use of extraterrestrial materials; and (5) disaster avoidance. When considering 21st-Century activities in space, each of these basic motivations must be treated in light of issues likely to be relevant to the 21st-Century earth. Many of the problems facing 21st-Century earth may stem from the need to maintain the world population of 8 to 10 billion people as is projected from expected growth rates. These problems are likely to include managing the impact of industrial processes on the terrestrial biosphere while providing adequate energy production and material goods for the growing population. The most important human activities in space in the latter half of the 21st Century may be associated with harnessing the resources of the near-earth asteroids for industrial processes. These above topics are discussed with an emphasis on space industrialization.
CASI
Asteroids; Extraterrestrial Resources; Space Exploration; Space Industrialization; Space Manufacturing; Space Processing

19910008821 Houston Univ., TX, USA
In-situ resource utilization in the design of advanced lunar facilities
USRA, Proceedings of the 6th Annual Summer Conference: NASA(USRA University Advanced Design Program; Nov 1, 1990; In English; No Copyright; Avail: CASI; A02, Hardcopy

Resource utilization will play an important role in the establishment and support of a permanently manned lunar base. At the University of Houston - College of Architecture and the Sasakawa International Center for Space Architecture, a study team recently investigated the potential use of lunar in-situ materials in the design of lunar facilities. The team identified seven potential lunar construction materials; concrete, sulfur concrete, cast basalt, sintered basalt, glass, fiberglass, and metals. Analysis and evaluation of these materials with respect to their physical properties, processes, energy requirements, resource

efficiency, and overall advantages and disadvantages lead to the selection of basalt materials as the more likely construction material for initial use on a lunar base. Basalt materials can be formed out of in-situ lunar regolith, with minor material beneficiation, by a simple process of heating and controlled cooling. The team then conceptualized a construction system that combines lunar regolith sintering and casting to make pressurized structures out of lunar resources. The design uses a machine that simultaneously excavates and sinters the lunar regolith to create a cylindrical hole, which is then enclosed with cast basalt slabs, allowing the volume to be pressurized for use as a living or work environment. Cylinder depths of up to 4 to 6 m in the lunar mare or 10 to 12 m in the lunar highlands are possible. Advantages of this construction system include maximum resource utilization, relatively large habitable volumes, interior flexibility, and minimal construction equipment needs. Conclusions of this study indicate that there is significant potential for the use of basalt, a lunar resource derived construction material, as a low cost alternative to Earth-based materials. It remains to be determined when in lunar base phasing this construction method should be implemented.
CASI

Casting; Concretes; Construction; Habitability; Lunar Bases; Lunar Resources; Lunar Rocks; Lunar Soil

19910004943 Arkansas Coll., Batesville, AR, USA

Kinetics of hydrogen release from lunar soil

Bustin, Roberta; Oct 1, 1990; In English

Contract(s)/Grant(s): NAG9-474

Report No.(s): NASA-CR-187363; NAS 1.26:187363; No Copyright; Avail: CASI; A03, Hardcopy

With increasing interest in a lunar base, there is a need for extensive examination of possible lunar resources. Hydrogen will be needed on a lunar base for many activities including providing fuel, making water, and serving as a reducing agent in the extraction of oxygen from its ores. Previous studies have shown the solar wind has implanted hydrogen in the lunar regolith and that hydrogen is present not only in the outer layer of soil but to considerable depths, depending on the sampling site. If this hydrogen is to be mined and used on the lunar surface, a number of questions need to be answered. How much energy must be expended in order to release the hydrogen from the soil. What temperatures must be attained, and how long must the soil be heated. This study was undertaken to provide answers to practical questions such as these. Hydrogen was determined using a Pyrolysis/GC technique in which hydrogen was released by heating the soil sample contained in a quartz tube in a resistance wire furnace, followed by separation and quantitative determination using a gas chromatograph with a helium ionization detector. Heating times and temperatures were varied, and particle separates were studied in addition to bulk soils. The typical sample size was 10 mg of lunar soil. All of the soils used were mature soils with similar hydrogen abundances. Pre-treatments with air and steam were used in an effort to find a more efficient way of releasing hydrogen.
CASI

Hydrogen; Lunar Mining; Lunar Resources; Lunar Rocks; Lunar Soil; Reaction Kinetics

19900067286 Georgia Inst. of Tech., Atlanta, GA, USA

A 10 meter lunar drill

Baker, Mark; Blum, Shawn; Green, Keith; Park, Young; Westphal, Mark; Mar 11, 1986; In English

Contract(s)/Grant(s): NGT-21-002-080

Report No.(s): NASA-CR-182478; NAS 1.26:182478; ME-4182-A; No Copyright; Avail: CASI; A05, Hardcopy

Core Sampling; Drill Bits; Drills; Lunar Resources; Mining

19900067275 Georgia Inst. of Tech., Atlanta, GA, USA

Mobile lunar miner for oxygen

Adams, David; Duncan, Jim; Johnson, Mark; Mcwhorter, Bruce; Otwell, Perry; Reisinger, Mike; Dec 4, 1985; In English

Contract(s)/Grant(s): NGT-21-002-080

Report No.(s): NASA-CR-183019; NAS 1.26:183019; No Copyright; Avail: CASI; A04, Hardcopy

Industrial Plants; Lunar Resources; Lunar Surface Vehicles; Oxygen; Plant Design; Space Industrialization; Strip Mining

19900066959 NASA John F. Kennedy Space Center, Cocoa Beach, FL, USA

Third Annual Meeting of the Working Group on Extraterrestrial Resources

JAN 1, 1964; In English, 18-20 Nov. 1964, Cocoa Beach, FL, USA

Report No.(s): NASA-TM-101119; NAS 1.15:101119; No Copyright; Avail: CASI; A15, Hardcopy

Biotechnology; Chemical Composition; Conferences; Economic Analysis; Logistics; Lunar Resources; Lunar Surface

19900046883 Eltron Research, Inc., Aurora, IL, USA

The electrochemical generation of useful chemical species from lunar materials

Tsai, Kan J.; Kuchynka, Daniel J.; Sammells, Anthony F.; Journal of Power Sources; Feb 1, 1990; ISSN 0378-7753; 29; In English

Contract(s)/Grant(s): NAS9-17991; Copyright; Avail: Other Sources

Electrochemical cells have been fabricated for the simultaneous generation of oxygen and lithium from a Li2O-containing molten salt (Li2O-LiCl-LiF). The cell utilizes an oxygen vacancy conducting solid electrolyte, yttria-stabilized zirconia (YSZ), to effect separation between oxygen evolving and lithium reduction half-cell reactions. The cell, which operates at 700-850 C, possesses rapid electrode kinetics at the lithium-alloy electrode with exchange current density values being greater than 60 mA/sq cm. When used in the electrolytic mode, lithium produced at the negative electrode would be continuously removed from the cell for later use (under lunar conditions) as an easily storable reducing agent for the chemical refining of lunar ores. Because of the high reversibility of this electrochemical system, it has also formed the basis for the lithium-oxygen secondary battery system which possesses the highest theoretical energy density yet investigated.

AIAA

Electrochemical Cells; Extraterrestrial Resources; Lithium Chlorides; Lithium Oxides; Lunar Exploration; Molten Salt Electrolytes

19900046880 NASA Lewis Research Center, Cleveland, OH, USA

Human exploration mission studies

Cataldo, Robert L.; Journal of Power Sources; Feb 1, 1990; ISSN 0378-7753; 29; In English; Copyright; Avail: Other Sources

This paper describes several case studies of human space exploration, considered by the NASA's Office of Exploration in 1988. Special attention is given to the mission scenarios, the critical technology required in these expeditions, and the extraterrestrial power requirements of significant system elements. The cases examined include a manned expedition to Phobos, the inner Martian moon; a human expedition to Mars; the Lunar Observatory; and a lunar outpost to early Mars evolution.

AIAA

Extraterrestrial Resources; Manned Mars Missions; Space Exploration

19900046422 Hawaii Univ., Honolulu, HI, USA, NASA Lyndon B. Johnson Space Center, Houston, TX, USA

Ilmenite-rich pyroclastic deposits - An ideal lunar resource

Hawke, B. R.; Clark, B.; Coombs, C. R.; JAN 1, 1990; In English; 20th Lunar and Planetary Science Conference, Mar. 13-17, 1989, Houston, TX, USA

Contract(s)/Grant(s): NAGW-237; Copyright; Avail: Other Sources

With a view of investigating possible economic benefits that a permanent lunar settlement might provide to the near-earth space infrastructures, consideration was given to the ilmenite-rich pyroclastic deposits as sources of oxygen (for use as a propellant) and He-3 (for nuclear fusion fuel). This paper demonstrates that ilmenite-rich pyroclastic deposits would be excellent sources of a wide variety of valuable elements besides O and He-3, including Fe, Ti, H2, N, C, S, Cu, Zn, Cd, Bi, and Pb. It is shown that several ilmenite-rich pyroclastic deposits of regional extent exist on the lunar surface. The suitability of regional pyroclastic deposits for lunar mining operations, construction activities, and the establishment of permanent lunar settlements is examined.

AIAA

Extraterrestrial Resources; Ilmenite; Lunar Exploration; Mineral Deposits

19900029506 NASA Marshall Space Flight Center, Huntsville, AL, USA

A get started approach for resource processing

Giudici, Bob; JAN 1, 1989; In English

Report No.(s): AAS PAPER 87-262; Copyright; Avail: Other Sources

A low-risk, high-value approach to implementing resource processing is presented. The design utilizes processing plants at Deimos and Mars, a fueling depot in a Mars parking orbit, and small shuttles transferring crew and cargo between sites. The system fuels Mars ascent and descent states and the earth-return stage. Fueling at Mars reduces launch requirements by 25 percent, or, alternatively, enables the substitution of payload for fuel on a near 1:1 basis and thereby triples the payload delivered to Mars.

AIAA

Extraterrestrial Resources; Planetary Bases; Space Industrialization; Space Logistics

19900026641 NASA Lyndon B. Johnson Space Center, Houston, TX, USA, Science Applications International Corp., Schaumburg, IL, USA

Lunar oasis

Duke, Michael B.; Niehoff, John; Oct 1, 1989; In English

Report No.(s): IAF PAPER 89-717; Copyright; Avail: Other Sources

The 'lunar oasis' emphasizes development toward self-sufficiency in order to reduce dependence on the earth for resupply, and to enable expansion utilizing indigeneous resources. The oasis phase includes: (1) habitation and work facilities for 10 people, (2) capability for extraction of volatile consumables (H2O, O2, N2, etc.) from indigenous resources for resupply of losses and filling of reservoirs, and (3) a highly closed life support system, including food production. In the consolidation phase, the base grows from 10 to 30 crewmembers. Lunar resources are used for expanding the lunar foothold, including construction of habitats, extraction of metals for the fabrication of products for maintenance and repair, and expansion of the power system. The strategy does not produce propellants for space transportation. A 10-year scenario is laid out, which contains all elements needed to allow the base to enter a self-expanding utilization phase. Three lunar missions yer year, two cargo missions and one crew flight, are required. At the end of a decade, the base is producing more than it requires for its continued support, although it is unlikely to be completely self-sufficient.

AIAA

Extraterrestrial Resources; Lunar Bases; Space Habitats; Space Logistics

19900026640 NASA Center for the Utilization of Local Planetary Resources, Arizona Univ., Tucson, AZ, USA, Arizona Univ., Tucson, AZ, USA

A 'figure-of-merit' approach to extraterrestrial resource utilization

Ramohalli, Kumar; Kirsch, Thomas; Oct 1, 1989; In English

Report No.(s): IAF PAPER 89-716; Copyright; Avail: Other Sources

An approach for interrelated optimizations in space missions that utilize extraterrestrial resources is developed, consisting in the concept of an overall mission 'figure-of-merit' leading to more realistic designs than through individual performance maximizations. After a brief discussion of this concept, the synthesis of four major components of any future space mission is considered. The four major components are: orbital mechanics of the transportation; performance of the rocket motors; support systems including power, thermal and process controls, and instruments; and in situ resource utilization plant equipment. The Mars Sample Return mission is the basis of an illustration of the proposed concept. A popular spreadsheet is used to quantitatively demonstrate the interdependent nature of the mission optimization. Future prospects are outlined, that promise great economy through extraterrestrial resource utilization and a quick evaluation technique.

AIAA

Extraterrestrial Resources; Figure of Merit; Gaseous Fuels; Space Missions

19900006527 Wisconsin Univ., Madison, WI, USA

Importance of helium-3 for the future

Kulcinski, Gerald L.; NASA, Langley Research Center, Report of NASA Lunar Energy Enterprise Case Study Task Force; Jul 1, 1989; In English; No Copyright; Avail: CASI; A03, Hardcopy

Relevant plasma physics principles of thermonuclear research; the state of plasma physics as it pertains to the D-He(3) cycle; the technological benefits of the D-He(3) fuel cycle; the availability of He(3); and its location, methods of extraction and cost are discussed. A perspective on the rate of progress toward the goal of heating the confined plasma fuel to sufficiently high temperatures at high enough densities and for long enough times to cause substantial fusion of the atoms to take place is given in graphical form. The main technological advantages resulting from the D-He(3) fuel cycle, when compared with the DT cycle, are as follows: (1) increased electrical conversion efficiency; (2) reduced radiation damage to reactors; (3) reduced radioactive waste; (4) an increased level of safety in case of an accident; (5) the lower cost of electricity; and (6) the shorter time to commercialization. An account is given of mining He(3) on the Moon.

CASI

Extraterrestrial Resources; Fusion Reactors; Helium Isotopes; Lunar Soil; Mining; Nuclear Electric Power Generation; Technology Assessment

19900006526 Boeing Aerospace Co., Huntsville, AL, USA

Transportation and operations aspects of space energy systems

Woodcock, Gordon R.; NASA, Langley Research Center, Report of NASA Lunar Energy Enterprise Case Study Task Force; Jul 1, 1989; In English; No Copyright; Avail: CASI; A04, Hardcopy

A brief comparative analysis was made for three concepts of supplying large-scale electrical energy to Earth from space. The concepts were: (1) mining helium-3 on the Moon and returning it to Earth; (2) constructing solar power satellites in geosynchronous orbit from lunar materials (the energy is beamed by microwave to receivers on Earth); and (3) constructing power collection and beaming systems on the Moon itself and transmitting the energy to Earth by microwave. This analysis concerned mainly space transportation and operations, but each of the systems is briefly characterized to provide a basis for space transportation and operations analysis.
CASI
Extraterrestrial Resources; Helium Isotopes; Lunar Bases; Lunar Surface; Mining; Power Beaming; Solar Power Satellites; Space Commercialization

19900006525 California Univ., San Diego, La Jolla, CA, USA
Lunar power system summary of studies for the lunar enterprise task force NASA-office of exploration
Criswell, David R.; NASA, Langley Research Center, Report of NASA Lunar Energy Enterprise Case Study Task Force; Jul 1, 1989; In English; No Copyright; Avail: CASI; A03, Hardcopy

The capacity of global power systems must be increased by a factor of ten to provide the predicted power needs of electric power by the year 2050. The Lunar Power System (LPS) would collect solar energy at power bases located on opposing limbs of the moon as seen from Earth. LPS can provide dependable, economic, renewable, and environmentally benign solar energy to Earth. A preliminary engineering and cash flow model of the LPS was developed. Results are shown for a system scaled to a peak capacity of 355 GWe on Earth and to provide 13,600 GWe-Yrs of energy over a 70 year life cycle of construction and full operation. The growth in capacity of the reference system from start of installation on the moon in 2005 to completion of its nominal life cycle in the year 2070 is shown. World needs for power could be accommodated by expansion in capacity of the reference LPS beyond 344 GWe. This would be done by steadily incorporating newer technology during full operation and by establishing additional bases. The results presented encourage consideration of a faster paced program than is assumed herein.
CASI
Economic Analysis; Extraterrestrial Resources; Lunar Bases; Microwave Power Beaming; Microwave Transmission; Solar Energy Conversion

19900006522 Wisconsin Univ., Madison, WI, USA
Analysis of the financial factors governing the profitability of lunar helium-3
Kulcinski, G. L.; Thompson, H.; Ott, S.; NASA, Langley Research Center, Report of NASA Lunar Energy Enterprise Case Study Task Force; Jul 1, 1989; In English; No Copyright; Avail: CASI; A03, Hardcopy

Financial factors influencing the profitability of the mining and utilization of lunar helium-3 are examined. The analysis addressed the following questions: (1) which financial factors have the greatest leverage on the profitability of He-3; (2) over what range can these factors be varied to keep the He-3 option profitable; and (3) what ultimate effect could this energy source have on the price of electricity for U.S. consumers. Two complementary methods of analysis were used in the assessment: rate of return on incremental investment required and reduction revenue requirements (total cost to customers) achieved. Some of the factors addressed include energy demand, power generation costs with and without fusion, profitability for D-He(3) fusion, annual capital and operating costs, launch mass and costs, He-3 price, and government funding. Specific conclusions are made with respect to each of the companies considered: utilities, lunar mining company, and integrated energy company.
M.G.
Cost Analysis; Economic Analysis; Extraterrestrial Resources; Helium; Lunar Surface; Mining; Nuclear Electric Power Generation; Nuclear Fusion; Space Commercialization

19900006521 NASA Langley Research Center, Hampton, VA, USA
Report of the NASA lunar energy enterprise case study task force
Report of NASA Lunar Energy Enterprise Case Study Task Force; Jul 1, 1989; In English; No Copyright; Avail: CASI; A03, Hardcopy

The Lunar Energy Enterprise Cast Study Task Force was formed to determine the economic viability and commercial business potential of mining and extracting He-3 from the lunar soil for use in earth-based fusion reactors. In addition, the Solar Power Satellite (SPS) and the Lunar Power Station (LPS) were also evaluated because they involve the use of lunar materials and could provide energy for lunar-based activities. The Task Force considered: (1) the legal and liability aspects of the space energy projects; (2) the long-range terrestrial energy needs and options; (3) the technical maturity of the three

space energy projects; and (4) their commercial potential. The use of electricity is expected to increase, but emerging environmental concerns and resource availability suggest changes for the national energy policy. All three options have the potential to provide a nearly inexhaustible, clean source of electricity for the U.S. and worldwide, without major adverse impacts on the Earth's environment. Assumption by industry of the total responsibility for these energy projects is not yet possible. Pursuit of these energy concepts requires the combined efforts of government and industry. The report identifies key steps necessary for the development of these concepts and an evolving industrial role.
M.G.
Economic Analysis; Extraterrestrial Resources; Government/Industry Relations; Helium; Lunar Soil; Lunar Surface; Mining; Nuclear Electric Power Generation; Space Commercialization

19900006520 NASA Langley Research Center, Hampton, VA, USA
Report of NASA Lunar Energy Enterprise Case Study Task Force
Kearney, John J.; Jul 1, 1989; In English; See also N90-15837 through N90-15843
Report No.(s): NASA-TM-101652; NAS 1.15:101652; No Copyright; Avail: CASI; A09, Hardcopy

The Lunar Energy Enterprise Case Study Task Force was asked to determine the economic viability and commercial potential of mining and extracting He-3 from the lunar soil, and transporting the material to Earth for use in a power-generating fusion reactor. Two other space energy projects, the Space Power Station (SPS) and the Lunar Power Station (LPS), were also reviewed because of several interrelated aspects of these projects. The specific findings of the Task Force are presented. Appendices contain related papers generated by individual Task Force Members.
Economic Analysis; Extraterrestrial Resources; Government/Industry Relations; Helium; Lunar Soil; Lunar Surface; Mining; Space Commercialization

19890050428 Stanford Univ., CA, USA, NASA Ames Research Center, Moffett Field, CA, USA
Use of Martian resources in a Controlled Ecological Life Support System (CELSS)
Smernoff, David T.; Macelroy, Robert D.; British Interplanetary Society, Journal; Apr 1, 1989; ISSN 0007-084X; 42; In English; Copyright; Avail: Other Sources

Possibile crew life support systems for Mars are reviewed, focusing on ways to use Martian resources as life support materials. A system for bioregenerative life support using photosynthetic organisms, known as the Controlled Ecological Life Support System (CELSS), is examined. The possible use of higher plants or algae to produce oxygen on Mars is investigated. The specific requirements for a CELSS on Mars are considered. The exploitation of water, respiratory gases, and mineral nutrients on Mars is discussed.
AIAA
Closed Ecological Systems; Extraterrestrial Resources; Life Support Systems; Mars Environment

19890050426 JRF Engineering Services, La Canada, CA, USA
Rocket propellants from Martian resources
French, J. R.; British Interplanetary Society, Journal; Apr 1, 1989; ISSN 0007-084X; 42; In English
Contract(s)/Grant(s): NAS7-100; Copyright; Avail: Other Sources

In order for extensive round trip travel to become feasible in terms of mass required in low Earth orbit, propellant manufacturing at Mars becomes essential. Martian resources lend themselves to relatively easy generation of several promising propellant combinations. Not only manned missions but also smaller unmanned missions such as sample return may benefit from this technology.
AIAA
Extraterrestrial Resources; Interplanetary Flight; Mars Atmosphere; Mission Planning; Rocket Propellants

19890050424 NASA Ames Research Center, Moffett Field, CA, USA, Boulder Center for Science and Policy, Boulder, CO, USA
The resources of Mars for human settlement
Meyer, Thomas R.; Mckay, Christopher P.; British Interplanetary Society, Journal; Apr 1, 1989; ISSN 0007-084X; 42; In English; Copyright; Avail: Other Sources

Spacecraft exploration of Marshas shown that the essential resources necessary for life support are present on the Martian surface. The key life-support compounds O2, N2, and H2O are available on Mars. The soil could be used as radiation shielding and could provide many useful industrial and construction materials. Compounds with high chemical energy, such as rocket

fuels, can be manufactured in-situ on Mars. Solar power, and possibly wind power, are available and practical on Mars. Preliminary engineering studies indicate that fairly autonomous processes can be designed to extract and stockpile Martian consumables.
AIAA
Extraterrestrial Resources; Mars (Planet); Planetary Composition; Space Colonies

19890049399 Hawaii Univ., Honolulu, HI, USA
Loss of water from Phobos
Fanale, Fraser P.; Salvail, James R.; Geophysical Research Letters; Apr 1, 1989; ISSN 0094-8276; 16; In English
Contract(s)/Grant(s): NAGW-133; Copyright; Avail: Other Sources

A quantitative model of the migrational history of any free water in the martian satellite Phobos is presented. Results include predicted depths of retained ice and current water fluxes as a function of latitude, regolith porosity and effective pore size. It is found that, despite Phobos' small size, low albedo and proximity to the sun, ice may be present within the sounding depth of the GRUNT experiment on the Soviet Phobos Mission - at least at mid to high latitudes. Implications for other experiments on the Phobos mission are also discussed.
AIAA
Extraterrestrial Resources; Phobos; Satellite Surfaces; Water

19890042176 Washington Univ., Seattle, WA, USA, Washington Univ., Saint Louis, MO, USA
Nature and distribution of surficial deposits in Chryse Planitia and vicinity, Mars
Arvidson, Raymond E.; Guinness, Edward A.; Dale-Bannister, Mary A.; Adams, John; Smith, Milton, et al.; Journal of Geophysical Research; Feb 10, 1989; ISSN 0148-0227; 94; In English
Contract(s)/Grant(s): NASW-4016; NSG-7087; NAGW-1059; Copyright; Avail: Other Sources

The properties and lateral distribution of surficial units for the Mutch Memorial Station region are examined, using color images of the dust deposits in the region obtained at variable incidence angles during sol 611. The radiance factors from the region are compared with values derived from Viking Orbiter images and the materials in and around the region are described. Viking, earth-based, and laboratory spectra are compared and a model is constructed for the nature and distribution of surficial units in the Chryse Planitia region.
AIAA
Extraterrestrial Resources; Mars Surface; Mineral Deposits; Planetary Composition; Radiance

19890040967 Arizona Univ., Tucson, AZ, USA, Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA, Old Dominion Univ., Norfolk, VA, USA
Recent concepts in missions to Mars - Extraterrestrial processes
Ramohalli, Kumar; Lawton, Emil; Ash, Robert; Journal of Propulsion and Power; Apr 1, 1989; ISSN 0748-4658; 5; In English; Copyright; Avail: Other Sources
Extraterrestrial Resources; Mars Landing; Return to Earth Space Flight; Space Processing; Spacecraft Power Supplies

19890040502 Aquanautics Corp., Emeryville, CA, USA
Oxygen extraction for a mission life support
Carnevale, Steven J.; Mcdonald, Anwyl; Jul 1, 1988; In English
Report No.(s): SAE PAPER 881077; Copyright; Avail: Other Sources

Research conducted to extract oxygen from air or water with possible applications to oxygen production on Mars, the moon, or the Space Station is discussed. The technology under development involves an electrochemical process which is energy-efficient, regenerative and, in combination with a fuel cell, will provide net positive power, and generate oxygen for life support systems. The history of chemical oxygen separation and details of the oxygen separation technology are presented.
AIAA
Extraterrestrial Resources; Life Support Systems; Oxygen Production

19890030490 General Dynamics Corp., San Diego, CA, USA
An analysis of possible advanced space strategies featuring the role of space resource utilization
Cordell, Bruce; Steinbronn, Otto; Oct 1, 1988; In English
Contract(s)/Grant(s): NAS3-24564
Report No.(s): IAF PAPER 88-587; Copyright; Avail: Other Sources

Unresolved issues in space planning in the U.S. are examined, focusing on space resource utilization. The role of the Space Station, determining the most profitable space exploration strategies, and space resource use are discussed. Performance modeling suggests that lunar oxygen is useful on the moon and economical in LEO if lunar hydrogen is available. It is found that the use of volatile materials from Phobos and Deimos might be undertaken if lunar hydrogen is unavailable. It is suggested that resource synergisms between operations in the Mars system and in earth-moon space have important commercial possibilities.
AIAA
Extraterrestrial Resources; Lunar Surface; Space Exploration; Space Stations

19880068223 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Lunar resources - Evaluation and development for use in a lunar base program
Burke, J. D.; Oct 1, 1988; In English
Report No.(s): IAF PAPER 88-586; Copyright; Avail: Other Sources

The implications of lunar crust characteristics for human habitation on the moon are considered. Sources for propellants in the crust are discussed, and the rationale for including mining among base objectives is examined. Present opportunities for extracting lunar crust resources are addressed.
AIAA
Extraterrestrial Resources; Lunar Bases; Resource Allocation; Space Colonies

19870066962 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA, California Inst. of Tech., Pasadena, CA, USA
The ballistic Mars hopper - An alternative Mars mobility concept
Sercel, Joel C.; Blandino, John J.; Wood, Kristin L.; Jun 1, 1987; In English
Report No.(s): AIAA PAPER 87-1901; Copyright; Avail: Other Sources

The ballistic Mars hopper is proposed as an alternative mobility concept for unmanned exploration of the Martian surface. In the concept, oxygen and carbon monoxide produced from the Martian atmosphere are used as propellants in a rocket propulsion system for an unmanned vehicle on suborbital trajectories between landing sites separated by distances of up to 1000 km. This mobility concept is seen as uniquely capable of allowing both intensive and extensive exploration of the planet using only a single landed vehicle of mass approximately 2000 kg. The technical challenges associated with in-situ propellant production on the surface of Mars are reviewed. A rocket propulsion subsystem capable of using oxygen and carbon monoxide as propellants is described. Finally, results of mission analysis and a hopper landing hazard simulation are reported. It is concluded that an attractive Mars hopper can be developed based on relatively near-term technology.
AIAA
Extraterrestrial Resources; Mars Landing; Rocket Propellants; Rocket Vehicles

19870065817 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Martian settlement
Roberts, Barney B.; JAN 1, 1987; In English
Report No.(s): AAS PAPER 86-117; Copyright; Avail: Other Sources

The rationale for a manned Mars mission and the establishment of a base is divided into three areas: science, resource utilization, and strategic issues. The effects of a Mars mission on the objectives of near-term NASA programs, and the applications of these programs to a Mars mission are examined. The use of extraterrestrial resources to supply space settlements and thereby reduce transportation costs is studied; the development of systems for extraterrestrial materials processing will need to be researched. The possibility of a joint U.S./Soviet Mars mission is discussed by the symposium participants.
AIAA
Extraterrestrial Resources; Manned Mars Missions; Mars Landing; Space Colonies; Space Logistics

19870064681 Computer Sciences Corp., Beltsville, MD, USA, Cornell Univ., Ithaca, NY, USA
Investigation of Martian H2O and CO2 via orbital gamma ray spectroscopy
Evans, Larry G.; Squyres, Steven W.; Journal of Geophysical Research; Aug 10, 1987; ISSN 0148-0227; 92; In English; Copyright; Avail: Other Sources

The capability of an orbital gamma ray spectrometer to address presently unanswered questions concerning H2O and CO2

on Mars is investigated. The gamma ray signal produced by the Martian atmosphere and by several simple models of Martian surface materials is calculated. Results are reported for: (1) the production of neutrons in the atmosphere and in the subsurface material by cosmic ray interactions, (2) the scattering of neutrons and the resultant neutron energy spectrum and spatial distributions, (3) the reproduction of gamma rays by neutron prompt capture and nonelastic scatter reactions, (4) the production of gamma rays by natural radionuclides, (5) the attenuation of the gamma ray signal by passage through surface materials and the Martian atmosphere, (6) the production of the gamma ray continuum background, and (7) the uncertainty in gamma ray line strengths that results from the combined signal and background observed by the detector.
AIAA
Carbon Dioxide; Extraterrestrial Resources; Gamma Ray Spectra; Mars Surface; Water

19870054334 Arizona Univ., Tucson, AZ, USA, Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA, Old Dominion Univ., Norfolk, VA, USA
Some aspects of space propulsion with extraterrestrial resources
Ramohalli, Kumar; Dowler, Warren; French, James; Ash, Robert; Journal of Spacecraft and Rockets; Jun 1, 1987; ISSN 0022-4650; 24; In English; Copyright; Avail: Other Sources

Extraterrestrial resources for space processing of chemicals, in general, and propellants, in particular, are explored quantitatively. It is seen that, for several candidate space mission scenarios, space processing of both space resources and earth-carried resources can make decisive differences in the mission success for a given payload. To fix ideas and demonstrate trends, the specific case of water splitting to extract oxygen, discard (or use without storage) the resulting hydrogen, and burn earth-carried noncryogenic liquid fuel(s) in a simple rocket motor, designed for periodic thrusting, is treated in some detail. Experimental hardware is assembled and demonstrated to perform adequately, besides showing compactness of the space-packaged 'capsule' module that is self-contained. Building upon previous studies, the concept of in situ propellant production (ISPP) is reexamined in light of more recent energy and materials technologies. Missions to comets and Mars Sample Return are mentioned as candidate scenarios. The mission duration, reliability-repairability of hardware, resource availability in low earth orbit (LEO), and the thrust requirements are considered in turn. It is seen that space storage of hydrogen for extended durations (5-10 years) involves problems that require detailed studies, besides involving many presently unanswered issues. A study of the energy option in LEO and in deep space is developed in simple terms. The different solar, radioisotope, and nuclear power sources are mentioned. Storage and handling of raw and processed chemicals are considered.
AIAA
Extraterrestrial Resources; Payload Mass Ratio; Rocket Propellants; Space Processing; Spacecraft Propulsion

19870037667 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
A new look at oxygen production on Mars - In situ propellant production (ISPP)
Frisbee, Robert H.; French, James R., Jr.; Lawton, Emil A.; Jan 1, 1987; In English
Report No.(s): AIAA PAPER 87-0236; Copyright; Avail: Other Sources

Consideration is given to the technique of producing oxygen on Mars from CO2 in the Martian atmosphere via in situ propellent production (ISPP). Mission implications of ISPP for both manned and unmanned Mars missions are described as well as ways to improve system reliability. Technology options that improve reliability and reduce power requirements include the use of adsorption pumps and advanced zirconia membranes. It is concluded that both manned and unmanned missions will benefit greatly from ISPP, especially in the context of a permanent manned base on Mars.
AIAA
Extraterrestrial Resources; Mars Atmosphere; Oxygen Production; Propellants; Space Processing

19870028628 Arizona Univ., Tucson, AZ, USA, Old Dominion Univ., Norfolk, VA, USA, Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Recent concepts in missions to Mars - Extraterrestrial processes
Ramohalli, K. N.; Ash, R. L.; Lawton, E. A.; French, J. R.; Frisbee, R. H., et al.; Oct 1, 1986; In English
Report No.(s): IAF PAPER 86-154; Copyright; Avail: Other Sources

This paper presents some recent concepts in Mars Sample Return (MSR) missions that utilize extraterrestrial resources. The concepts examined include the power and energy needs of this mission. It is shown that solar energy is not especially attractive. Radioisotopic power generator and a Rankine cycle use are seen to be viable options. Quantitative estimates, taking into consideration state-of-the-art and projected technologies indicate that the power/energy per se is not critical to the mission

- but reliability is. Hence, various modern options for the components of the power generation and utilization are discussed. The dramatic savings in Shuttle (or other) vehicle launches are quantitatively plotted. The basic system that is discussed here is the production of hydrocarbon (methane) fuel and oxygen from Martian atmosphere. For the simplest mission, it is seen that earth-carried methane burned with oxygen produced on site provides the best system.
AIAA
Extraterrestrial Resources; Mars Landing; Space Processing; Spacecraft Power Supplies

19870025838 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Lunar materials and processes
Burke, J. D.; JAN 1, 1986; In English; Copyright; Avail: Other Sources

The paper surveys current information, describes some important unknowns about lunar materials, and discusses ways to gain more scientific and engineering knowledge concerning the industrial processes that could be used on the moon for the production of products useful in future enterprises in space. Lunar rocks and soils are rich in oxygen, but it is mostly chemically bound in silicates, so that chemical or thermal energy must be supplied to recover it. Iron and titanium are abundant and, in some of their known forms, readily recoverable; aluminum is plentiful but harder to extract. Methods for recovering lunar oxygen and metals fall into three classes: chemical, electrolytic, and dissociative, broadly characterized by their respective process temperatures. Examples of these methods are briefly discussed.
AIAA
Extraterrestrial Resources; Lunar Surface; Materials Recovery; Moon; Space Processing

19860057992 Old Dominion Univ., Norfolk, VA, USA, NASA Langley Research Center, Hampton, VA, USA
Elements of oxygen production systems using Martian atmosphere
Ash, R. L.; Huang, J.-K.; Johnson, P. B.; Sivertson, W. E., Jr.; Jun 1, 1986; In English
Report No.(s): AIAA PAPER 86-1586; Copyright; Avail: Other Sources

Hardware elements have been studied in terms of their applicability to Mars oxygen production systems. Various aspects of the system design are discussed and areas requiring further research are identified. Initial work on system reliability is discussed and a methodology for applying expert system technology to the oxygen processor is described.
AIAA
Extraterrestrial Resources; Mars Atmosphere; Materials Recovery; Oxygen Production

19860050254 NASA, Washington, DC, USA, General Research Corp., McLean, VA, USA
Enabling technologies for transition to utilization of space-based resources and operations
Sadin, S. R.; Litty, J. D.; Apr 1, 1985; In English; Copyright; Avail: Other Sources

This article explores a potential scenario for the further development of space infrastructure resources and operations management. It is a scenario that transitions from the current ground-based system to an architecture that is predominantly space-based by exploiting key mission systems in an operational support role. If this view is accurate, an examination of the range of potential infrastructure elements and how they might interact in a maximally productive space-based operations complex is needed, innovative technologies beyond the current Shuttle and Space Station legacy need to be identified, and research programs pursued. Development of technologies within the areas of telerobotics, machine autonomy, human autonomy, in-space manufacturing and construction, propulsion and energy is discussed.
AIAA
Extraterrestrial Resources; Mission Planning; Space Bases; Space Industrialization; Space Logistics; Technological Forecasting

19860049986 Houston Univ., Clear Lake, TX, USA, Max-Planck-Inst. fuer Plasmaphysik, Garching, Germany, Centre National de la Recherche Scientifique, Orsay, France
'On-line' analyses of simulated solar wind implantations of terrestrial analogs of lunar materials
Blanford, G. E.; Bergesen, P.; Moeller, W.; Maurette, M.; Monart, B.; Journal of Geophysical Research; Mar 30, 1986; ISSN 0148-0227; 91; In English
Contract(s)/Grant(s): NSG-9043; Copyright; Avail: Other Sources

In connection with the establishment of a lunar base, it would be necessary to provide water, and the feasibility to obtain water from solar wind (SW) implanted lunar soils has been considered. In this context, a project involving the examination of materials under conditions of simulated SW irradiation has been initiated. A description is presented of initial results on

oligoclase, ilmenite, and simulated lunar glass (SLG). Attention is given to the reaction chamber, the target materials, the saturation concentrations, aspects of water release, depth profiles, thermal release, effects from helium-3 preimplants, mechanisms of possible water release related to direct emission and thermal release, and lunar soil components enriched in trapped SW hydrogen. It is found that ilmenite stores about twice as much deuterium as the other target materials. However, it is unknown whether the small enrichment factor will be sufficient to make the material a potential source of lunar water.
AIAA
Extraterrestrial Resources; Lunar Bases; Lunar Soil; Proton Irradiation; Solar Wind; Water Reclamation

19860045423 Texas Univ. at Dallas, Richardson, TX, USA
Lunar regolith fines - A source of hydrogen
Carter, J. L.; JAN 1, 1985; In English
Contract(s)/Grant(s): NAG9-99; Copyright; Avail: Other Sources

The theoretical evaluation of the lunar regolith fines as a primary source of hydrogen reveals that a minimum order of magnitude increase in hydrogen content is possible in beneficiated fines because both particle size and particle shape play a significant role in the relationship of volume percent of surface coating to grain size. The lunar regolith fines meet the basic requirement for beneficiation because a major portion (minimum two-thirds) of the hydrogen occurs in the less than 20-micron-size fraction, a relatively small part of the fines. Beneficiation should be accomplished by a combination of vibratory screening followed by cyclone and/or possibly electrostatic separation. Early exploitation of the lunar regolith fines for hydrogen probably will be limited to hydrogen obtained as a by-product or co-product from the mining and processing for other elements or materials because a minimum of about 13,600 tons to about 19,600 tons of 100 ppm hydrogen-bearing lunar regolith fines will have to be processed with about 3,100 tons to about 4,500 tons, respectively, of concentrate heated to supply 1 ton of hydrogen, yielding a recovery of about 74 percent to about 51 percent respectively, of the hydrogen.
AIAA
Extraterrestrial Resources; Hydrogen Production; Lunar Rocks; Regolith

19860045421 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Oxygen extraction from lunar materials - An experimental test of an ilmenite reduction process
Williams, R. J.; JAN 1, 1985; In English; Copyright; Avail: Other Sources

The reaction of ilmenite with hydrogen to produce water has been studied experimentally in order to evaluate the effectiveness of using a cold trap to improve yields in a continuous flow process. Yields were enhanced, but not to the degree observed in batch processing systems. The terrestrial simulant used in these studies contained traces of iron sulfide, which released H2S during processing with a deleterious effect on several components of the test system. More sophisticated testing should be undertaken to obtain kinetic data and attention given to the removal of sulfides in the pre-process beneficiation.
AIAA
Extraterrestrial Resources; Ilmenite; Lunar Soil; Oxygen Production; Reduction (Chemistry)

19850018457 Purdue Univ., West Lafayette, IN, USA, Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Studies on the processing methods for extraterrestrial materials
Grimley, R. T.; Lipschutz, M. E.; May 8, 1984; In English
Contract(s)/Grant(s): JPL-956322
Report No.(s): NASA-CR-175778; JPL-9950-1065; NAS 1.26:175778; No Copyright; Avail: CASI; A01, Hardcopy

The literature was surveyed for high temperature mass spectrometric research on single oxides, complex oxides, and minerals in an effort to develop a means of separating elements and compounds from lunar and other extraterrestrial materials. A data acquisition system for determining vaporization rates as a function of time and temperature and software for the IEEE-488 Apple-ORTEC interface are discussed. Experimental design information from a 1000 C furnace were used with heat transfer calculations to develop the basic design for a 1600 C furnace. A controller was built for the higher temperature furnace and drawings are being made for the furnace.
A.R.H.
Extraterrestrial Resources; High Temperature; Vacuum Furnaces; Vaporizing

19840066571 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Toward a lunar base
Duke, M. B.; Mendell, W. W.; Roberts, B. B.; Aerospace America; Oct 1, 1984; ISSN 0740-722X; 22; In English; Copyright; Avail: Other Sources

A research program leading to the development of a design for a permanent manned lunar base is described. Attention is given to the advantages offered by the lunar environment for materials processing and scientific investigations, due to the absence of an atmosphere and the plentiful supply of certain materials (iron and titanium). It is shown that once a controlled environment capsule is placed on the lunar surface, work could begin toward the construction of a permanent facility using lunar materials. It is pointed out that the research effort required for the design of a lunar base could perform concurrently with the R&D for the Space Station, resulting in the emplacement of a controlled environment capsule by the year 2007.
AIAA
Extraterrestrial Resources; Lunar Bases; Mission Planning; Space Exploration

19840056451 NASA Ames Research Center, Moffett Field, CA, USA
The atmosphere of Mars - Resources for the exploration and settlement of Mars
Meyer, T. R.; Mckay, C. P.; JAN 1, 1984; In English
Report No.(s): AAS PAPER 81-244; Copyright; Avail: Other Sources
This paper describes methods of processing the Mars atmosphere to supply water, oxygen and buffer gas for a Mars base. Existing life support system technology is combined with innovative methods of water extraction, and buffer gas processing. The design may also be extended to incorporate an integrated greenhouse to supply food, oxygen and water recycling. It is found that the work required to supply one kilogram of an argon/nitrogen buffer gas is 9.4 kW-hr. To extract water from the dry Martian atmosphere can require up to 102.8 kW-hr per kilogram of water depending on the relative humidity of the air.
AIAA
Extraterrestrial Resources; Life Support Systems; Mars Atmosphere; Space Bases; Space Processing

19840047089 Purdue Univ., West Lafayette, IN, USA
Processing of extraterrestrial materials by high temperature vacuum vaporization
Grimley, R. T.; Lipschutz, M. E.; JAN 1, 1983; In English
Contract(s)/Grant(s): JPL-956322
Report No.(s): AAS PAPER 83-235; Copyright; Avail: Other Sources
It is noted that problems associated with the extraction and concentration of elements and commpounds important for the construction and operation of space habitats have received little attention. High temperature vacuum vaporization is considered a promising approach; this is a technique for which the space environment offers advantages in the form of low ambient pressures and temperatures and the possibility of sustained high temperatures via solar thermal energy. To establish and refine this new technology, experimental determinations must be made of the material release profiles as a function of temperature, of the release kinetics and chemical forms of material being transported, and of the various means of altering release kinetics. Trace element data determined by neutron activation analysis of meteorites heated to 1400 C in vacuum is summarized. The principal tool, high temperature spectrometry, is used to examine the vaporization thermodynamics and kinetics of major and minor elements from complex multicomponent extraterrestrial materials.
AIAA
Extraterrestrial Resources; High Temperature; Materials Recovery; Space Processing; Vacuum Effects; Vaporizing

19840028105 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Finding ‘paydirt’ on the moon and asteroids
Staehle, R. L.; Astronautics and Aeronautics; Nov 1, 1983; ISSN 0004-6213; 21; In English
Contract(s)/Grant(s): NAS7-918; Copyright; Avail: Other Sources
Lunar polar region water ice, the Trojan asteroids of the earth, accessible, volatile substance-rich near-earth asteroids, and lunar gas deposits, are theoretically identified extraterrestrial resources for application to space transportation whose existence and economical exploitability could be confirmed by explorations conducted with relatively simple spacecraft. Any of these resources could improve the economics of interorbit transportation, thereby permitting launch vehicle payloads to be devoted to the transport of revenue-generating or services-providing equipment, rather than to the large propellant volumes required for the placing of large payloads on station. Among the verification missions cited is a simple lunar prospector orbiter, carrying a gamma-ray spectrometer and an electromagnetic sounder, which could ascertain the presence of water ice at the lunar poles.
AIAA
Asteroids; Extraterrestrial Resources; Lunar Composition; Space Transportation

19840014527 Science Applications, Inc., Schaumburg, IL, USA
A review of in situ propellant production techniques for solar system exploration
Hoffman, S. J.; Apr 1, 1983; In English
Contract(s)/Grant(s): NASW-3622
Report No.(s): NASA-CR-173494; NAS 1.26:173494; SAI-1-120-340-S15; No Copyright; Avail: CASI; A04, Hardcopy

Representative studies done in the area of extraterrestrial chemical production as it applies to solar system exploration are presented. A description of the In Situ Propellant Production (ISPP) system is presented. Various propellant combinations and direct applications along with the previously mentioned benefits and liens are discussed. A series of mission scenarios is presented which is studied in the greatest detail. A general description of the method(s) of analysis used to study each mission is provided. Each section will be closed by an assessment of the performance advantage, if any, that can be provided by ISPP. A final section briefly summarizes those missions which, as a result of the studies completed thus far, should see a sizable benefit from the use of ISPP.
M.A.C.
Chemical Propulsion; Energy Conversion; Extraterrestrial Resources; Propellants; Spacecraft Power Supplies; Spacecraft Propulsion

19840008159 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Research on the use of space resources
Carroll, W. F., editor; Mar 1, 1983; In English
Contract(s)/Grant(s): NAS7-100; RTOP 618-21-01
Report No.(s): NASA-CR-173213; JPL-PUB-83-36; NAS 1.26:173213; No Copyright; Avail: CASI; A15, Hardcopy

The second year of a multiyear research program on the processing and use of extraterrestrial resources is covered. The research tasks included: (1) silicate processing, (2) magma electrolysis, (3) vapor phase reduction, and (4) metals separation. Concomitant studies included: (1) energy systems, (2) transportation systems, (3) utilization analysis, and (4) resource exploration missions. Emphasis in fiscal year 1982 was placed on the magma electrolysis and vapor phase reduction processes (both analytical and experimental) for separation of oxygen and metals from lunar regolith. The early experimental work on magma electrolysis resulted in gram quantities of iron (mixed metals) and the identification of significant anode, cathode, and container problems. In the vapor phase reduction tasks a detailed analysis of various process concepts led to the selection of two specific processes designated as ''Vapor Separation'' and ''Selective Ionization.'' Experimental work was deferred to fiscal year 1983. In the Silicate Processing task a thermophysical model of the casting process was developed and used to study the effect of variations in material properties on the cooling behavior of lunar basalt.
CASI
Electrolysis; Extraterrestrial Resources; Magma

19830077472 General Dynamics/Convair, San Diego, CA, USA
Lunar resources utilization for space construction. Volume 3: Appendices
Apr 30, 1979; In English; 3volumes
Contract(s)/Grant(s): NAS9-15560
Report No.(s): NASA-CR-173025; NAS 1.26:173025; GDC-ASP79-001-VOL-3; No Copyright; Avail: CASI; A17, Hardcopy
Extraterrestrial Resources; Lunar Bases; Moon; Space Manufacturing; Spacecraft Construction Materials

19830077471 General Dynamics/Convair, San Diego, CA, USA
Lunar resources utilization for space construction. Volume 2: Study results
Apr 30, 1979; In English; 3volumes
Contract(s)/Grant(s): NAS9-15560
Report No.(s): NASA-CR-173024; NAS 1.26:173024; GDC-ASP79-001-VOL-2; No Copyright; Avail: CASI; A21, Hardcopy
Extraterrestrial Resources; Lunar Bases; Moon; Space Manufacturing; Spacecraft Construction Materials

19830077470 General Dynamics/Convair, San Diego, CA, USA
Lunar resources utilization for space construction. Volume 1: Executive summary
Apr 30, 1979; In English; 3volumes
Contract(s)/Grant(s): NAS9-15560
Report No.(s): NASA-CR-173023; NAS 1.26:173023; GDC-ASP79-001-VOL-1; No Copyright; Avail: CASI; A04, Hardcopy
Extraterrestrial Resources; Lunar Bases; Moon; Space Manufacturing; Spacecraft Construction Materials; Substitutes

19830064639 Rockwell International Corp., Downey, CA, USA
Lunar utilization
Waldron, R. D.; Criswell, D. R.; JAN 1, 1982; In English
Contract(s)/Grant(s): NSR-09-051-001; Copyright; Avail: Other Sources

The resources, techniques, and purposes to which lunar materials could be put are discussed, with attention given to transporting lunar materials to cislunar space for the construction of space manufacturing and habitable facilities. A model molecule, demandite, which represents the mole fraction of all materials used in the U.S. in 1967, is used to assess the lunar resources defined during Apollo missions. It is shown that duplication of the same manufacturing, fuel, and life-support systems in space as those on earth would cost several orders of magnitude more if the materials originated on earth than on the moon. The demandite would be sent into cislunar orbit using linear electric motors. Lunar surface concentrations of pyroxenes, olivine, feldspars, ilmenite, basalts, anorthostatic rocks, and breccias are reviewed, noting that carbon in the regolith is solar-wind derived, while in lunar rocks the carbon is indigenous. Lunar mining techniques are envisioned, especially the capacity to move large masses at 1/6 the effort required on the earth.
AIAA
Earth-Moon Trajectories; Extraterrestrial Resources; Lunar Composition; Space Industrialization; Space Manufacturing; Space Transportation

19830064637 Rockwell International Corp., Downey, CA, USA
Materials processing in space
Waldron, R. D.; Criswell, D. R.; JAN 1, 1982; In English
Contract(s)/Grant(s): NSR-09-051-001; Copyright; Avail: Other Sources

Processing-refining of raw materials from extraterrestrial sources is detailed for a space materials handling facility. The discussion is constrained to those steps necessary to separate desired components from raw or altered input ores, semi-purified feedstocks, or process scrap and convert the material into elements, alloys, and consumables. The materials are regarded as originating from dead satellites and boosters, lunar materials, and asteroids. Strong attention will be given to recycling reagent substances to avoid the necessity of transporting replacements. It is assumed that since no aqueous processes exist on the moon, the distribution of minerals will be homogeneous. The processing-refining scenario will include hydrochemical, pyrochemical, electrochemical, and physical techniques selected for the output mass rate/unit plant mass ratio. Flow charts of the various materials processing operations which could be performed with lunar materials are provided, noting the necessity of delivering several alloying elements from the earth due to scarcities on the moon.
AIAA
Extraterrestrial Resources; Production Engineering; Space Processing

19830055131 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
An analysis of propulsion options for transport of lunar materials to earth orbit
Frisbee, R. H.; Jones, R. M.; Jun 1, 1983; In English
Report No.(s): AIAA PAPER 83-1344; Copyright; Avail: Other Sources

This paper describes the results of analyses of space-based transportation systems for the transport of extraterrestrial materials from their point of origin on the lunar surface to final delivery point in earth orbit and transport of equipment and supplies for extraterrestrial processing to the operational site. The emphasis has been on the use of near-term (pre-year 2000) propulsion systems, such as advanced chemical (H2, O2) and nuclear-electric systems. More exotic systems (mass drivers, nuclear-thermal rockets, etc.) were also considered to evaluate the potential to be gained by use of post-year 2000 technologies. Finally, the effects of using extraterrestrial propellants (e.g., H2 from lunar polar water-ice for chemical systems) were compared to those of propulsion systems deriving all or part of their propellants from the earth.
AIAA
Extraterrestrial Resources; Moon-Earth Trajectories; Space Transportation; Spacecraft Propulsion

19830054556 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Should we make products on the moon?
Carroll, W. F.; Steurer, W. H.; Frisbee, R. H.; Jones, R. M.; Astronautics and Aeronautics; Jun 1, 1983; ISSN 0004-6213; 21; In English; Copyright; Avail: Other Sources

It is pointed out that products from extraterrestrial materials can play a major role in future space operations within the useful lifetime of the first major space station, now in the planning stage. Possible economic advantages regarding the use of

such products could be related to the recognition that it takes seven times more energy to get one kilogram from the earth's surface to low earth orbit (LEO) than it does to move one kilogram from the moon's surface to LEO. An analysis regarding the margin of advantage of extraterrestrial materials as been conducted, taking into account equipment and supplies which ust be launched from earth to make the acquisition of extraterrestrial products feasible. The present investigation is concerned with a study of engineering practicality. Attention is given to the transport of processing equipment from LEO to the lunar surface and of lunar products to LEO and the geosynchronous orbit. It is found that lunar oxygen and radiation shielding could possibly be utilized by the turn of the century.
AIAA
Economic Analysis; Extraterrestrial Resources; Lunar Surface; Space Industrialization; Space Manufacturing; Space Processing

19820052101 Rockwell International Corp., Downey, CA, USA
Electrorefining process for lunar free metal - Space and terrestrial applications and implications
Waldron, R. D.; JAN 1, 1981; In English; Space manufacturing 4, May 18-21, 1981, Princeton, NJ
Contract(s)/Grant(s): NSR-09-051-001; Copyright; Avail: Other Sources

An electrochemical refining process is proposed for the separation and recovery of principal and trace elements from reduced metallic particles found in lunar soils. A process variation is presented for purification and recovery of chromium and manganese from electrodeposited impure iron available from lunar silicate and other minerals. The process involves anodic dissolution of impure metal and cathodic deposition in divided cells using aqueous chloride solutions. The anolyte is withdrawn and separated using ion exchange techniques.
AIAA
Electrochemistry; Electrorefining; Extraterrestrial Resources; Ion Exchanging; Lunar Soil; Trace Elements

19820052082 Princeton Univ., NJ, USA
A small scale lunar launcher for early lunar material utilization
Snow, W. R.; Kubby, J. A.; Dunbar, R. S.; JAN 1, 1981; In English; Space manufacturing 4, May 18-21, 1981, Princeton, NJ
Contract(s)/Grant(s): NSG-3176; Copyright; Avail: Other Sources

A system for the launching of lunar derived oxygen or raw materials into low lunar orbit or to L2 for transfer to low earth orbit is presented. The system described is a greatly simplified version of the conventional and sophisticated approach suggested by O'Neill using mass drivers with recirculating buckets. An electromagnetic accelerator is located on the lunar surface which launches 125 kg 'smart' containers of liquid oxygen or raw materials into a transfer orbit. Upon reaching apolune a kick motor is fired to circularize the orbit at 100 km altitude or L2. These containers are collected and their payloads transferred to a tanker OTV. The empty containers then have their kick motors refurbished and then are returned to the launcher site on the lunar surface for reuse. Initial launch capability is designed for about 500T of liquid oxygen delivered to low earth orbit per year with upgrading to higher levels, delivery of lunar soil for shielding, or raw materials for processing given the demand.
AIAA
Electromagnetic Acceleration; Extraterrestrial Resources; Lunar Soil; Mass Drivers; Space Manufacturing; Transfer Orbits

19820023464 Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, USA
Extraterrestrial materials processing
Steurer, W. H.; Apr 15, 1982; In English
Contract(s)/Grant(s): NAS7-100
Report No.(s): NASA-CR-169268; JPL-Pub-82-41; NAS 1.26:169268; No Copyright; Avail: CASI; A07, Hardcopy

The first year results of a multi-year study of processing extraterrestrial materials for use in space are summarized. Theoretically, there are potential major advantages to be derived from the use of such materials for future space endeavors. The types of known or postulated starting raw materials are described including silicate-rich mixed oxides on the Moon, some asteroids and Mars; free metals in some asteroids and in small quantities in the lunar soil; and probably volatiles like water and CO2 on Mars and some asteroids. Candidate processes for space materials are likely to be significantly different from their terrestrial counterparts largely because of: absence of atmosphere; lack of of readily available working fluids; low- or micro-gravity; no carbon-based fuels; readily available solar energy; and severe constraints on manned intervention. The

extraction of metals and oxygen from lunar material by magma electrolysis or by vapor/ion phase separation appears practical.
CASI
Carbon Dioxide; Electrolysis; Extraterrestrial Resources; Ion Exchanging; Metals; Mineral Deposits; Mining; Silicates; Silicon Oxides

19820004116 NASA, Washington, DC, USA
Agreement governing the activities of states on the Moon and other celestial bodies
Gaggero, E. D.; Ripoll, R. P.; Sep 1, 1981; In English
Contract(s)/Grant(s): NASW-3541
Report No.(s): NASA-TM-76730; No Copyright; Avail: CASI; A03, Hardcopy

The treaty on the Moon is not revolutionary but it embodies the legal rule for future activities of man on the Moon as opposed to the Space Treaty of 1967 which was too general. The new text is conservative but still allows some room for the developing States as in the law of the sea. The Moon is declared the 'Common Heritage of Mankind' but the regime of exploitation of its resources is still blurred with imprecise guidelines still needing to be developed. The two superpowers cannot as in the past, ignore the rest of the world in the conquest of space and the fact that the U.N. is the depositary for ratifications, and not the two superpowers as in previous treaties, is the first sign of wider participation in the creation of Space Law.
CASI
Extraterrestrial Resources; Lunar Exploration; Meteoroids; Moon; Outer Space Treaty; Space Law

19810014566 NASA, Washington, DC, USA
The utilization of nonterrestrial materials
Mar 1, 1981; In English, Jun. 1977, Palo Alto, CA, USA
Report No.(s): NASA-TM-83106; No Copyright; Avail: CASI; A09, Hardcopy

The development of research and technology programs on the user of nonterrestrial materials for space applications was considered with emphasis on the space power satellite system as a model of large space systems for which the use of nonterrestrial materials may be economically viable. Sample topics discussed include the mining of raw materials and the conversion of raw materials into useful products. These topics were considered against a background of the comparative costs of using terrestrial materials. Exploratory activities involved in the preparation of a nonterrestrial materials utilization program, and the human factors involved were also addressed. Several recommendations from the workshop are now incorporated in NASA activities.
A.R.H.
Conferences; Extraterrestrial Resources; Mining; Solar Power Satellites; Space Industrialization

19810014469 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Report of Workshop on Methodology for Evaluating Potential Lunar Resources Sites
Williams, R. J.; Hubbard, N.; Feb 1, 1981; In English, Houston, TX, USA
Contract(s)/Grant(s): RTOP 152-85-00-00-72
Report No.(s): NASA-TM-58235; JSC-17058; No Copyright; Avail: CASI; A04, Hardcopy

The type and quantity of lunar materials needed to support a space power satellite program was used to define the type and quality of geological information required to certify a site for exploitation. The existing geological, geochemical, and geophysical data are summarized. The difference between these data and the required data for exploitation is used to define program requirements. Most of these requirements involve linear extensions of existing capabilities, fuller utilization of existing data, or expanded use of automated systems.
CASI
Extraterrestrial Resources; Geochemistry; Lunar Exploration; Site Selection; Space Industrialization

19800062215 Carnegie-Mellon Univ., Pittsburgh, PA, USA, Lunar and Planetary Inst., Houston, TX, USA
Economic considerations in space industrialization
Ayres, R. U.; Ayres, L. W.; Criswell, D. R.; JAN 1, 1979; In English; Space manufacturing III, May 14-17, 1979, Princeton, NJ
Contract(s)/Grant(s): NSR-09-051-001; Copyright; Avail: Other Sources

The industrial categories of the USA economy are surveyed to identify those which can function using dominantly lunar

raw materials or lunar derived feedstocks (LDF) and solar energy. Sixty-four standard industrial categories (SIC) appear to be compatible with LDF inputs; another 166 SIC's might be adaptable to LDF and space industry if substitution of materials and/or terrestrial supplements were introduced. Analytic tools are presented to use in deciding optimal strategies by which a generalized economy can be developed in space in an optimal manner within given constraints of capital, products derived at a given time, local production costs, cost of import from earth and other factors.
AIAA
Economic Development; Economic Factors; Extraterrestrial Resources; Lunar Soil; Materials Recovery; Space Industrialization; United States

19790069289 General Dynamics/Convair, San Diego, CA, USA
Cost comparisons for the use of nonterrestrial materials in space manufacturing of large structures
Bock, E. H.; Risley, R. C.; Sep 1, 1979; In English; 30th International Astronautical Federation, International Astronautical Congress, Sept. 17-22, 1979, Munich
Report No.(s): IAF PAPER 79-115; Copyright; Avail: Other Sources

This paper presents results of a study sponsored by NASA to evaluate the relative merits of constructing solar power satellites (SPS) using resources obtained from the earth and from the moon. Three representative lunar resources utilization (LRU) concepts are developed and compared with a previously defined earth baseline concept. Economic assessment of the alternatives includes cost determination, economic threshold sensitivity to manufacturing cost variations, cost uncertainties, program funding schedule, and present value of costs. Results indicate that LRU for space construction is competitive with the earth baseline approach for a program requiring 100,000 metric tons per year of completed satellites. LRU can reduce earth-launched cargo requirements to less than 10% of that needed to build satellites exclusively from earth materials. LRU is potentially more cost-effective than earth-derived material utilization, due to significant reductions in both transportation and manufacturing costs. Because of uncertainties, cost-effectiveness cannot be ascertained with great confidence. The probability of LRU attaining a lower total program cost within the 30-year program appears to range from 57 to 93%.
AIAA
Cost Analysis; Extraterrestrial Resources; Large Space Structures; Lunar Soil; Solar Power Satellites; Space Manufacturing; Spacecraft Construction Materials

19790066222 Lunar and Planetary Inst., Houston, TX, USA, Lockheed Electronics Co., Houston, TX, USA
The role of chemical engineering in space manufacturing
Waldron, R. D.; Criswell, D. R.; Erstfeld, T. E.; Chemical Engineering; Feb 12, 1979; In English
Contract(s)/Grant(s): NSR-09-051-001; Copyright; Avail: Other Sources

A survey of factors involved in space manufacturing is presented. It is shown that it will be more economical to obtain the necessary raw materials from the moon than from earth due to earth's greater gravity and atmosphere. Discussion covers what resources can be mined and recovered from the moon and what ranges of industrial feedstock can be provided from lunar materials, noting that metallurgy will be different in space due to the lack of key elements such as H, C, Na, Cl, etc. Also covered are chemical plant design, space environmental factors such as vacuum and zero gravity, recycling requirments, reagent and equipment mass, and unit operations such as materials handling and phase separation. It is concluded that a pilot plant in space could be an economic boon to mankind.
AIAA
Chemical Engineering; Extraterrestrial Resources; Industrial Plants; Lunar Soil; Materials Recovery; Space Manufacturing

19790059234 NASA Marshall Space Flight Center, Huntsville, AL, USA
Nonterrestrial material processing and manufacturing of large space systems
Von Tiesenhausen, G.; JAN 1, 1979; In English; 24th The enigma of the eighties: Environment, economics, energy; Twenty-fourth National Symposium and Exhibition, May 8-10, 1979, San Francisco, CA; Copyright; Avail: Other Sources

Nonterrestrial processing of materials and manufacturing of large space system components from preprocessed lunar materials at a manufacturing site in space is described. Lunar materials mined and preprocessed at the lunar resource complex will be flown to the space manufacturing facility (SMF), where together with supplementary terrestrial materials, they will be final processed and fabricated into space communication systems, solar cell blankets, radio frequency generators, and electrical equipment. Satellite Power System (SPS) material requirements and lunar material availability and utilization are

detailed, and the SMF processing, refining, fabricating facilities, material flow and manpower requirements are described.
AIAA
Extraterrestrial Resources; Large Space Structures; Lunar Rocks; Space Manufacturing; Space Processing

19790050831 General Dynamics/Convair, San Diego, CA, USA
Development of space manufacturing systems concepts utilizing lunar resources
Bock, E. H.; May 1, 1979; In English; Princeton University and American Institute of Aeronautics and Astronautics, Conference on Space Manufacturing Facilities, 4th, Princeton University, May 14-17, 1979, Princeton, NJ
Report No.(s): AIAA PAPER 79-1411; Copyright; Avail: Other Sources

Results of a NASA sponsored study to evaluate the merits of constructing solar power satellites using lunar and terrestrial resources are reviewed. Three representative lunar resources utilization (LRU) concepts were developed and compared with a previously designed earth baseline concept, and major system hardware elements as well as personnel requirements were defined. LRU for space construction was shown to be competitive with earth baseline approach for a program requiring 10 to the 5th metric tons per year of completed satellites. Results also indicated that LRU can reduce earth launched cargo requirements to less than 10% of that needed to build satellites exclusively from earth materials, with a significant percentage of the reduction due to the use of liquid oxygen derived from lunar soil. A concept using the mass driver to catapult lunar material into space was found to be superior to the other LRU logistics techniques investigated.
AIAA
Extraterrestrial Resources; Lunar Soil; NASA Programs; Satellite Solar Power Stations; Space Manufacturing

19790050818 Washington Univ., Saint Louis, MO, USA
Electrochemistry of lunar rocks
Lindstrom, D. J.; Haskin, L. A.; May 1, 1979; In English; Princeton University and American Institute of Aeronautics and Astronautics, Conference on Space Manufacturing Facilities, 4th, Princeton University, May 14-17, 1979, Princeton, NJ
Contract(s)/Grant(s): NSG-9073; NSG-7372
Report No.(s): AIAA PAPER 79-1380; Copyright; Avail: Other Sources

Electrolysis of silicate melts has been shown to be an effective means of producing metals from common silicate materials. No fluxing agents need be added to the melts. From solution in melts of diopside (CaMgSi2O6) composition, the elements Si, Ti, Ni, and Fe have been reduced to their metallic states. Platinum is a satisfactory anode material, but other cathode materials are needed. Electrolysis of compositional analogs of lunar rocks initially produces iron metal at the cathode and oxygen gas at the anode. Utilizing mainly heat and electricity which are readily available from sunlight, direct electrolysis is capable of producing useful metals from common feedstocks without the need for expendable chemicals. This simple process and the products obtained from it deserve further study for use in materials processing in space.
AIAA
Electrolysis; Extraterrestrial Resources; Liquid Phases; Lunar Rocks; Silicates

19790050817 Lunar and Planetary Inst., Houston, TX, USA, Lockheed Electronics Co., Houston, TX, USA
Overview of methods for extraterrestrial materials processing
Waldron, R. D.; Criswell, D. R.; Erstfeld, T. E.; May 1, 1979; In English; Princeton University and American Institute of Aeronautics and Astronautics, Conference on Space Manufacturing Facilities, 4th, Princeton University, May 14-17, 1979, Princeton, NJ
Contract(s)/Grant(s): NSR-09-051-001
Report No.(s): AIAA PAPER 79-1379; Copyright; Avail: Other Sources

A brief survey of processing systems suitable for conversion of lunar soil fractions to refined industrial feedstocks are given. Description of a ‘baseline’ process using hydrochemical or metallurgical separation of compounds of major and minor elements using HF acid leaching as the initial step is presented. Rough engineering parameters including power and heat rejection requirements, potential loss of earth supplied reagents during recycling, and mass: output ratios of equipment, reagent inventory, and associated power and radiator facilities are described. Minimal practical scales for such systems and manpower requirements are discussed.
AIAA
Extraterrestrial Resources; Industrial Plants; Lunar Soil; Space Processing

19790050815
Excavation costs for lunar materials
Carrier, W. D., III; May 1, 1979; In English; Princeton University and American Institute of Aeronautics and Astronautics, Conference on Space Manufacturing Facilities, 4th, Princeton University, May 14-17, 1979, Princeton, NJ
Report No.(s): AIAA PAPER 79-1376; Copyright; Avail: Other Sources

A lunar strip mining system is presented which is capable of excavating and transporting 3 million metric tons of ore per year to a central processing plant on the moon's surface. The mining system would grow from a single front-end loader in the first year, to a fleet of ten haulers in the 30th year. Lunar personnel requirements would consist of a single individual, whose primary function would be to perform maintenance. All of the mining equipment would either operate automatically or by remote control from earth. The projected cost for the lunar mining system is approximately $12 to $37 per ton of ore over the life of the mine, an important part of the overall economics of exploiting lunar resources.
AIAA
Economic Analysis; Extraterrestrial Resources; Lunar Crust; Strip Mining

19790049735 Lunar and Planetary Inst., Houston, TX, USA
Commercial prospects for extraterrestrial materials
Criswell, D. R.; Waldron, R. D.; Journal of Contemporary Business; JAN 1, 1978; 7, 3, 19; In English
Contract(s)/Grant(s): NSR-09-051-001; Copyright; Avail: Other Sources

Prospects for using lunar resources as materials for spaceborne construction are examined. The use of lunar construction materials is considered economically justifiable in the case of such large scale projects as space power stations (SPS). A proposed scenario for the acquisition and space processing of lunar materials involves the use of space shuttles to deliver an assembly base to earth orbit, where a solar powered mass driver reaction engine rocket is assembled and used to bring sections of a lunar base from low earth orbit to the moon. The rocket would then be positioned at the L2 equilibrium point in order to catch lunar soil propelled into space by a mass driver and bring it to the assembly base for chemical processing. Cost factors would be comparable to those of the terrestrial deployment of the first SPS, and such a project could be in operation before the end of the century.
AIAA
Extraterrestrial Resources; Lunar Bases; Market Research; Satellite Solar Power Stations; Space Industrialization

19790037267 Lunar and Planetary Inst., Houston, TX, USA
Utilization of lunar materials in space
Criswell, D. R.; Waldron, R. D.; Oct 1, 1978; In English; 25th American Astronautical Society, Anniversary Conference, Oct. 30, 1978-Nov. 2, 1978, Houston, TX
Contract(s)/Grant(s): NSR-09-051-001
Report No.(s): AAS PAPER 78-198; Copyright; Avail: Other Sources

Reasons for conducting commercial mining operations on the moon are discussed with attention to physical parameters, material abundances, and economics. Adaptations of currently used mining techniques are considered, and space applications of moon-derived materials are suggested. Possible organization of the mining project is examined, and it is suggested that the transition from concept phase to implementation could proceed rapidly. Characteristics of maturing space industries and the roles of the public and the private sectors are considered.
AIAA
Extraterrestrial Resources; Lunar Rocks; Mining; Orbital Assembly; Space Industrialization

19790021033 Lunar and Planetary Inst., Houston, TX, USA
Extraterrestrial materials processing and construction
Criswell, D. R.; Sep 30, 1978; In English
Contract(s)/Grant(s): NSR-09-051-001
Report No.(s): NASA-CR-158870; REPT-713-488-5200; No Copyright; Avail: CASI; A21, Hardcopy

Applications of available terrestrial skills to the gathering of lunar materials and the processing of raw lunar materials into industrial feed stock were investigated. The literature on lunar soils and rocks was reviewed and the chemical processes by which major oxides and chemical elements can be extracted were identified. The gathering of lunar soil by means of excavation equipment was studied in terms of terrestrial experience with strip mining operations on earth. The application of electrostatic benefication techniques was examined for use on the moon to minimize the quantity of materials requiring surface

transport and to optimize the stream of raw materials to be transported off the moon for subsequent industrial use.
R.E.S.
Extraterrestrial Resources; Moon; Space Industrialization; Space Manufacturing

19780044024 Lunar Science Inst., Houston, TX, USA
Demandite, lunar materials and space industrialization
Criswell, D. R.; JAN 1, 1977; In English; 3rd Conference on Space manufacturing facilities II - Space colonies, May 9-12, 1977, Princeton, NJ
Contract(s)/Grant(s): NSR-09-051-001; Copyright; Avail: Other Sources

Terrestrial industry consumes a wide range of elements in producing the outputs which support and make industrial societies possible. 'Demandite' is a conceptual or synthetic molecule which is composed of the weight fractions of the major elements consumed by industry. Demandite needed for mature industrial activities in space will differ from the terrestrial composition because solar energy must replace hydrocarbon-energy, lunar and asteroidal bulk compositions are different from mineral deposits on the earth, and the major bulk processing in space will be the creation of radiation shielding for human habitats to provide real estate in space complete with water, atmosphere and life-stock elements. Demandite cost may be dominated by earth to deep space transport cost of minor elemental constituents depleted in the lunar soils unless careful attention is given to substitution of materials, searches of the moon (polar regions) and asteroids for the depleted elements, and continuing lowering of earth to deep space transport costs.
AIAA
Extraterrestrial Resources; Space Manufacturing

19780044023 Lunar Science Inst., Houston, TX, USA
Lunar materials for construction of space manufacturing facilities
Criswell, D. R.; JAN 1, 1977; In English; 3rd Conference on Space manufacturing facilities II - Space colonies, May 9-12, 1977, Princeton, NJ
Contract(s)/Grant(s): NSR-09-051-001; Copyright; Avail: Other Sources

Development of industrial operations in deep space would be prohibitively expensive if most of the construction and expendable masses had to be transported from earth. Use of lunar materials reduces the needed investments by a factor of 15 to 20. It is shown in this paper that judicious selection of lunar materials will allow one to obtain hydrogen, nitrogen, carbon, helium and other specific elements critical to the support of life in large space habitats at relatively low costs and lower total investment even further. Necessary selection techniques and extraction schemes are outlined. In addition, tables are presented of the oxide and elemental abundances characteristic of the mare and highland regions of the moon which should be useful in evaluating what can be extracted from the lunar soils.
AIAA
Extraterrestrial Resources; Orbital Assembly; Space Manufacturing

19780033279 Lunar Science Inst., Houston, TX, USA, NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Lunar resources and their utilization
Phinney, W. C.; Criswell, D.; Drexler, E.; Garmirian, J.; JAN 1, 1977; In English; Copyright; Avail: Other Sources

The paper reviews the physical and chemical characteristics of lunar surface materials noting the thickness of the regolith, grain size distribution, regolith petrography, and the chemical composition of the regolith. A comprehensive design of a processing system for the production of structural metals, oxygen, silicon, glass, and ceramic materials is presented. Specifications regarding the location of the processing plant, and its mass, volume, and power requirements are reviewed.
AIAA
Chemical Composition; Extraterrestrial Resources; Lunar Surface; Space Processing

19780013237 Lunar Science Inst., Houston, TX, USA
Utilization of lunar materials and expertise for large scale operations in space: Abstracts
Criswell, D. R., editor; JAN 1, 1976; In English, 16 Mar. 1976, Houston, TX, USA
Report No.(s): NASA-CR-156167; Copyright; Avail: CASI; A09, Hardcopy

The practicality of exploiting the moon, not only as a source of materials for large habitable structures at Lagrangian points, but also as a base for colonization is discussed in abstracts of papers presented at a special session on lunar utilization.

Questions and answers which followed each presentation are included after the appropriate abstract. Author and subject indexes are provided.
A.R.H.
Abstracts; Conferences; Extraterrestrial Resources; Lunar Bases; Space Industrialization; Space Processing

19780009030 NASA Lyndon B. Johnson Space Center, Houston, TX, USA
Summer Workshop on Near-Earth Resources
Arnold, J. R., editor; Duke, M. B., editor; Jan 1, 1978; In English, 6-13 Aug. 1977, La Jolla, CA, USA
Contract(s)/Grant(s): RTOP 383-85-00-00-72
Report No.(s): NASA-CP-2031; S-482; JSC-13139; No Copyright; Avail: CASI; A06, Hardcopy

The possible large scale use of extraterrestrial resources was addressed, either to construct structures in space or to return to Earth as supplements for terrestrial resources. To that end, various specific recommendations were made by the participants in the summer study on near-Earth resources, held at La Jolla, California, 6 to 13 August, 1977. The Moon and Earth-approaching asteroids were considered. Summaries are included of what is known about their compositions and what needs to be learned, along with recommendations for missions designed to provide the needed data. Tentative schedules for these projects are also offered.
CASI
Asteroids; Extraterrestrial Resources; Lunar Soil; Resources Management

19770057796 Princeton Univ., NJ, USA
Mining the Apollo and Amor asteroids
Oleary, B.; Science; Jul 22, 1977; 197; In English
Contract(s)/Grant(s): NSG-2062; Copyright; Avail: Other Sources

Earth-approaching asteroids could provide raw materials for space manufacturing. For certain asteroids the total energy per unit mass for the transfer of asteroidal resources to a manufacturing site in high earth orbit is comparable to that for lunar materials. For logistical reasons the cost may be many times less. Optical studies suggest that these asteroids have compositions corresponding to those of carbonaceous and ordinary chondrites, with some containing large quantities of iron and nickel; other are thought to contain carbon, nitrogen, and hydrogen, elements that appear to be lacking on the moon. The prospect that several new candidate asteroids will be discovered over the next few years increases the likelihood that a variety of asteroidal resource materials can be retrieved on low-energy missions.
AIAA
Asteroids; Extraterrestrial Resources; Space Manufacturing

19770052951 California Inst. of Tech., Pasadena, CA, USA
Transport of lunar material to the sites of the colonies
Heppenheimer, T. A.; JAN 1, 1977; In English; Princeton Conference on Space manufacturing facilities: Space colonies, May 7-9, 1975, Princeton, NJ
Contract(s)/Grant(s): NGL-05-002-003; Copyright; Avail: Other Sources

An 'existence proof' is attempted for the feasibility of transport of lunar material to colonies in space. Masses of lunar material are accelerated to lunar escape by a tracked magnetically levitated mass driver; aim precision is to 1 km miss distance at L5 per mm/sec velocity error at the lunar surface. Mass driver design and linear synchronous motor drive design are discussed; laser-sensed checkpoints aid in velocity and directional precision. Moon-L5 trajectories are calculated. The design of the L5 construction station, or 'catcher vehicle,' is described; loads are received by chambers operating in a 'Venus flytrap' mode. Further research studies needed to round out the concept are listed explicitly.
AIAA
Extraterrestrial Resources; Lunar Surface; Space Colonies; Space Transportation; Spacecraft Propulsion

19770049201 Princeton Univ., NJ, USA
Mass driver retrievals of earth-approaching asteroids
Oleary, B.; May 1, 1977; In English; 3rd Conference on Space Manufacturing Facilities, May 9-12, 1977, Princeton, NJ, US
Contract(s)/Grant(s): NSG-2062
Report No.(s): AIAA PAPER 77-528; Copyright; Avail: Other Sources

Mass driver tugs can be designed to move Apollo and Amor asteroids at opportunities of low velocity increment to the

vicinity of the earth. The cost of transferring asteroids through a velocity interval of 3 km/sec by mass driver is about 16 cents per kilogram amortized over 10 years, about ten times less than that required to retrieve lunar resources during the early phases of a program of space manufacturing. About 22 per cent of a 200-meter diameter asteroid could be transferred to high earth orbit by an automated 100 megawatt solar-powered mass driver in a period of five years for a cost of approximately $1 billion. Estimates of the total investment of a space manufacturing program could be reduced twofold by using asteroidal instead of lunar resources; such a program could begin several years sooner with minimal concurrent development if asteroidal search programs and mass driver development are immediately accelerated.
AIAA
Accelerators; Asteroids; Electromagnetic Propulsion; Extraterrestrial Resources; Space Manufacturing; Space Transportation

19770049199 California Univ., La Jolla, CA, USA
Lunar resource surveys from orbit
Arnold, J. R.; May 1, 1977; In English; 3rd Conference on Space Manufacturing Facilities, May 9-12, 1977, Princeton, NJ, US
Contract(s)/Grant(s): NSG-07-027
Report No.(s): AIAA PAPER 77-526; Copyright; Avail: Other Sources

The chemical composition of lunar soil and rocks is known now for nine surface sites, by analysis of returned samples. Three classes of silicate material, mare basalt, KREEP, and highland material (sometimes called ANT) have been identified as major components. Gamma-ray and X-ray instruments have mapped the Apollo 15 and 16 ground tracks for major elements, K, and Th. It is hoped that the Lunar Polar Orbiter will carry instruments capable of producing a chemical map of the entire moon. The most exciting possibility is that ice may exist in shadowed regions near the lunar pole.
AIAA
Chemical Composition; Extraterrestrial Resources; Geological Surveys; Lunar Composition

19740024403 Kanner (Leo) Associates, Redwood City, CA, USA
Who owns the moon?
Zhukov, G. P.; Inhabited Space, Pt. 2 (NASA-TT-F-820); Jul 1, 1974; In English; No Copyright; Avail: CASI; A02, Hardcopy

It is stipulated that all of mankind owns the moon and that lunar exploration must be exclusively for peaceful purposes. In addition to the right to build stations on the moon, every country has the right to utilize the moon's natural resources. This includes: exploration, extraction, and processing of minerals and other natural resources, and their utilization and processing for local needs and possible also for export to earth.
G.G.
Extraterrestrial Resources; Lunar Bases; Lunar Exploration; Space Law

19740024398 Kanner (Leo) Associates, Redwood City, CA, USA
Space and man
Kolman, E.; Inhabited Space, Pt. 2 (NASA-TT-F-820); Jul 1, 1974; In English; No Copyright; Avail: CASI; A02, Hardcopy

The effects of man's entry into space on changes in economics and technology, politics and law, science, philosophy, and art are considered. A single world economy, extracting from the natural resources of the moon and other cosmic bodies raw materials and energy, will avoid terrestrial limitations and improve society by eliminating the inequalities of economic and social status. However, a spacecraft for interplanetary travel require thermonuclear engines that achieve an escape velocity of 0.1 times the speed of light in order to allow an astronaut stellar expedition corresponding to the active life of a single generation.
G.G.
Economic Factors; Extraterrestrial Resources; Manned Space Flight; Planetary Bases

19720062444 Bureau of Mines, Minneapolis, MN, USA
Multidisciplinary research leading to utilization of extraterrestrial resources
Oct 1, 1971; In English
Contract(s)/Grant(s): NASA ORDER R-09-040-001
Report No.(s): NASA-CR-125427; No Copyright; Avail: CASI; A03, Hardcopy
Extraterrestrial Resources; Lunar Exploration; Multidisciplinary Research

19710026674 Bureau of Mines, Minneapolis, MN, USA
Multidisciplinary research leading to utilization of extraterrestrial resources
Fogelson, D. E.; Jul 1, 1971; In English
Contract(s)/Grant(s): NASA ORDER R-09-040-001
Report No.(s): NASA-CR-121915; No Copyright; Avail: CASI; A03, Hardcopy

Properties of rocks, soils, and minerals in ultrahigh vacuum facility simulating lunar environment, for extraterrestrial resource utilization

CASI
Extraterrestrial Resources; Lunar Environment; Lunar Rocks; Lunar Soil; Minerals; Multidisciplinary Research

19700054082
Resources on the moon - Implications for manned lunar missions
Johnson, R. W.; JAN 1, 1970; In English; 4TH IN- APPLIED SCIENCES RESEARCH and UTILIZATION of LUNAR RESOURCES, INTERNATIONAL ACADEMY of ASTRONAUTICS, INTERNATIONAL ASTRONAUTICAL CONGRESS, 19TH, LUNAR INTERNATIONAL LAB. SYMPOSIUM, 4TH, OCT. 17, 1968, NEW YORK, NY; Copyright; Avail: Other Sources

Lunar resources classified as rocket fuel, construction and life support materials, discussing implications for manned surface exploration missions

AIAA
Construction Materials; Extraterrestrial Resources; Life Support Systems; Lunar Exploration; Rocket Propellants

19700032243 Bureau of Mines, Minneapolis, MN, USA
Multidisciplinary research leading to utilization of extraterrestrial resources Annual status report, FY 1970
Jul 1, 1970; In English
Contract(s)/Grant(s): NASA ORDER R-09-040-001
Report No.(s): NASA-CR-113920; No Copyright; Avail: CASI; A03, Hardcopy

Lunar environment simulation to determine applications of rocks and minerals in future space missions

CASI
Extraterrestrial Resources; Lunar Environment; Minerals; Multidisciplinary Research; Space Environment Simulation; Space Missions

19700029978 Bureau of Mines, Reno, NV, USA
Electrowinning oxygen from silicate rocks
Kesterke, D. G.; NASA, WASHINGTON PROC. of THE 7TH ANN. WORKING GROUP ON EXTRATERREST. RESOURCES 1970; JAN 1, 1970; In English; No Copyright; Avail: CASI; A02, Hardcopy

Electrowinning oxygen from silicate rocks for utilization of extraterrestrial resources

CASI
Electrowinning; Extraterrestrial Resources; Oxygen; Rocks; Silicates

19700029960 NASA, Washington, DC, USA
Proceedings of the Seventh Annual Working Group on Extraterrestrial Resources
JAN 1, 1970; In English, 17-18 JUL. 1969, DENVER
Report No.(s): NASA-SP-229; No Copyright; Avail: CASI; A07, Hardcopy

Lunar water detection and removal, soil adhesion and friction, and other lunar and planetary resources recovery - conferences

CASI
Adhesion; Conferences; Extraterrestrial Resources; Friction; Hydrogeology; Lunar Exploration; Lunar Soil

19700016353 Techtran Corp., Glen Burnie, MD, USA
The development of Tsiolkovskiy's ideas concerning the settlement of space
Ulubekov, A. T.; TRANS. of THE FIRST LECTURES DEDICATED to THE DEVELOP. of THE SCI. HERITAGE of K. E. TSIOLKOVSKIY APR. 1970; Apr 1, 1970; In English; No Copyright; Avail: CASI; A02, Hardcopy

Power and raw material potentials of solar system for planetary bases
CASI
Extraterrestrial Resources; Planetary Bases; Planetary Mass; Solar Energy

19700015331 Bureau of Mines, Minneapolis, MN, USA
Multidisciplinary research leading to utilization of extraterrestrial resources Quarterly status report, 1 Oct. 1969 - 1 Jan. 1970
Jan 1, 1970; In English
Contract(s)/Grant(s): NASA ORDER R-09-040-001
Report No.(s): NASA-CR-109399; No Copyright; Avail: CASI; A03, Hardcopy
Utilization of extraterrestrial resources including lunar simulation and rock experiments
CASI
Extraterrestrial Resources; Lunar Topography; Multidisciplinary Research; Rocks

19700006190 Bureau of Mines, Minneapolis, MN, USA
Multidisciplinary research leading to utilization of extraterrestrial resources Quarterly status report, 1 Jul. - 1 Oct. 1969
Atchison, T. C.; Oct 1, 1969; In English
Contract(s)/Grant(s): NASA ORDER R-09-040-001
Report No.(s): NASA-CR-107552; No Copyright; Avail: CASI; A03, Hardcopy
Surface properties, failure processes, and thermodynamic properties of rock in simulated lunar environments
CASI
Environment Simulation; Extraterrestrial Resources; Lunar Environment; Multidisciplinary Research; Rocks

19690063631
Sampling.
Hotz, G. M.; Jul 1, 1969; In English; Copyright; Avail: Other Sources
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AIAA
Exobiology; Extraterrestrial Resources; Geology; Landing Sites; Planetary Surfaces; Samplers

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CASI
Extraterrestrial Resources; Lunar Environment; Minerals; Multidisciplinary Research; Space Missions

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CASI
Extraterrestrial Resources; Lunar Bases; Space Exploration

19690012879 Martin Co., Denver, CO, USA
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CASI
Extraterrestrial Resources; Lunar Exploration; Lunar Geology; Mission Planning; Spacecraft Propulsion

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CASI
Environment Simulation; Extraterrestrial Resources; Lunar Geology; Volcanology

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CASI
Extraterrestrial Resources; Geomorphology; Lunar Geology

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CASI
Extraterrestrial Resources; Lunar Luminescence; Lunar Maps; Minerals; Silicates

19690012864 NASA, Washington, DC, USA
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CASI
Conferences; Extraterrestrial Resources; Lunar Bases; Lunar Exploration; Mission Planning

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CASI
Extraterrestrial Resources; Lunar Exploration; Mineralogy; Multidisciplinary Research; Petrology

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Extraterrestrial Resources; Minerals; Multidisciplinary Research; Research Projects

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CASI
Extraterrestrial Resources; Minerals; Multidisciplinary Research; Research Projects

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AIAA
Extraction; Life Support Systems; Lunar Exploration; Lunar Logistics; Lunar Resources; Meteorites; Meteoritic Microstructures; Mineral Deposits; Solar Radiation; Space Commercialization; Space Exploration

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Author (CASI)
Apollo Project; Extraterrestrial Resources; Literature; Lunar Soil; Lunar Surface; Ogo; Physical Properties; Rocks; Space Commercialization; Surface Properties

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Author (CASI)
Extraterrestrial Environments; Extraterrestrial Resources; Research Projects; Space Commercialization

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Author (CASI)
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Author (CASI)
Biochemistry; Carbon Dioxide; Conferences; Exploitation; Extraterrestrial Environments; Extraterrestrial Resources; Food; Life Support Systems; Lunar Bases; Lunar Logistics; Microorganisms; NASA Programs; Space Commercialization; Water Reclamation

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Author (CASI)
Extraterrestrial Matter; Extraterrestrial Resources; Lunar Rocks; Lunar Soil; Space Commercialization

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Author (CASI)
Extraction; Lunar Exploration; Lunar Resources; Mining; Space Commercialization; Space Exploration

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Author (CASI)
Extraterrestrial Resources; Literature; Lunar Surface; Rocks; Simulation; Space Commercialization

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Author (CASI)
Excavation; Extraterrestrial Environments; Extraterrestrial Resources; Lunar Exploration; Lunar Geology; Lunar Resources; Mining; Space Commercialization; Space Exploration; Surface Layers

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Author (CASI)
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Author (CASI)
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Author (CASI)
Extraterrestrial Resources; Impulses; Interplanetary Flight; Mars (Planet); Moon; Propellants; Propulsion; Refueling; Space Commercialization; Venus (Planet)

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Recovery of water from rocks and minerals on lunar surface
Author (CASI)
Basalt; Conferences; Lunar Resources; Lunar Surface; Minerals; Rocks; Space Commercialization; Water; Water Reclamation; Water Resources

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Author (CASI)
Conferences; Extraterrestrial Environments; Extraterrestrial Resources; Interplanetary Flight; Leakage; Lunar Exploration; Manufacturing; Space Commercialization

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Author (CASI)
Extraction; Extraterrestrial Matter; Extraterrestrial Resources; Mineral Deposits; Mineralogy; Mining; Space Commercialization

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Author (CASI)
Carbon; Carbon Monoxide; Catalysis; Catalytic Activity; Extraterrestrial Resources; Fabrication; Hydrogen; Igneous Rocks; Laboratory Equipment; Methane; Reduction; Space Commercialization

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Author (CASI)
Carbon Monoxide; Catalysts; Extraterrestrial Resources; Reactors; Resistance Heating; Silicates; Space Commercialization

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Author (CASI)
Carbon Monoxide; Catalysts; Extraterrestrial Resources; Silicates; Space Commercialization

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Author (CASI)
Carbon Monoxide; Extraterrestrial Resources; Silicates; Space Commercialization

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Laboratory apparatus to study catalytic reduction of carbon monoxide with hydrogen - utilization of lunar raw materials to produce oxygen
Author (CASI)
Carbon Monoxide; Catalysis; Catalytic Activity; Extraterrestrial Resources; Hydrogen; Laboratory Equipment; Lunar Composition; Lunar Rocks; Lunar Soil; Oxygen; Space Commercialization

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Contract(s)/Grant(s): NAS7-225
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Laboratory apparatus to study reduction of igneous rock with carbon, hydrogen, and methane - utilization of lunar resources
Author (CASI)
Carbon; Extraterrestrial Resources; Hydrogen; Igneous Rocks; Laboratory Equipment; Methane; Space Commercialization

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Chemical reactions of natural silicates with methane, methane-hydrogen mixtures, carbon, and silicon carbides - utilization of lunar resources
Author (CASI)
Carbon; Chemical Reactions; Extraterrestrial Resources; Hydrogen; Methane; Moon; Silicates; Silicon Carbides; Space Commercialization

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Author (CASI)
Carbon Monoxide; Extraterrestrial Resources; Lunar Geology; Oxygen Production; Silicates; Slags; Space Commercialization

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Research on processes for utilization of lunar resources quarterly report <22 apr.-31 jul. 1963<

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Processes for utilization of lunar resources - reduction of silicates to produce oxygen

Author (CASI)

Catalysis; Extraterrestrial Resources; Lunar Composition; Oxygen; Oxygen Analyzers; Silicates; Space Commercialization

Subject Term Index

LUNAR COMPOSITION

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