INTRODUCTION

In the four years since the University of Arizona/NASA Space Engineering Research Center was established, it has become recognized as a national and international center for space resources research, development, and education. Perhaps equally important, it has become recognized within NASA as the premier center of activities in the area popularly known as In-Situ Resource Utilization (ISRU) or Indigenous Space Materials Utilization (ISMU). By providing a central focus, the Center has served a wide range of NASA needs in this important field of space technology development.

A team of outstanding scientists and engineers devoted to continuing work in the field has been assembled and many publications of their work issued. A large number of dedicated graduate and undergraduate students have been trained and a number of popular new space science and engineering courses and degree options introduced to the University of Arizona's curriculum. Annual symposia and several specialized workshops of high quality have been sponsored by the Center. And every major aerospace industrial organization in the country has become involved in supporting the Center's program.

The key element in our philosophy of research is emphasis on a practical approach, interweaving engineering and science skills and knowledge. The hands-on training emphasized in the Center's research projects has attracted an excellent corps of graduate and undergraduate students. Our strong commitment to education is also inextricably interwoven with all SERC activities. After screening for scientific soundness — which often involves separate science projects — technical feasibility is established through preliminary research. The next step is thorough testing of the components and assembled systems under anticipated operating conditions. Data from such testing are mandatory for proof-of-concept, and are obtained from carefully designed testbeds.

The testbed approach involves the principal processing unit and supporting components assembled in a single small system. Lessons learned from experiments performed on this are then used to design and operate larger scale testbeds. Two are
NASA Grant
Year Renewal of the Basic
Supporting Proposal for A Live-
By of the Space Apparate in our
Farm, as well as Lo the Econo-
Region and Development Pro-
1 to the Nation's Space Explo-
Industrial Outreach Activities
Research, Educational, and
Contributions of the Centers
Year are noted. Details of the
accomplishments of the last
Center is changed, and major
the historic course of the
In the sections that follow,
industry, and Government
SERC the major meeting place for space resources research interests in academ,
while technologies and hardware. Our efforts in this regard have made U/NASA
with private-sector industry in the development of technologies and economically
Major benefits derived from our research projects include the opportunity to work
specifications are preserved.
It is incorporated in a breadboard of a realisitically packaged system and production
until it reaches the proper soil. After a complex physical phase these two minerals,
on from carbon dioxide and water: another for the production of oxygen and water-
currently in operation at the Center: one for hydrogen, and methane produce.
HISTORY AND PURPOSE

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 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 NASA center of excellence allows the University of Arizona to utilize its talented faculty for the benefit of the U.S. Space Program and ultimately for a better society.

— Michael Cusanovich
Vice President for Research and Graduate Studies
University of Arizona
The role of the U/NSA Space Engineering Research Center (SERC) is to develop aerospace engineering departments.

National efforts were started here in the mid-1980s in the University of Arizona's Aerospace Engineering Department. Several space-related activities have been found in Tucson, the space business center, in the regions of observatories and related sciences. In Tucson, the University of Arizona and the Tucson Basin together on space-related projects. Tucson and Arizona contribute a world-renowned reputation of knowledgeable scientists and engineers with a long tradition of successful, demonstrating broad capabilities.

The proposal submitted by the University of Arizona was faced many challenges, including the following:

1. Operations began here in early May 1988, one year after the University of Arizona's proposal was received.
2. The University of Arizona, one year after the proposal was received, was awarded Center funding for a minimum of $500,000.
3. The center would respond to NASA proposals directly, enabling significant contributions to the university and its associated research institutions.
4. The center's initial budget was $500,000.
5. The center would focus on research and development activities.
6. The center's initial budget was $500,000.

Tucson is a growing center of space-related activities, a modern city with a rich cultural heritage and unique arts.
materials and sources of energy that occur naturally in near-Earth space — thus the Center's subtitle: "for Utilization of Local Planetary Resources." This mission is fundamental to accelerating progress in space exploration and making space development activities economically feasible.

From this charge has grown a unique program of research and instruction dedicated to the use of space resources for propellants, and structural and shielding materials. In the little more than four years since UA/NASA SERC was established, a tightly integrated group of research and development projects in engineering and science has been created. The UA Center is the only place in the nation where In-Situ Resource Utilization (ISRU) is being reduced to hardware and engineering practice. A strong emphasis on student involvement in research projects has produced a remarkable level of enthusiasm, dedication, and creativity. As a result, the Center has drawn an excellent group of bright and energetic graduate and undergraduate students.

Another part of the Center's emphasis on education involves outreach to the community. SERC investigators give numerous lectures at elementary schools and high schools in Tucson and the surrounding area, featuring current information on national space activities and demonstrations of high-tech devices developed and used at the Center. Local middle school and high school interns often participate in SERC programs.

Central to the overall SERC mission are collaborative projects with private-sector industry partners to develop strategies and hardware for resources utilization in future space ventures. Despite federal budget uncertainties and a lack of NASA funding for the Space Exploration Initiative (SEI) in recent years, and the consequent
The University of North Dakota’s Rockwell International, Eclectic Daniel and a number of other aerospace companies, such as Rockwell International, have received enthusiastic support from organizations such as universities, and from space enthusiasts and other fields. The center has also received more than $200,000 in the form of research support from external sources, including the aerospace and other industries. The center has also received support for external research. The center has been a key player in the field of aerospace, industry, and government agencies. In the process of developing these relationships, the center has been recognized as a production leader in the field of space technologies, especially notable in this regard is the loan of Hamilton Standard Division's Micrometal Division, which is one of the largest and best manufac-
of consulting firms. A formal report was published based on the discussions and papers presented at the MISM Workshop. Also, in February 1992, the Center's Third Annual Symposium was held. The program was organized around a possible Lunar Outpost scenario, and featured industrial technologies, systems, and components applicable to the extraction, processing, and fabrication of local materials. The Symposium, like the MISM Workshop, brought together representatives from academia and industry, but in addition to the customary space resources experts, investigators from outside the field whose knowledge could be applied to space development activities were included. Presentations came from a diverse group of specialists in fields such as minerals processing, environmental control, and communications. What resulted was a fresh look at a number of old problems, as well as a variety of new ideas and approaches.

A collection of abstracts was published for attendees at the Symposium, and the Proceedings volume containing all papers presented will soon follow. Since its founding, the Center has published a popular quarterly newsletter, featuring articles by SERC investigators and an annual issue devoted to student papers, and, of course, the Center regularly publishes progress reports containing technical information on its research and development projects.

As a center for space resources research, a leader in education, a partner with private-sector industry in the development of new technologies, and a forum for space experts and others with relevant knowledge, the University of Arizona/NASA SERC has in four short years become what a NASA spokesman recently termed one of the leading Centers in the University Space Engineering Research program.

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Arizona and the University of Arizona/NASA Space Engineering Research Center have long been national leaders in the aerospace industry. SERC's academic mission will ensure our State has an ample supply of well-trained space professionals and its active research will ensure that we have developed the necessary technologies to utilize newly discovered space resources. If Arizona is to maintain its legacy of leadership in the aerospace industry in the 21st century, SERC will indeed play a vital role.

— Senator Dennis DeConcini
The fundamental plan for SEIK engineering programs continues to focus on the many technologies that have reduced to working hardware, many of these important space centers. This research is needed to support the U.S. Space Agency (NASA) in its efforts to develop and use space technologies. While fundamental research is needed before committing to space missions, it is important to keep this research and the results of the research on the front burner and usable. The basic resource utilizations, or courses, of the University of Arizona, dedicated specifically to such efforts, should receive much needed attention. The basic resource utilizations, or courses, of the University of Arizona, dedicated specifically to such efforts, should receive much needed attention. The basic resource utilizations, or courses, of the University of Arizona, dedicated specifically to such efforts, should receive much needed attention.
inputs/outputs and critical internal variables, diagnostics, and emergency shutdown in an orderly manner were also demonstrated. Moreover, 4-cell and 16-cell units capable of much higher rates of production were assembled and tested.

— Robotic handling of materials processing modules was initiated in the spring of 1992. Subsequent work resulted in the detailed design and modelling of a miniaturized self-contained processing module for small-payload precursor missions to the Moon and Mars. This lander unit utilizes an automated arm for sample collection, an intelligent control and communications system, and concentrated solar heating. The project was featured in Space News and was well received at the Artemis workshop in February 1992. Because the technology is crucial for many future ISMU units, the project is being continued.

The 16-cell oxygen plant, which produces 0.2 kg of oxygen per day, in operation.

Full-scale mock-up of the oxygen plant (kg/day class)

Scale model of the proposed lunar lander
Dean, College of Engineering & Mines

Ernest J. Smerdon (Member, National Academy of Engineering)

Many human benefits from space engineering are now being realized. While development of advanced space missions and technologies, tech devices, developed by bright students, these are the humble of economical space missions and satellites.

As a result of carbon layers on particles of lunar material — demonstration of 200% increase in the cataphoretic reduction of an iron bearing silicate-chlorophyl.

Experiments exhibit an improvement of several orders of magnitude in dust/particle emissions — proof that less sensitive of lunar soil with small amounts of metallic additives, recrystallized at moderate silicon-based polymers from indigestible lunar material.

Experiments in processing of glass ceramics from lunar resources established the feasibility of producing for, including direct enhancement by solar radiation absorption — demonstration of an apparent 800% increase in the conversion rates of invisible in a plasma-augmented react.
The SERC science program is dedicated to the discovery and characterization of non-terrestrial resources, defining the natural materials and environments within which processing of these resources can occur, and to screening candidate processing schemes and transportation system architectures for the retrieval of these resources and delivery to their site of use.

During the past year we have reached a number of milestones in the science program. Prof. Singer and his co-workers in the Planetary Image Research Laboratory have completed an ambitious project for mapping the titanium abundance (limonite content) of the Near basin, on the near side of the Moon. Prof. Lebofsky and Dr. Nelson have developed a technique for determining the interpretation of asteroid and lunar spectra. Prof. Haskin and Dr. Cobson (at Washington University) are now undertaking a scale-up of their apparatus designed to extract oxygen from lunar regolith materials by melt electrolysis using platinum electrodes, and are working on the problems of container stability and electrode consumption. Prof. Freiser and Dr. Muradhan have developed a compact system and efficient procedure for extraction and separation of platinum-group metals to recover and recycle the lost electrode materials.

Prof. Lewis and Mr. Jenkins have made substantial progress in understanding the extraction of ferrous metals from cathode electrolysis deposits, limonite reductions, cathodic products, and magnetite extracts of lunar and asteroidal regoliths via low-temperature iron and nickel volatilization.
The 0.9-meter Speckwaich Telescope

Arizona Telescope Hill 0.9-meter Telescope North is approximately in upper left.

Lunar landscape: Image of western-facing Tranquillo like at 708 m with University of Arizona Telescope Hill 0.9-meter Telescope.

An eclipse in edge of Earth-apparent disks of Earth-approaching objects of our knowledge of the apparent Speckwaich is limb in the gap asteroids are observed. The nearest and smallest now discovered more than 26 near-Earth asteroids, including this new discovered more than become fully operational, and the Spectroscopic program has reduced scheme.

Carbonyls: The CO beam would into a CO-CO$_2$ full kinetic energy.
diameter range, confirming a dramatic excess of bodies less than about 30 m in diameter relative to a linear extrapolation of the Belt asteroid population line.

A detailed Monte Carlo simulation of the comet and asteroid bombardment of the Earth has been developed by Prof. Lewis which incorporates our new data on the numbers and compositions of these bodies. This model permits a new assessment of the hazards of Earth-crossing bodies from data originally collected to assess their resource importance.

Prof. Ganguly and Kunal Bose have developed equipment and procedures for studying the dehydration behavior of water-bearing minerals and applied their technique to the study of the dependence of outgassing rate on mineral grain size. Also, our improving understanding of the abundance and extractability of water in near-Earth asteroids has permitted a study of the transportation-system implications of the availability of large amounts of water in near-Earth space. This study demonstrates mass payback of roughly 100 tons of water returned to Earth orbit per ton of equipment launched from the Space Station for multi-flight missions to known near-Earth asteroids, and suggests that the most attractive resource in the inner solar system may be asteroidal water.
Congressman Jim Kolbe

The economic future of Tucson and Southern Arizona may well be linked to the development of space technologies. The University of Arizona is part of this exciting new phase.

ECONOMIC IMPACT
The University of Arizona/NASA Space Engineering Research Center plays a key role in making our state a center for space activities. The team of engineers and scientists associated with the Center has created a strong program of research and instruction in space sciences. Along with its academic mission, the Center also actively seeks the involvement of private-sector industry in the development of commercially viable space technologies. This union of academia and industry, in turn, generates a major spin-off effect on the regional economy by advancing the region's economic base and improving the economic prospects of the state.

The Center has demonstrated its value to the regional economy by advancing the region's economic base and improving the economic prospects of the state.