THE UCSD
CENTER FOR ENERGY RESEARCH
– CHARTING THE COURSE FROM 2005 – 2010

Submitted by the

Center for Energy Research
University of California, San Diego
Jacobs School of Engineering

January, 2001

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Executive Summary

There are vital national and international needs for long-term, reliable energy supply options with attractive environmental features. Recent developments in California clearly indicate the importance of reliable energy for the state's economy and well being. The Center for Energy Research is making nationally recognized contributions to fusion and combustion energy research. The Center plans to expand its research activities into the energy policy/assessment field and selected aspects of alternative energy options (e.g. fuel cells). These activities will be closely coordinated with related environmental and other policy studies on the campus leading to much expanded multi-disciplinary research opportunities at UC San Diego. This research will also greatly help the university, Jacobs School of Engineering, and academic departments meet growth goals for graduate student education over the next decade.

1.0 Vision for the 21st Century, Goal, and Objectives

Humankind needs ever increasing acceptable sources of energy to experience a fulfilling quality of life. Energy availability plays an essential role in the overall well-being and security of the world and each of its nations. As world population and energy consumption (particularly in less-developed nations) continue to grow and concerns about global environmental impacts increase, there is a vital need for long-term, available and reliable energy supply options with attractive environmental features. Reliable energy supply is also a key issue on a regional and local basis, as witnessed by recent developments in Southern California. The Center for Energy Research (CER) at the University of California, San Diego was created to foster research and educational activities devoted to critical energy needs.

The Center for Energy Research provides an academic research unit for interdisciplinary interactions among UC San Diego faculty, research staff and students aimed at promoting and coordinating energy research and education. The CER complements academic departments of instruction and research with an emphasis on bridging the various disciplines related to energy research on the campus. The CER also provides a vehicle for developing other dimensions of energy research, including energy policy, economics and ecology.

The overall goal of the CER is to continue to be internationally respected and nationally recognized as a center of excellence in energy research as well as the leading center of energy expertise in the Southern California region. Current research areas emphasize plasma and fusion energy sciences, fundamental and applied combustion science and selected topics in alternative energy technologies and in energy policy issues. Future expansion is planned especially in these latter areas.

The specific objectives of the CER are to:

- Advance the knowledge needed to develop essential environmentally friendly and reliable energy alternatives.
- Provide an inter-departmental coordinating function for energy research groups and projects at UC San Diego.
- Enhance the prospects of extramural research funding involving inter-departmental and multi-disciplinary collaborations in energy research.
- Promote the visibility of energy topics in undergraduate and graduate programs at UC San Diego.
- Provide a mechanism for interacting with other institutions involved in energy research with particular attention to potential industrial partners.
- Promote the visibility of energy research at UC San Diego to potential sponsors and funding agencies.

2.0 Research Thrusts and Opportunities

The research opportunities in energy are very challenging and broad. The research portfolio of the CER seeks to provide a balance between breadth of national and regional interests as well as a focus on topics of high intellectual challenge which build on technical strengths at UC San Diego. A key measure is to be world leaders in selected, high-leverage research areas, which provide robust opportunities for diversified funding sources. Research topics are also selected which foster multi-disciplinary approaches. There is a particularly strong connection with environmental research at UC San Diego.

Over the next decade, the CER is envisioned as having three principal themes:

- plasma and fusion energy science
- fundamental and applied combustion science.
- alternative energy technologies and energy assessments

The first two themes are well established and have an excellent future with many opportunities for new and/or expanded research tasks. The third theme is in a formative phase and needs to grow over the next decade.

2.1 *PLASMA AND FUSION ENERGY SCIENCE*

Everyone is familiar with three states of matter - solids, liquids, and gases – and the way in which matter can change between these forms. However, most of the universe is composed of matter which is in a completely different state: the Plasma State. Plasma is distinguished from the other more familiar forms of matter by the fact that it is ionized – that is, the atomic nuclei which compose the plasma have been stripped of some or all of their

electrons. The plasma medium is extremely useful for scientific and technological applications such as nuclear fusion, materials processing, astrophysics, and nanometer-scale manufacturing.

Scientists and engineers in the CER are actively exploring the fields of applied plasma physics and fusion energy. Energy production via the merging of hydrogen nuclei into helium, a process known as nuclear fusion, holds the promise of a long-term energy solution for mankind with potentially less environmental impact than other long-term energy sources. However, turning this promise into reality is an extremely challenging task which requires continual progress in experimental, theoretical, and computational research. Scientists must learn how to create and confine a fusion plasma at temperatures exceeding 100,000,000 deg C. CER scientists work on methods using both magnetic fields and high-power lasers (inertial fusion). CER scientists are contributing to this task by studying how to confine such plasma more efficiently, understanding how heat and particles escape from such plasmas, and then helping to devise the means to reduce or eliminate these loss mechanisms. CER scientists develop new theories and use state-of-the-art computers to model these processes. Once a fusion-grade plasma has been created, at some point it comes in contact with material surfaces. The resulting interface between hot fusion-grade plasmas and the outside world provides a number of technical challenges which CER scientists and engineers are also addressing via on-campus experiments as well as via off-site collaborations. CER scientists and engineers lead a nation-wide effort aimed at evaluating the technical and economic feasibility of fusion energy power plants. Results from such studies are then used to guide the choice of future world-wide fusion research efforts. The CER also hosts a nationally-based Virtual Laboratory for Technology for fusion energy research.

The CER also hosts the Department of Energy's (DOE) Virtual Laboratory for Technology (VLT) for Fusion Energy Sciences. This is a national endeavor responsible for coordinating all fusion technology and materials activities in the U.S. – an enterprise that includes many universities, national laboratories, and industries. The VLT is responsible for coordinating national activities of the DOE with an annual budget of about $35M.

Plasmas-based technologies also form the basis of one of the key enabling technologies of the information economy. For example, plasma etching and deposition techniques are used to manufacture wireless, computer, information display, and Internet hardware devices. In addition, the use of plasmas in these key technologies is likely to increase in the future. For example in the next 5-7 years, plasma-based soft x-ray light sources will likely become the dominant technology for imaging the circuit design pattern into nano-scale integrated circuits. Thus plasmas are a key enabling technology for the information revolution now underway. Research at the CER focuses upon several aspects of this critical application including plasma chemistry, plasma and neutral gas interaction issues, and next-generation plasma process reactor research.

2.2 *FUNDAMENTAL AND APPLIED COMBUSTION SCIENCE*

Improvements in energy use and combustion are becoming increasingly important as the finite supply of fossil fuels decreases. The CER is concerned with research advancing abilities to utilize fossil-fuel resources properly. A central objective is to determine how to burn fuels more cleanly, efficiently and safely. Ramifications extend to considerations of fire safety, air pollution, waste incineration, greenhouse-gas reduction, ozone depletion and vehicle propulsion on the earth's surface, in the air and in space. A myriad of evolving societal problems can benefit from the knowledge being developed in combustion research.

Examples of ongoing research in combustion-related areas are projects in mitigation of combustion-generated air pollution, propellant combustion and combustion instability, control of initiation and propagation of detonations in pulse-detonation engines, incineration of toxic and non-toxic waste materials, and finding replacements for halogen-containing fire suppressants to reduce ozone depletion. On the applications side, CER addresses important societal problems such as the efficient use and production of energy, the design and propulsion of airborne and waterborne vehicles, water quality and reclamation technology, aspects of materials processing, including self-propagating high-temperature synthesis, and practical uses of catalysis.

2.3 *ALTERNATIVE ENERGY TECHNOLOGIES AND ENERGY ASSESSMENTS*

The Center for Energy Research evolved from the Center for Energy and Combustion Research which, in turn, grew out of the UCSD Energy Center, established officially as an ORU in 1974, with Professor S.S. Penner as Director. The original mission was to contribute to meeting university, state, national and international needs in energy-related areas by addressing fundamental problems pertaining to the development of energy resources, applications of combustion in energy and propulsion, environmental concerns associated with energy production and toxic waste, and economic aspects of energy management, including related sociological and policy issues. This mission was pursued through research, education and public-service activities involving professors, students, resident researchers, visitors and external collaborators. In a sense, the CER is returning to its roots in the original Energy Center. The wide-ranging impact of energy developments calls for a cross-disciplinary approach to addressing the many issues that impinge on the CER mission.

The CER goal will require broadened funding and could result in development of additional activities in some of the following areas:

- Energy Production in Fuel-Cell and Hybrid Systems
- Development of Renewable Energy Technologies
- Economics of Energy Needs and Resources
- Fossil Fuel Recovery and Use
- Air Pollution from Fuels and Combustion

- Studies of Energy Conservation
- Environmental Effects of Trace Species
- Toxic Waste Disposal
- Mitigation of Greenhouse Effect

Strengthening the CER presence in any of these areas would increase the interdisciplinary character of the center and broaden its impact on policy issues.

Many of these topics are closely associated with environmental research issues and thus offer excellent opportunities for collaborative research between scientists in the CER and environmental research programs; e.g., Prof. Paul Linden (MAE) and the Scripps Institution of Oceanography.

3.0 Teaching Contributions

The CER teaching activities are closely coordinated with research. Graduate students are involved in theoretical, computational and experimental work associated with the specific topics of research identified above, and the most thorough and definitive presentation of results often appears in the theses of graduate students. Undergraduate students also participate in the laboratory research. The teaching involves extensive individual contacts of students with professors and research staff. In today's rapidly changing world, there is need for disciplinary flexibility and international exposure in education. The students associated with CER achieve this through contacts and travels outside UCSD. Students and researchers associated with universities throughout the U.S. and the world spend periods of time in research at CER, and UCSD students in CER often pursue part of their thesis research at these external institutions. The cooperation provides an important broadening of perspective.

Formal courses of instruction are associated with CER at both the undergraduate and graduate levels in the MAE and ECE departments. There is a four-quarter undergraduate sequence in energy, covering thermodynamics, energy from fossil fuels, nuclear-fission energy and nuclear-fusion energy. Enrollments are typically around thirty students per course per year. A larger number of graduate courses are given in the discipline areas of fluid mechanics, gas dynamics, heat and mass transfer, combustion, propulsion, turbulence, numerical and mathematical methods, and plasma science and engineering. These courses are taken by most of the graduate students in CER. There are, in addition, a number of CER seminars, including a regular summer seminar series and different special seminar series throughout the year. By attending these seminars students extend their knowledge outside their immediate area of specialization.

Expansion of these teaching programs would occur in connection with the proposed expansion of CER. If, for example, an appointment in energy policy was made, then additional seminars and courses would be instituted. The extended teaching activity would apply mainly

at the graduate level and would greatly increase the cross-disciplinary components of CER, leading to beneficial influences on a wider range of societal endeavors.

4.0 Interdisciplinary Interactions

Energy research is by its very nature a multi-disciplinary research endeavor. Such research not only offers many opportunities for collaborative work across many disciplines, but it requires such an approach to be successful. The CER brings together faculty, researchers and students from across a broad range of disciplines: applied mathematics, physics, chemistry, oceanography, meteorology and economics, as well as mechanical, nuclear, aerospace, civil and chemical engineering. At present, the vast majority of faculty, research staff and students come from the Department of Mechanical and Aerospace Engineering (MAE); the Department of Electrical and Computer Engineering (ECE); the Programs in Chemical Engineering; and the Graduate Program in Materials Science. Experimental, analytical and computational research methods are used to study chemical and physical aspects of combustion and fusion phenomena. Collaborative study of problems using all three of these basic methods is a particular goal of the CER.

There is need to expand CER activities, to add to its internationally recognized plasma/fusion research and fundamental combustion research augmented components that are more active in renewable energy, environmental effects and energy and environmental policy. This expansion would enhance the interdisciplinary character of CER beyond the Jacobs School of Engineering to include, for example, elements in International Relations Pacific Studies (IRPS), Scripps Institution of Oceanography (SIO), the San Diego Supercomputer Center and the Departments of Economics, of Mathematics, of Physics, and of Chemistry and Biochemistry.

5.0 Resource Needs

Currently the CER has an annual budget of $6.84M which comes from several funding agencies; e.g., NSF, DOE, NASA, ORNL, LLNL, ONR, UC SMART, UCOP, UCEI and General Atomics Co. The CER has nine affiliated faculty, 20 research and post-graduate research staff, 14 affiliated graduate students and 16 laboratory and administrative staff for a total participation of about 60 people. The Center staff and laboratories currently occupy about 13,000 s.f. of space mainly in Engineering Building Unit II.

The five and ten-year projections of Center funding, faculty, staff, students and space are summarized in Table 1. The indicated growth in research expenditures is considered very achievable given anticipated growth in the fusion and combustion areas along with a broadening of Center activities in the direction of alternative energy technologies (e.g., fuel cells) and/or

energy assessment studies. Growth in research and support staff will track this projected growth in funding.

Table 1. CER Resource Summary

	2000 (Current)	2005 (Projection)	2010 (Projection)
Research Funding	**$6.8M**	**$10.0M**	**$12.0M**
Affiliated Faculty	**9.0**	**12.0**	**15.0**
Research Staff	**20.0**	**30.0**	**35.0**
Affiliated Graduate Students*	**14.0**	**35.0**	**50.0**
Support Staff	**16.0**	**22.0**	**26.0**
Space	**13,000 s.f.**	**19,000 s.f.**	**23,000 s.f.**

***It is assumed CER affiliated faculty will also have graduate students not associated with the CER.**

The present space occupied by the CER (previously designated for the CECR, provided by the MAE Department and by the JSOE Dean's Office) is fully occupied with no room for more staff and laboratories. As the CER research funding grows, commensurate growth in space will need to be provided. This will require about an additional 10,000 sf. of space over the next ten years.

It is proposed that the faculty affiliated with the CER be increased by three over the next three to four years and by a total of six (i.e., three more) over the next ten years. (See next section for proposed areas of research for new faculty members.) It is anticipated that the FTE's will not be allocated to the CER but will be allocated to a home academic department for each faculty member. The same approach will continue to be followed for graduate students. Thus, academic departments will be responsible for providing the space for faculty and graduate students.

Presently, the majority of the administrative staff (seven people) are paid out of research grants, which is not appropriate. Most, if not all, of the administrative staff should be paid out of Center funds received from the Office of the Vice Chancellor for Research. This will need to be increased, probably in a step-wise fashion, over the next three years.

6.0 Implementation Steps

To meet the research and teaching objectives described in the previous sections and to obtain the necessary resources, the following key steps will be pursued:

1. Work with appropriate departments to recruit the desired new faculty members in the following areas:

   - one senior faculty member to lead an area of fuel cells, renewable energy or energy assessment and policy studies.
   - a junior faculty member in the area of plasma-assisted nano-scale manufacturing.
   - a junior faculty member in computational plasma physics or laser-plasma interactions.
   - a junior faculty member in combustion chemistry.
   - a junior faculty member at the interface between energy and environmental research.

2. Work closely with faculty and staff engaged in environmental research, particularly coordinating activities with Prof. Paul Linden (MAE).

3. With academic departments, significantly expand recruiting efforts for graduate students affiliated with the CER.

4. Increase outreach activities to expand the visibility and effectiveness of the CER within and outside the campus.

5. Work with the VC-Research, JSOE Dean and department heads to obtain the necessary space for the expanded Center.

6. Obtain increased support from the VC-Research for administrative staff and increased recognition of their contributions.

7. Working with academic departments, develop and implement a strong curriculum on plasma and fusion science as well as general energy topics. (Combustion research topic already has a solid curriculum.)

Appendix A

CER Members & Affiliates

Members (M) and Affiliates (A) of the Center for Energy Research

Charles Baker	(M)	Adjunct Professor/MAE
David Benson	(A)	Professor/MAE
José Boedo	(M)	Research Scientist/MAE
Robert Cattolica	(M)	Professor/MAE
Leo Chousal	(M)	Senior Development Engineer/FERP
Robert Conn	(M)	Dean, Professor/MAE
Russ Doerner	(M)	Associate Research Engineer/ECE
Alvin Gordon	(M)	Adjunct Professor/MAE
Arthur Grossman	(M)	Associate Development Engineer/FERP
Rolondo Hernandez	(M)	Associate Development Engineer/FERP
Sergei Krasheninnikov	(M)	Professor/MAE
Juan Lasheras	(A)	Professor/MAE
Shui-Chi Li	(M)	Assistant Research Engineer/MAE
Paul Libby	(M)	Professor Emeritus/MAE
Stan Luckhardt	(M)	Research Scientist, Lecturer/MAE
Kurt Lund	(M)	Assistant Research Engineer/MAE
T. K. Mau	(M)	Research Scientist/ECE
Marc Meyers	(A)	Professor/MAE
David Miller	(A)	Professor/MAE
Ronald Miller	(M)	Project Scientist/MAE
Rick Moyer	(M)	Research Scientist/MAE
Farrokh Najmabadi	(M)	Professor/ECE
Vitale Nesterenko	(A)	Professor/MAE
Keiko Nomura	(A)	Assistant Professor/MAE
Stanford Penner	(M)	Professor Emeritus/MAE
René Raffray	(M)	Specialist/MAE
Sutanu Sarkar	(A)	Associate Professor/MAE
Ray Seraydarian	(M)	Associate Development Engineer/FERP
K. Seshadri	(M)	Professor/MAE
Massoud Simnad	(M)	Adjunct Professor/MAE
Daniel Sze	(M)	Assistant Project Scientist/MAE
Mark Tillack	(M)	Research Scientist/MAE
George Tynan	(M)	Assistant Professor/MAE
Xueren Wang	(M)	Staff Research Associate/FERP
Dennis Whyte	(M)	Associate Research Scientist/MAE
Forman Williams	(M)	Professor/MAE

Appendix B
CER Grants

FUSION ENERGY Research Division

Funding Source	Grant Title	PI	Current Funding ($)
GA	Divertor Materials Evaluation Systems (DiMES) Coordinator	Whyte	57,715
DOE	Edge Physics & Disruption Experiments on the DIII-D	Luckhardt, Moyer, Boedo	590,000
UC SMART	Physics & Chemistry of Next Generation Plasma Processing Reactors	Tynan	194,946
UC SMART	Study of Neutral Reactant and Etch By-Product Transport Mechanisms for Sub-100nm Plasma Processing	Tynan	171,875
DOE	PISCES Program: Advanced Fusion Materials & Plasma Science of Boundary Interactions	Conn, Luckhardt, Doerner	1,345,000
ORNL/ Battelle	National Compact Stellarator Experiment (NCSX)	Grossman	20,000
DOE	Controlled Shear Decorrelation Experiment (CSDE)	Tynan	140,000
DOE	Edge Physics Studies on the NSTX Spherical Tokamaks	Boedo, Moyer	188,331
DOE	Edge, SOL and Divertor Plasma Turbulence & Macroscopic Transport	Krasheninnikov	266,000
DOE	New Diagnostic for Boundary Plasma	Boedo	100,000
GA	Tokamak Edge Plasma Turbulence	Krasheninnikov	50,000
ORNL/ Battelle	Virtual Laboratory for Technology	Baker	650,000
DOE	Advanced Design Program	Conn, Najmabadi, Tillack	822,000
DOE	Analysis of High-Harmonic Fast Wave Current Drive & Heating in NSTX Discharges	Mau, Najmabadi	42,917
DOE	IFE Chamber Dynamics & Laser Propagation Simulations Tests	Tillack, Najmabadi	153,364
GA	IFE Target Injection & Tracking	Tillack	87,343
CEC	Improved Performance of Energy Recovery Ventilators Using Advanced Porous Heat Transfer Media	Tillack, Raffray	74,762
PPI	Advanced Heat Sink Material for Fusion Energy Devices	Raffray, Tillack	33,341
	Total Fusion Energy Research		**$4,987,595**

Appendix B (cont'd)
CER Grants

COMBUSTION Research Division

Funding Source	Grant Title	PI	Current Funding ($)
UCEI	Laser Raleigh Measurement of Temperature Across a Strained Flamelet at Ignition	Cattolica	24,600
SML	Torque & Stability of Bodies of Revolution in Low Speed Laminar Flow	Lund	2,500
Energy Sci	Heat Transfer Enhancement on Surfaces with Flocked Carbon Fibers	Lund	5,000
NSF	Chemical-Kinetic Characterization of Ignition of Fuels	Seshadri	225,000
ARO	Chemical-Kinetic Characterization of Autoignition and Combustion of Diesel and JP-8	Seshadri	100,000
U of Ill.	Globalization and Employability for Overseas Educational Exchanges	Seshadri	27,807
LLNL	Chemical-Kinetic Characterization of Autoignition and Combustion of Surrogate Diesel	Seshadri	43,000
ARO	Chemical-Kinetic Characterization of Autoignition and Combustion of Liquid Hydrocarbon Fuels	Seshadri	34,000
UCOP	Presidential Chair in Energy & Combustion Research	Williams	55,058
NASA	Stretched Diffusion Flames in Von Karman Swirling Flows	Williams	10,000
NSF	Theory of Combustion by Analytical Methods for Real Chemistry	Williams	91,000
NASA/ LEW	High-Pressure Combustion of Binary Fuel Sprays	Williams	34,620
ONR	Tailored-Injection, Variable-Frequency Pulse D	Williams	940,000
NASA	Dynamics of Droplet Extinction in Slow Convective Flows	Williams	7,865
NSF	Burning Velocities of Flamelets in Turbulent P	Williams	12,050
AFOSR	Combustion Processes & Instabilities in Liquid-Propellant Rocket Engines	Williams	89,049
NASA	Scientific Support for a Proposed Space Shuttle Droplet Burning Experiment	Williams	119,000
	Total Combustion Research		**$1,820,549**
	TOTAL CER GRANT FUNDING		**$6,808,144**