Summary of Energy Activities at Arizona State University

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INTRODUCTION

Arizona State University has a long history of energy-related research, teaching and service within several disciplines. These disciplines include Applied Biological Sciences, Architecture, Chemistry and Biochemistry, Construction, Engineering, Geography, Life Sciences, and Public Policy. This work has targeted theoretical and practical problems in such topics as power systems, electrical transmission, coal transport, wind and geothermal energy, nuclear energy, solar energy, hydrogen production, fuel cells, photovoltaic testing, energy efficiency construction, directional drilling, and the urban heat island.

This report outlines the research, teaching, and personnel that are directly related to energy topics or have a strong ancillary relationship to energy. For example, while power systems and solar energy are emphasized, so too are the environmental considerations of energy development and the importance of photosynthesis research to a future hydrogen economy.

Also summarized are the various centers, laboratories, offices, and testing facilities that play a significant role in energy activities.

Collectively, over the past decade, ASU has been awarded tens of millions of dollars for energy research, teaching, and outreach.

COLLEGE OF LIBERAL ARTS AND SCIENCES

Recent and Current Research

- Optimization modeling of energy facility location
- Increasing the efficiency of producing hydrogen to facilitate the use of renewable energy to produce hydrogen.
- Energy transport systems
- Wind energy development in Arizona
- Coal and electricity transport in China
- Solar-powered detoxification of waste in Phoenix
- Geothermal district heating in Mammoth Lakes, CA.
- Coal mining labor productivity
- Locating hydrogen refueling stations
- Sustainable energy and transport systems
- Geothermal energy outreach
- Aesthetic impacts of wind power deployment
- Energy surety through renewable energy
- Energy development and environmental costs at the US/Mexico Border

Sample of Research Facilities

The Photosynthesis Center: Center faculty use exemplars from photosynthetic organisms to design and create synthetic, solar driven, water splitting systems that will make possible the synthesis of high energy carbon-based fuels and hydrogen. Bio-inspired catalysts for hydrogen production will allow hydrogen to be produced both directly from water using solar energy and by electrolysis of water using renewable energy resources such as solar and wind to produce the required electricity to drive electrolysis. This would reduce the use of fossil fuels (heavily natural gas at present) to produce the

hydrogen. The synthesis of high energy fuels from water and carbon dioxide (CO2) is sustainable and can reduce atmospheric levels of CO2. This strategy offers the substantial advantage of making use of the existing energy infrastructure which is largely based on carbon fuels. Web site: http://photoscience.la.asu.edu/photosyn/.

The Office of Climatology: Houses the largest collection of climate data in the state. The State Climatologist is a member of the faculty in the Department of Geography. Web site: http://geography.asu.edu/azclimate/

COLLEGE OF ARCHITECTURE AND ENVIRONMENTAL DESIGN

Recent and Current Research

- Training Requirements for the Development of a Mexican Energy Service Industry
- Industrial Energy Consumption Among US and Mexican Manufacturers in the Southwest Border Region
- Energy efficient building design
- Solar design and testing
- Solar construction
- Home energy efficiency modeling

Sample of Programs

The Energy & Climate concentration leads to the MS Building Design. The Energy and Climate concentration educates students to become experts in energy efficient design and technology. The program requires a minimum of 30 semester hours of approved course work at the advanced level, including 6 hours of thesis credit. Students admitted to the program will take a two-year program addressing research methods and courses in their area of concentration. Web site - http://www.caed.asu.edu/msenergy/about.html

Sample of Facilities

High Bay Research Laboratory: This laboratory (2500 s.f.) provides space for mock-ups of large studio demonstrations and research experiments. Computer systems are integrated with video and data logging equipment to record full-scale simulations of architectural, interior design and product design research.

Lighting Simulation Laboratory: The college maintains an indoor laboratory (1200 s.f.) for lighting experimentation and a collection of instruments and data-gathering equipment for lighting and daylight simulation.

Solar Energy Library: Housed in the Architecture 14,000 square foot library are world renowned archival collections of Maria Telkes, Victor Olgyay, and John Yellott. The solar energy collection includes the collection of the International Solar Energy Society.

Lighting Simulation Laboratory: There are demonstration facilities for numerous light sources, model testing, measurement facilities. A mirrored sky is used for simulating overcast sky conditions, while outdoor testing is performed at the rooftop solar lab.

Energy Simulation Laboratory: Sponsored by the Arizona Public Service Company electric utility, this facility includes the latest computer technology and simulation programs for the design profession.

Solar Laboratory: A facility for testing and data collection of climate data, fenestration products, evaporative cooling, solar hot water heating, daylighting measurements, architectural models and building components is housed on the roof of the Architecture building.

Thermal Comfort Laboratory: This laboratory contains a full-sized environmental test chamber with the capability for controlling the variables that effect comfort: temperature, humidity and air motion.

IRA A. FULTON SCHOOL OF ENGINEERING

Recent and Current Research

- The Ira A. Fulton School of Engineering is a member of PSerc, the Power Systems Engineering Research Center, which is a multi-university research effort under the aegis of the National Science Foundation. PSerc is the largest Industry University Cooperative Research Center supported by the National Science Foundation. There are 13 participating universities, about 50 industry sponsors in a total nationwide program with about 3.0 million dollars annual budget. PSerc web site: http://www.pserc.wisc.edu/
- An educational program in power systems with a home web site: http://ceaspub.eas.asu.edu/PowerZone/
- The Propagation of Disturbances from the Primary Distribution System to End Use
- The Impact of Widespread Distributed Generation on SRP Power Distribution Systems
- Effect of Soil Thermal Conductance Variation on Power Cables Ampacity
- The Use of Ultrasound for Fowl Deterrence at Power Stations
- Issues Associated with the Interaction of a Fuel Cell Technology and the Local Electrical System
- Evaluation of New Nonceramic Insulator Designs within the SRP System
- Evaluation of XLPE Cable and Switchgear Used for Distribution in the SRP System
- Instrumenting Wind Loading Under Mircoburst Conditions
- Improving Modeling to Enhance Real-Time Power Flow Reliability and Accuracy
- New Implications of Power System Fault Current Limits
- Identification and Tracking of Parameters for a Large Synchronous Generator
- Differential GPS Measurement of Overhead Conductor Sag
- Flashover Prediction of Insulators as a means of Enhancing Reliability in an Aging Infrastructure used in Power Delivery

- Performance Assessment of Advanced Digital Measurement and Protection System
- Development of Energy Star Residential certification program through cooperative agreement with Environmental Protection Agency
- Solar water heating for large-scale residential projects in Phoenix
- Residential energy analysis software for residential use
- Vibration problems in turbomachinery and other equipment of electrical generating stations
- Integrated Micro- Electro-Mechanical Systems (MEMS) and advanced technologies for the next generation power distribution system
- Blended Cement Systems for Sustainability and Energy Conservation
- Development of "Pipeline Benchmarking" chapter for Governor's Essential Services Task Force Report related to the gasoline pipeline break 2003.
- Thermoconductivity Study of Joint Directional Boring of Multi-Duct Electrical Cables
- Lean Underground Installation Processes
- Investigate the effects of crystalline and metallic defects on cell efficiency in multicrystalline silicon solar cells

Sample of Additional Energy Research Facilities

The Energy Management Laboratory (EML) - A part of the Environmental Fluid Dynamics Program and is financially supported by the Department of Energy to conduct relevant research in energy and waste conservation. The purpose of the EML is to offer technical assistance in energy and waste conservation measures to commercial entities throughout Arizona, while providing education experience and research opportunities to engineering students. Interests include: Desalinization of water using hydraulic refrigeration systems; Increase of chiller efficiency through use of cool water storage; Analysis of integral solar collectors; Using finite-element analysis to improve double-walled heat exchangers; Analysis of lead-acid batteries used in photo-voltaic systems; Modeling of natural ventilation flows in buildings; Investigation of thermal contact resistance in manufacturing applications. Web site: http://www.fulton.asu.edu/~eml/.

The Industrial Assessment Center (IAC) - Provides free energy, waste and productivity analysis studies to qualified Arizona and Nevada Manufacturers, recommending methods to conserve resources, and reduce operating costs. Funding is paid by taxation revenue through the US Department of Energy. Web site: http://www.eas.asu.edu/~iac/.

High voltage engineering research lab #1 – A laboratory containing state of the art electrochemistry and microscopic imaging equipment. Supported by Salt River Project, PSerc, and various industries.

High voltage engineering research lab #2 – A state of the art facility for insulator testing. The laboratory staff runs short courses, seminars, and testing programs. More information at: http://www.eas.asu.edu/~eee/FacultyStaff/Gorur/gorur.html

High voltage engineering laboratory #3 - A facility with both AC and DC high voltage sources as well as electromagnetic interference test equipment. The laboratory includes a roof top facility. More information at:
http://www.eas.asu.edu/~eee/FacultyStaff/Karady/karady.html

Power system instrumentation and control laboratory: A facility for computer controls and digital instrumentation of power systems. More information at:
http://www.eas.asu.edu/~eee/FacultyStaff/Holbert/holbert.html

Power electronics laboratories: A new facility for the design, construction and testing of power electronic devices. Two facilities are maintained in this effort. More information at: http://www.eas.asu.edu/~eee/FacultyStaff/Ayyanar/ayyanar.html

Power engineering computing laboratory: A facility for research and education in power engineering. The facility consists of PCs, scanners, videoconferencing equipment, printers, and related hardware. Power engineering software is installed on the computers in this laboratory.

MAE Laboratories. These include:

- Combustion Laboratory - The Combustion Laboratory supports fundamental and applied research aimed at developing clean, efficient, safe, multi-fueled combustion equipment. Current topics are spray combustion, pollutant formation/control, combustion in porous media, and hot surface ignition. Applications include aeroengine propulsion, industrial furnaces/boilers/dryers, radiant heaters, and fuel systems safety. Robert Peck, Director
- Atmospheric Measurements Laboratory – R. Calhoun/ J. Anderson, co-Directors
- Environmental Fluid Dynamics Laboratory – J. Fernando, Director
- Thermofluids Laboratory – T. Lee, Director
- Energy Management Laboratory – P. Phelan, Director
- Gas Turbine Heat Transfer Laboratory – R. Roy, Director
- Computational Mechanics Laboratory – K. Squires, Director

INTERNATIONAL INSTITUTE FOR SUSTAINABILITY (formerly the Center for Environmental Studies)

The mission of the IIS is to facilitate collaboration among Arizona State University faculty researchers and to assist in decision making about sustainability. The IIS advances identification of key local and global environmental issues and collects reliable information to be used by scholars, policymakers and the greater public. Some of the projects have a strong energy component.

- Solar ADsorption Cooling in the Southwest. Solar energy for air conditioning.
- Develop and apply renewable technologies and sustainable materials at City Hall in Phoenix and within close proximity.
- Long term project at Sky Harbor Airport to develop the "most sustainable" new terminal (replacing terminal 2) utilizing renewable technologies and sustainable materials based on our urban climate

- Coordinating the use of Sustainable Energy sources as director of the International Sustainable Technologies Alliance (ISTA) with MIT, Cambridge, IIT-Delhi, University of Cape Town and Tec de Monterrey.
- Developing 498-598 Sustainable Energies Course
- Energy reduction research for schools via mechanical and material functions
- energy reduction systems and designs for high-tech manufacturing facilities

ASU EAST CAMPUS

ASU East research activities include:

- Evaluation of several residential fuel cell systems for US Army and SRP/EPRI
- Component and product R&D of fuel cells and photovoltaics
- Fuel cell system development for various applications including UPS for up to 60 desktop computers
- Solar steam electrolysis to generate hydrogen at lower costs
- National and international standards developments for photovoltaics
- Several outreach programs and workshops for the undergraduate and secondary school students
- Battery evaluation for various applications (planned to be initiated)

Photovoltaic Testing Laboratory - ASU East's Photovoltaic Laboratory is one of three in the world certified to evaluate the performance, reliability and durability of "photovoltaic modules," that is, solar panel components that convert sunlight into electricity. It is the only such laboratory in the United States. It is located on the ASU East Campus.

ASU FACULTY - ENERGY AND RELATED FIELDS OF RESEARCH AND INSTRUCTION

Allen, James (Ph.D University of Illinois). Chemistry and Biochemistry. Catalysts for bio-inspired solar water splitting and hydrogen production. :jallen@asu.edu
Angell, C. Austen, (Ph.D University of London) Regents' Professor of Chemistry, New materials for high efficiency batteries. aa@asu.edu
Allenby, Braden R (Ph.D. Rutgers University; J.D. University of Virginia). Civil and Environmental Engineering, and Law. Design for Environment, industrial ecology, telework and netcentric organizations, and earth systems engineering and management. Braden.Allenby@asu.edu.
Anbar, Ariel D. (Ph.D., Caltech) Geological Sciences/Chemistry and Biochemistry. Environmental abundances of metals used in biological energy production, capture and transfer, and toxic metal byproducts of industrial energy production. anbar@asu.edu.
Ariaratnam, Samuel (Ph.D. University of Illinois at Urbana-Champaign) Construction. Urban underground infrastructure systems including: sewer and water networks; fiber-optic cables; electrical lines; and pipelines. Samuel.Ariaratnam@asu.edu
Ayyanar, Raja (PhD. University of Minnesota) **–** Electrical engineering. Power electronics. rayyanar@asu.edu

Bashford, Howard H. (Ph.D., Brigham Young University) Construction. Building technology, sustainable developments, energy efficient building modules.. Howard.bashford@asu.edu

Beckman, James (Ph.D. University of Arizona) Chemical and Materials Engineering. Power plant cooling, evaporation techniques, and water quality. jim.beckman@asu.edu

Blankenship, Robert (Ph.D University of California, Berkeley). Photosynthetic water splitting and hydrogen production by organisms living under extreme conditions. :RBlankenship@asu.edu

Bryan, Harvey (Ph.D., University of California, Berkeley) – Architecture. building technology, energy-efficient design, focusing on the interface between technology and the design of ecologically-responsible environments. Harvey.bryan@asu.edu.

Caudle, M. Tyler (Ph.D Duke University) – Chemistry and Biochemistry.The synthesis of catalysts for water oxidation and hydrogen production. TCaudle@asu.edu.

Crittenden, John (Ph.D. University of Michigan) Civil and Environmental Engineering. Member of the National Academy of Engineering. Sustainable energy resources. jcritt@asu.edu.

Day, Thomas (Ph.D Colorado State University). School of Life Sciences. Environmental influences on photosynthetic efficiency of plants. tadday@asu.edu.

Farmer, Richard G. (MSEE, Arizona State University) Adjunct Professor in Electrical Engineering. 50 years of electric power industry experience. Co-authored a book on the application of series capacitors in power systems. aargf@asu.edu.

Frasch, Wayne (Ph.D University of Kentucky). School of Life Sciences. Energy transformations in biological systems. frasch@asu.edu

Fromme, Petra, (Ph.D Technical University of Berlin). Chemistry and Biochemistry. Photosynthetic catalysts for water splitting and energy transformation. pfromme@asu.edu

Garcia-Pichel, Ferran (Ph.D University of Oregon) School of Life Sciences. The discovery of new organisms capable of hydrogen production, pertinent to future hydrogen economy**.** ferran@asu.edu

Gel, Esma S. (Ph.D. Northwestern University) Industrial Engineering, Reliability analysis of power transmission systems using applied probability techniques, optimal maintenance policies for power systems Esma.Gel@asu.edu.

Gervasio, Dominic (Ph.D. Case Western University) Center for Applied NanoBioScience (ANBC). Fuel cells for portable power sources as well as catalysis, sensors and micro chemical reactors.

Gorur, Ravi (Ph.D., University of Windsor, Canada) High-voltage engineering. Dielectrics and electrical insulating materials, electric field calculations, pulsed power, power electronics, dielectric fluids, HV testing techniques and computer aided design. gorur@asu.edu

Gould, Ian (Ph.D., Manchester University, England) Chemistry and Biochemistry. Mechanisms and theories of the photo-induced electron and energy transfer processes which represent the fundamental primary steps in photosynthesis and other important light induced processes. igould@asu.edu.

Gust, Devens, Jr. (Ph.D., Princeton University) Foundation Professor of Chemistry and Biochemistry design, synthesis, and spectroscopic study of complex molecular devices that mimic photosynthetic electron and energy transfer, adding to understanding of

natural photosynthesis and aiding in the design of solar energy harvesting systems for production of hydrogen and electricity, and molecular-scale electronic devices. Gust@asu.edu

Heydt, Gerald (Ph.D. Purdue University) Regents Professor of Electrical Engineering. National Academy of Engineering. Director, Power Systems Engineering Research Center, Power systems analysis design; transmission and distribution. He has industrial experience with the Commonwealth Edison Company, Chicago, E.G. & G. in Mercury, Nev., and with the United Nations Development Program. In 1990, he served as the program manager of the National Science Foundation program in power systems engineering. He is the author of two books in the area of power engineering. heydt@asu.edu

Holbert, Keith (Ph.D. University of Tennessee) Electrical Engineering. Power plant monitoring and diagnostics; instrumentation; fuzzy logic. keith.holbert@asu.edu

Hubele, Norma F. (PhD Rensselaer Polytechnic Institute) Industrial Engineering. Reliability, industrial engineering application in power, and probability. hubele@asu.edu

Johnson, Paul. (Ph.D. Princeton University) Civil and Chemical Engineering. Hydrocarbon source longevity assessment, impacts of leaking underground storage tanks to groundwater resources, subsurface vapor migration modeling and assessment, aquifer recharge, and MTBE bioremediation. paul.c.johnson@asu.edu

Karady, George G. (Ph.D. Technical Sciences University of Budapest) Salt River Project Chair Professor. Electrical Engineering. EBASCO Services chief consulting electrical engineer, manager of electrical systems, and chief engineer of computer technology. Electrical task supervisor for the Tokamak Fusion Test reactor project in Princeton. karady@asu.edu

Kuby, Michael (Ph.D. Boston University) Geography. Coal and electricity transport optimization modeling; hydrogen refueling station location modeling. Michael.kuby@asu.edu.

Matyushov, Dmitry (Ph.D Ukrainian Academy of Science) Chemistry and Biochemistry. Theoretical analysis and design of catalytic structures capable of water splitting and hydrogen production. dmitrym@asu.edu

Mignolet, Marc (Ph.D., Rice University) Mechanical and Aerospace Engineering. Vibrations in power plant equipment, dynamics, rigid body and structural dynamics. marc.mignolet@asu.edu

Mili, Lamine (PhD. University of Liege) Fellow of the IEEE and international authority on state estimation as applied to power engineering. Also a Professor at Virginia Tech in Blacksburg, VA.

Moore, Ana (PhD Texas Tech University). Chemistry and Biochemistry. Synthesis and photochemical studies of molecular-level photovoltaic materials for solar energy harvesting and conversion.. amoore@asu.edu

Moore, Thomas A. (Ph.D., Texas Tech University). Chemistry and Biochemistry. Assembly of large structures that incorporate molecular-level devices capable of solar energy conversion. Tom.Moore@asu.edu

Mobasher, Barzin (Ph.D., Northwestern University) Civil and Environmental Engineering. Properties of concrete and the use of power plant fly ash. barzin@asu.edu

Mushkatel, Alvin (Ph.D. University of Oregon) Professor of Environmental Policy, Department of Applied Biological Science. - Socio-economic impacts from siting of a

high-level nuclear waste repository, emergency management training and evaluation for high-level nuclear waste incidents. Alvin.Mushkatel@asu.edu.

O'Keeffe, Michael (Ph. D., D. Sc. University of Bristol, England) Regents' Professor of Chemistry. Atomic and electronic structure and properties of crystalline inorganic solids. Hydrogen storage. mokeefe@asu.edu.

Pasqualetti, Martin J. (Mike) (Ph.D., UC Riverside) – Geography. Solar, wind, and geothermal energy impacts; nuclear power plant decommissioning. Pasqualetti@asu.edu.

Peck, Robert (Ph.D. UC, Irvine) – Chair, Mechanical and Space Engineering. Director, Combustion Laboratory, which supports fundamental and applied research aimed at developing clean, efficient, safe, multi-fueled combustion equipment. Robert.Peck@asu.edu.

Phelan, Patrick (Ph.D, UC Berkeley) Mechanical and Aerospace Engineering. Energy Management Laboratory: ASU Industrial Assessment Center; Solar-powered cooling; Industrial energy intensity. phelan@asu.edu

Pijawka, K. David. (Ph.D. Clark University) – Planning. Nuclear waste transport and disposal; risk perceptions of energy technologies. Pijawka@asu.edu.

Rez, Peter (Ph.D. University of Oxford, UK) – Physics and Astronomy. Theoretical research on materials for Li batteries, involving electronic structure calculations to understand how different materials work and how to optimize performance in terms of battery capacity and lifetime. Peter.Rez@asu.edu

Roy, Ramendra (Ph.D. UC Berkeley). Mechanical and Aerospace Engineering, combustion and power plant operation. Nuclear power. Heat transfer and thermodynamics. roy@asu.edu

Sarewitz, Daniel (Ph.D., Cornell University), Director, Consortium for Science, Policy & Outcomes. Professor of Science and Society. Research focuses on design of publicly funded research and development programs to maximize societal benefit. Daniel.Sarewitz@asu.edu.

Schroder, Dieter (Ph.D. University of Illinois) – Electrical Engineering. Solar energy, solar cells, integrated circuits, semiconductor materials/devices. schroder@asu.edu

Si, Jennie (PhD. University of Notre Dame) Electrical Engineering. Power systems engineering related to learning systems, and in power markets. si@asu.edu

Shock, Everett (Ph.D. UC Berkeley) Director, W.M. Keck Laboratory for Environmental Biogeochemistry, Professor, Geological Sciences and Chemistry & Biochemistry. Transfer of energy between geochemical and biological systems. Thermodynamics of aqueous solutions. Dynamics of aqueous transport. eshock@asu.edu.

Tamizh-Mani, Govindasamy (Ph.D. in Solar Cells, Indian Institute of Technology), Director, ASU Photovoltaic Testing Laboratory. PV, fuel cells and batteries. manit@asu.edu.

Thallam, Rao (PhD. University of Waterloo) - Adjunct professor. Salt River Project. Electric power quality engineering.

Thornton, Trevor J. (Ph.D., Cambridge University) Electrical Engineering. Director of the Center for Solid State Electronics Research, Mesoscopic physics and silicon device processing. t.thornton@asu.edu

Thorpe, Michael F. (D. Phil., Oxford University). Biodesign Institute at Arizona State University. Foundation Professor of Physics, Chemistry & Biochemistry Theoretical

Physics. Computer modeling of materials for solar energy like amorphous silicon. Studies of assembly pathways for membrane photosystems in plants. mft@asu.edu
Tylavsky, Daniel J. , (Ph.D., Pennsylvania State University) Electrical Engineering. Power systems analysis. Analysis and simulation of the large-scale power-system generation/transmission problems. Electric power systems, numerical methods applied to large-scale system problems, parallel numerical algorithms, new educational methods and technologies. tylavsky@asu.edu
Vermaas, Wim (D.Sc Agricultural University, Netherlands). School of Life Sciences. The structure of biological catalysts for hydrogen production. wim@asu.edu
Vijay Vittal. (Ph.D., Iowa State University) Ira A. Fulton Chair in Electrical Engineering**,**: Electric power, power system dynamics and controls, nonlinear systems, computer applications in power, sustainable energy, modeling and simulation of complex systems. National Academy of Engineering. Vijay.Vittal@asu.edu
Webber, Andrew (PhD University of Essex). School of Life Sciences. Regulation of hydrogen production by photosynthetic organisms. andrew.webber@asu.edu.
Westerhoff, Paul (Ph.D. University of Colorado) **–** Power plant water quality at ASU with partial funding from SRP. P.westerhoff@asu.edu.
Woodbury, Neal. (Ph.D., University of Washington). Chemistry and Biochemistry. Role of the protein component of this apparatus plays in the initial light-driven reactions of photosynthesis. nwoodbury@asu.edu

ENERGY-RELATED COURSES OFFERED AT ASU

Course	Title
ABS 130	Intro to Environmental Science
ABS 333	Water Resources Management
ABS 381	Natural Resource Policy
ABS 440	Ecological Restoration Techniques
ABS 465	Surface Water Quality
ABS 480/598	Ecosystem Management and Planning
ABS 481	Riparian and Wetland Restoration
ABS 482	Ecology and Planning for Restoration
ABS 485	GIS in Natural Resources
ABS 486	Introduction to Remote Sensing
ABS 487	Remote Sensing in Environmental Resources
AGB 455	Resource Management
ATE 521	Bldg Environmental Science
ATE 530	Daylighting Design
ATE 550	Passive Heating and Cooling I
ATE 551	Passive Heating and Cooling II
ATE 552	Energy Parameters in Buildings
ATE 554	Bldg Energy Efficiency

ATE 558	Bioclimatic Parameters
ATE 560	Bldg Energy Analysis
ATE 561	Energy Analysis Techniques
ATE 598	Environmental Rating Systems for Buildings
BCH 568	Molecular Mechanisms of Photosynthesis.
BIO 303	Radiation and Life
CEE 441/598	Water Resource Engineering
CEE 361	Intro to Environmental Engineering
CEE 561	Physical Chemical Treatment of Water
CEE 563	Environmental Chemistry Laboratory
CHE 479	Air Quality Control
CHE 502	Intro to Energy Transport
CHE 554	New Energy Technology
CHE 553/CEE 598	Air Quality Control
CON 494	Trenchless Construction Methods
CON 598	Horizontal Directional Drilling Applications
CON 494	Sustainable Housing
CON 598	Sustainable Housing
EEE 360	Energy Conversion and Transport
EEE 360	Energy Conversion and Transport
EEE 460	Nuclear Concepts for the 21st Century
EEE 463	Electric Power Plants
EEE 471	Power System Analysis
EEE 573	Electric Power Quality
EEE 574	Computer Solution of Power Systems
EEE 577	Power Engineering Operations and Planning
EEE 579	Power Transmission and Distribution
EET 208	Electric Circuit Analysis I
EET 301	Electric Circuit Analysis II
EET 407	Energy Conversion and Applications
EET 460	Power Electronics
EET 494/598	Introduction to Photovoltaics
EET 494/598	Fuel Cells: Applied Science and Engineering
EET 598/MET 598	Fuel Cells App and Sci Eng
ETC 340	Applied Thermodynamics & Heat Transfer
GCU 364	Energy in the Global Arena
GCU 494	Sustainable Housing
GCU 598	Sustainable Housing
GCU 591C	Energy Landscapes
GPH 405	Energy and Environment
GPH 412	Physical Climatology
GPH 414/GPH 598	Climate Change
GPH 598	Energy and Environment
HON394	Energy and Society
MAE 382	Thermodynamics
MAE 433	Air Conditioning & Refrigeration

MAE 434	Internal Combustion Engines
MAE 436	Combustion
MAE 446	Thermal Systems Design
MAE 498A	Air Pollution Emissions & Transport
MAE 536	Combustion
MAE 581	Thermodynamics
MAE 589	Heat Transfer
MAE 598	Sustainable Energy Systems
MET 435	Alternative Energy Systems
PLB 320/BIO 319	Environmental Science
PHY 531	Electricity and Magnetism
PHY 561	Nuclear Physics
PHY 562	Nuclear Physics