1990 25TH Intersociety Energy Conversion Engineering Conference

Vol. 1

IECEC-90
August 12-17, 1990
Reno, Nevada

Participating
Societies

PROCEEDINGS OF THE 25th INTERSOCIETY ENERGY CONVERSION ENGINEERING CONFERENCE

VOLUME 1

Aerospace Power Systems
Space Power Requirements and Issues
Space Power Systems
Space Nuclear Power
Automation
Power Electronics
Burst and Pulse Power
Power Management and Distribution
Space Energy Conversion
Space Solar Power

Editors:
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"Energy and the Environment: A Continuing Partnership"

THE 26th INTERSOCIETY ENERGY CONVERSION ENGINEERING CONFERENCE

Boston Marriott at Copley Place • Boston, Massachusetts • August 3-9, 1991

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Call for Papers

The American Nuclear Society (ANS) announces the 26th Intersociety Energy Conversion Engineering Conference. As in prior years, IECEC-91 will deal broadly with energy conversion systems, advanced energy systems, unconventional energy systems and devices, and also with energy policy implications for research, development, and utilization of technologies. Papers on all engineering aspects and disciplines of terrestrial power, advanced energy, and aerospace power and propulsion systems are welcome. Both ground power and aerospace power systems will be featured in IECEC-91 sessions covering the topical areas listed below. Special sessions directed to broad areas of technical and policy interest will also be included.

The IECEC series is sponsored jointly by seven participating societies. In addition to the ANS these are: the Society of Automotive Engineers (SAE), the American Chemical Society (ACS), the American Institute of Aeronautics and Astronautics (AIAA), the American Society of Mechanical Engineers (ASME), the Institute of Electrical and Electronic Engineers (IEEE), and the American Institute of Chemical Engineers (AIChE).

1991 IECEC Topical Areas

Aerospace Power Systems
Automation
Burst and Pulse Power
Computer Simulation
Environmental Effects
Power Electronics
Power Management and Distribution
Space Energy Conversion Technologies: Static and Dynamics
Space Nuclear Systems
Space Power Requirements and Issues
Space Station Power
Thermal Management

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Thermionics
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Batteries for Aerospace Power
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Energy Systems Alternative Fuels
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Greenhouse Effects on Energy Choices
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Solar Thermal Energy
Wind Systems

Stirling Engines and Application

Systems and Cycles
Fossil Fuel Systems and Technologies
Marine Energy
Nuclear Fission and Fusion Systems

Instructions for Submission of Abstracts

Four copies of each abstract should be submitted to the address below by **December 14, 1990**, for review by the Program Committee. Submissions dealing with any topic within the scope of the IECEC series will be considered. **Abstracts should be about 500 words in length and include sufficient information to explain and support the NEW and SIGNIFICANT results to be presented in the proposed paper. The topical area appropriate to the abstract and the name and address of the author to whom correspondence should be addressed must be clearly stated at the top of the first page.**

Authors will be notified of abstract acceptance and will receive instruction kits for manuscript preparation in early February 1991. The deadline for the receipt of finished manuscripts is **Monday, May 10, 1991**. Only accepted papers published in the IECEC-91 Proceedings will be presented at the Conference.

Four copies of abstracts should be submitted to:

Dr. Patrick G. Bailey
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555 North Kensington Avenue
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Abstracts Due: December 14, 1990

Final Manuscripts: May 10, 1991

25th Intersociety Energy Conversion Engineering Conference

Bally's Hotel, Reno, Nevada

August 12-17, 1990

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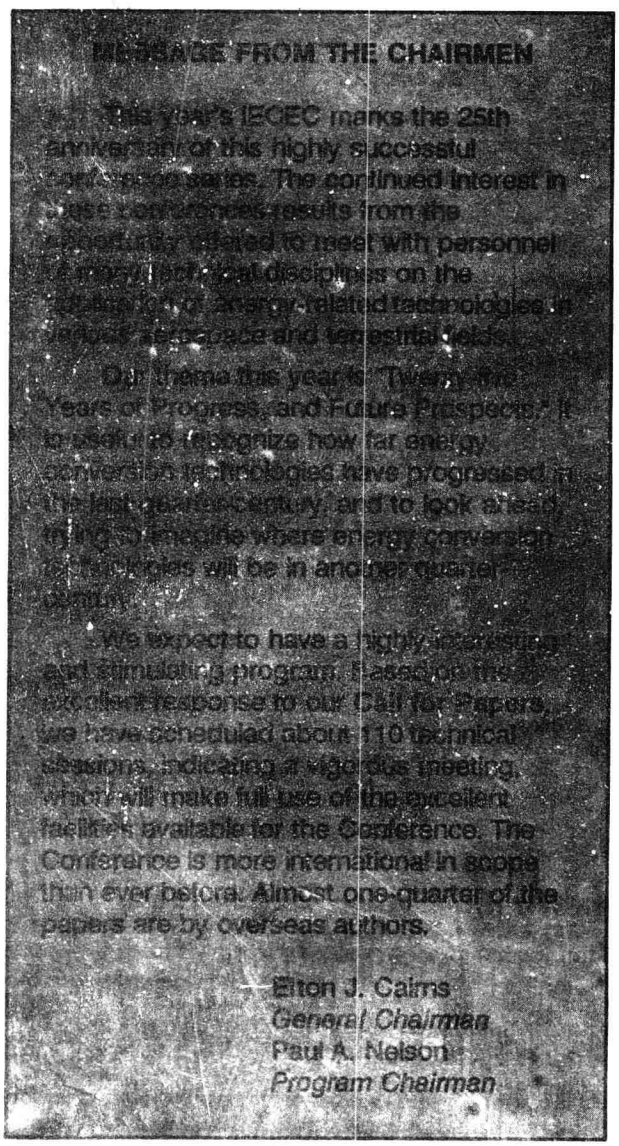

MESSAGE FROM THE CHAIRMEN

This year's IECEC marks the 25th anniversary of this highly successful conference series. The continued interest in these conferences results from the opportunity related to meet with personnel in many technical disciplines on the advancement of energy-related technologies in various aerospace and terrestrial fields.

Our theme this year is "Twenty-five Years of Progress, and Future Prospects." It is designed to recognize how far energy conversion technologies have progressed in the last quarter-century, and to look ahead in time to a decade where energy conversion technologies will be in another quarter-century.

We expect to have a highly informative and stimulating program. Based on the excellent response to our Call for Papers, we have scheduled about 110 technical sessions, indicating a vigorous meeting. Attendees will make full use of the excellent facilities available for the Conference. The Conference is more international in scope than ever before. Almost one-quarter of the papers are by overseas authors.

Elton J. Cairns
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Dr. Robert E. Wilson, Oregon State University

PANEL SESSIONS

Wednesday, August 15, 2:30-5:00 p.m.
"History of Space Power"
Chairman: A. W. Adam, Sundstrand ATG

Wednesday, August 15, 2:30-5:00 p.m.
"Solar-Power Vehicles: Results of the GM/DOE/SAE Sunrayce"
Chairman: R. P. Larsen

PREFACE

The 1990 IECEC continues many trends of the recent past. The Conference is becoming increasingly international in scope and this trend is reflected in our appointing Overseas Coordinators for the second year and in the many overseas papers contained in this year's *Proceedings*. A new organizational level, that of Topical Coordinator for major topical areas, was formally designated. With their help, we involved a larger number of Topical Organizers than in the past and, thus, maintained a high level of organizing effort by experts in many separate technical areas. We believe the result has been a more interesting conference with better attendance.

There has been a greater use of computer programming in planning the Conference than in the past. For the second year, Business Assistants of Gaithersburg, Maryland, has carried out this effort. Their very cooperative efforts have made possible close communications between the Organizers and the technical committee in expediting the preparation of abstracts and papers. A data base was prepared beginning with the receipt of the first abstracts and this data base was used in the publishing of the Preliminary and Final Programs and the table of contents and the Indexes of the *Proceedings*. An overview of the table of contents is given on the copyright page of each volume. Also, each volume contains its own detailed table of contents.

The Indexes were prepared by a new method this year. The data base developed in tracking the paper was employed in organizing the index. The index headings under which the papers are listed were revised from the set used in previous years. Also, the references for both the subject and author indexes are more complete than in the past, providing the year, the volume number, and the page number on which the article begins. Unfortunately, with these changes it was possible to include references only for papers presented in 1989 and 1990. In the future, it is expected that the IECEC *Proceedings* will again include references for four years, as in the past.

Editors:

Paul A. Nelson
William W. Schertz
Russell H. Till

CONTENTS

NOTE: Please check Post-deadline Section in Volume 6 for any missing papers.

AEROSPACE POWER SYSTEMS

SPACE POWER REQUIREMENTS AND ISSUES—SESSION 1.1

SPACE POWER SYSTEMS 1—SESSION 2.1

SPACE SOLAR ARRAY TECHNOLOGY—SESSION 10.1

ADVANCED SPACE SOLAR CELLS—SESSION 10.2

SPACE SYSTEMS REQUIREMENTS AND ISSUES: THE NEXT DECADE

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ABSTRACT

This paper describes some of the more important space power technology issues, requirements and challenges as we enter the decade of the 1990's and provides an assessment of the impact of new component technology on the overall performance of space power systems. The paper emphasizes advanced component, subsystem and system technologies which will "make a difference" for the future in terms of the performance, reliability and survivability of next generation baseload and burst mode space power systems. The paper primarily addresses technology disciplines related to power sources (solar/nuclear and chemical), power conversion, energy storage, power conditioning/distribution and control and waste heat acquisition, transport and rejection. For some of these technology disciplines, performance trends are developed which can be used as the basis for projecting future, advanced power system performance. Performance capabilities for several different types of space power systems for both baseload and burst mode applications are postulated based on evolving technology and point designs which incorporate projections of advanced component capabilities.

SPACE POWER REQUIREMENTS

Civil and military space missions during the next decade will require reliable sources of electrical power. Figure 1 shows the projected trends in space power requirements for both baseload (station keeping power) and for burst mode "special application" loads. Baseload requirements must be met with long life power systems which can supply the station keeping power demands of satellites for periods ranging from 5 years in low earth orbit to 15 years in geosynchronous orbit. For the majority of future missions, typical baseload power requirements will fall in the range from 5-100 kilowatts. Burst mode power requirements may be met by short duration power systems which only have to operate for a few thousand seconds to meet the energy demand of "special application" loads. These "special application" load power requirements range from tens to hundreds of megawatts.

POWER SOURCE OPTIONS

As shown in Figure 2, the power source options are Solar (Photovoltaic Arrays and Solar Dynamic), Nuclear Reactor (Static and Dynamic), Chemical (Turbogenerator), Electrochemical (Batteries and Fuel Cells) and Radioisotope (Static and Dynamic). Only solar, nuclear and radioisotope source options are viable candidates for long duration (5-15 year) space missions. Figure 3 shows a range of mission orbits and pertinent orbital parameters which must be known for sizing the solar array and energy storage elements of solar array/battery power systems. Of course, the other important considerations are the natural radiation environment which will be encountered during the mission lifetime and any overdesign for system penalties induced by compensation related to a military threat environment. Figure 4 shows the state-of-the-art (SOTA) and projected performance of baseload (long duration) power systems.

Chemical turbogeneration and Electrochemical energy sources (high power density fuel cells and batteries) can provide very high levels of power on demand but can only be used as power sources for very short duration missions due to their weight. The useful operating time of these sources for short duration missions depends on total energy requirements the product of power and time which may range from 3.0E05 to 1.6E09 kilojoules.

SNAPSHOT OF CURRENT PROGRAM

The current Air Force space power program includes research and development efforts covering a wide range of advanced space power system components, subsystems and systems. Much of the ongoing work is directed toward innovative solutions which push the state-of-the-art in virtually every technology discipline. The work addresses both baseload and burst mode power. At the forefront of the program are efforts to (a) develop large area (6 cm x 6 cm), 20 percent efficient gallium arsenide on germanium solar cells and demonstrate their produceability (b) multiple bandgap cells at 30 percent efficiency (c) sodium-sulfur batteries which can deliver 100 watt hours/kilogram in the near term (CY1995) and 200 watt hours per kilogram in the far term (CY2000) (d) a factor of two or more reduction (from 10-15 kilograms per kilowatt to 3-5 kilograms per kilowatt) in power conditioning distribution and control weight for baseload power (e) forty percent reduction in the weight of survivable radiators from 10 kilograms/square meter to 6 kilograms/square meter (f) hyperconducting (hydrogen cooled) alternators that weigh only .03 kilograms/kilowatt and (f) advanced dielectrics, capacitors and semiconductor power switches that enable .05-.08 kilogram/kilowatt high power inverters.

PHOTOVOLTAIC TECHNOLOGY

Figures 5, 6 and 7 illustrate three advanced solar array/battery power system concepts in current development under the Survivable Power Subsystem Demonstration (SUPER) program. The SUPER program is a phased advanced development program which began in August/September of 1988 and will culminate in the space flight qualification and orbital flight test of an advanced solar power system for Strategic Defense Initiative and Air Force applications by 1994.

In the meantime efforts are in progress on advanced gallium arsenide on germanium solar cells, multiple bandgap solar cells and sodium-sulfur batteries that will offer significant improvements in system specific power (watts/kilogram). These projected improvements, which are based solely on advanced component technologies, are illustrated in Figure 8.

ENERGY STORAGE TECHNOLOGY

Typically, the heaviest component of a solar array/battery power system is the energy storage element needed for eclipse operation;