

## **University of Southern California Energy Institute** **Key Areas of Research and Capabilities in Energy Technology and Impacts**

The University of Southern California fosters and supports an extensive set of research activities that relates to energy issues. These span research in conventional and alternative energy, environmental impacts, economics and policy. In addition, USC's significant technological research expands the boundaries on key areas of energy production, distribution, and fuel testing. Our approach to cross-disciplinary research promotes innovative solutions to energy problems of today and alternative energy sources of tomorrow. This presentation describes current research efforts in technologies, as well as environmental impacts and applications to energy-related issues. Areas of current research include:

### 1. ENERGY TECHNOLOGY

#### RENEWABLES, ALTERNATIVE ENERGY AND EFFICIENCY

- Photovoltaics
- Biofuels
- Lighting
- Transport Efficiency
- Buildings, Cities and Landscapes
- Fuel Cells
- Waste to Energy and Water Purification
- Methanol to Olefins
- Storage

#### CONVENTIONAL FUELS

- Combustion Research
- Oil

### 2. CLIMATE CHANGE

- Science
- Carbon Sequestration
- Carbon Separation
- Carbon Trading
- Policy

### 3. ENVIRONMENTAL IMPACTS

- Impact of Air Pollution on Health
- Particulate Matter: Monitoring, Characterization, Evaluation and Interpretation
- Life-Cycle Environmental Impacts
- Land Use and Environmental Implications
- Coastal and Marine Environmental Studies
- Environmental Justice
- Transportation Planning
- Policy and Regulatory Analysis

### 4. ENERGY IMPACTS AND ISSUES

- End Use Energy Efficiency Analysis
- Energy Security
- Economics and Modeling
- Geographical Information Systems
- Sustainable Planning
- Energy and Environmental Governance
- International Issues
- Information Sciences

# 1. ENERGY TECHNOLOGY

## RENEWABLE AND ALTERNATIVE ENERGY:

### Photovoltaics

**Key research:** Innovation in materials to improve efficiency and reduce the cost of photovoltaics.

**Activities:** Molecular/polymeric materials for optical studies and nanoscale materials and devices for sensing and catalytic studies including new light emitting device technologies for flat panel displays and general illumination, solar energy conversion using devices based on molecular and polymeric materials, nanowire and nanotube based sensors, and bioadhesives. Creating architecture of a "Small Molecule" Organic Solar Cell.

The study of the self assembly of dyes/chromophores that absorb (sun)light and transfer the excited state energy to a secondary chromophore in the assembly. Processes of this type are involved in photosynthesis. The objective in this case is to obtain information regarding the processing of light in light harvesting and organic light emitting devices. Areas of application are photovoltaics and light emitting devices (LEDs).

Use of optically active semiconductor nanocrystals to enhance the efficiency of photovoltaic solar cells. We have designed and fabricated Si solar cells. Further research involved deposition of thin films of varying thickness of nanocrystals on to the silicon photovoltaic cells and measurement of the change in the efficiency. We have obtained encouraging results with the largest sized CdSe nanocrystals in terms of enhancement of the efficiency.

### Biofuels

**Key research:** Understanding the fundamentals of the combustion behavior of biofuels used in land and air transportation, as well as economic evaluation of biofuels.

**Activities:** Characterize biofuel combustion properties that would affect engine operation and harmful emissions. More specifically, there is evidence that burning biofuels can result in lower burning intensity as well as higher emissions of nitrogen oxides and aldehydes that are carcinogenic. On the other hand, they are known to produce less particulate matter. Combined experimental and detailed numerical investigations will provide the necessary scientific insight into the controlling mechanisms of burning and emissions.

Another area of research focuses on the effect of increased ethanol production on crops--and all the goods and services in the economy to which they contribute directly and indirectly--to determine the extent to which these price changes affect various income groups. If agricultural land for corn and soybean production is limited, the price increases are projected to be significant.

### Lighting

**Key research:** Innovation in materials to develop new lighting options.

**Activities:** Development of new light emitting device technologies for flat panel displays and general illumination; development of polymeric materials that are used in organic light emitting diodes.

## Transport efficiency

**Key research:** Understand the process of water sheet break-up leading to droplet formation when a rolling tire takes up water from the roadway.

**Activities:** Experimental apparatus to study spray formation under controlled conditions. The apparatus could also be used to study the increase in tire rolling resistance in the presence of water on the roadway. Increases in rolling resistance increase fuel consumption for cars and trucks.

## Buildings, Cities and Landscapes

**Key research:** Technologies, systems and applications for improving efficiency in buildings, cities and landscapes

**Activities:** Research in this field involves a wide range of areas, including:

- Energy efficient design processes that explore form in response to natural forces: sun, wind, water, seismic and thermal
- Landscape design that saves energy
- Building systems integration: structure, mechanical, electrical, envelope, for fit and synergy with architectural energy efficiency objectives
- Passive and active solar building design for heating and cooling
- Natural and artificial lighting in buildings
- Sustainable materials and methods of construction
- Energy efficient Manufactured and Emergency Housing
- Computer simulations of building energy, resources and/or daylighting

## Fuel Cells

**Key research:** Material research for improving efficiency as well as creating lower cost, and smaller sized, fuel cells.

**Activities:** Development of polymeric materials (to be used in fuel cells) that modulate the release of methanol and other fuels and minimize methanol crossover for application in the use of methanol in fuel cells. Also, experiments with micro-scale fuel cells; design and efficiency developments.

Micro-scale fuel cells are a promising technology for replacing batteries in portable electronic devices, with greatly increased storage capacity compared to conventional batteries. Besides methanol fuel cells, there is a program starting to study direct propane or butane fuel cells, which have some potential advantages over methanol (i.e., higher energy density, less cross-over problems).

The research on implantable fuel cells aims to develop a biofuel cell that can be used to power implanted medical devices. This biofuel cell will use specific enzymes as biocatalysts. Glucose in blood is used as the anodic fuel and oxygen in the blood functions as a cathodic oxidizer. The electric power will be provided constantly as long as fuels (glucose and oxygen) are present in the blood.

## Waste to Energy and Water Purification

**Key research:** The use of microbes to clean sewage waste as well as reduce contaminants in water.

**Activities:** Design and development of microbial fuel cells for the production of energy and clean water from waste materials. Municipal, industrial and agricultural waste can all be used as fuel for generating electricity, and in a microbial fuel cell system, the electricity production relates directly to

the removal of harmful organic pollutants from water streams. In addition, microbial fuel cells are being designed as tools for bioremediation of metal pollutants such as chromium.

The microbial fuel cell research focuses on the optimization of microbes as catalysts on the electrodes, the understanding of microbial processes, the study of environments and the associated microbial communities that are involved in rapid and extensive carbon sequestration; the development of novel processes to extract electric energy from inorganics, and using electrochemical techniques to study the bacterial interactions with these systems and optimize fuel cell designs.

## **Methanol to Olefins**

**Key research:** Develop methanol as a feed stock.

**Activities:** In the past several years, many of the details of the hydrocarbon pool mechanism in methanol-to-olefin (MTO) catalysis have been elucidated. MTO is a long-standing scientific problem and it is the crucial central step in the conversion of methane to polyolefins. This understanding is being exploited to synthesize new MTO catalysts. Other mechanistic projects involve hydrocarbon cracking and partial oxidation catalysis.

## **Storage**

**Key research:** Fluorocarbon-based materials development for storage applications.

**Activities:** Developing novel materials for rechargeable lithium ion batteries with applications also for LEDs and methanol fuel cells for commercialization by Merck KgaA.

## **CONVENTIONAL FUELS:**

### **Combustion research**

**Key research:** Improve efficiency of combustion in combustion engines using conventional and alternative fuels.

**Activities:** Studies of the combustion of conventional and alternative fuels under conditions that are of relevance to modern engines designed to produce less nitrogen oxides, one of the main ingredients required for the formation of photochemical smog. Micro-scale combustion, premixed flame ignition by pulsed corona discharges, propagating fronts in motile bacteria, turbulent combustion, edge flames, flame propagation in confined geometries, internal combustion engines, premixed-gas combustion at microgravity, flame spread over solid fuel beds, and radiatively-driven flows and heat transfer. Studies of aerodynamic and kinetic processes in flames, air-breathing propulsion, particle-laden reacting flows and laser diagnostics. Combustion chemistry, high-temperature chemical kinetics, soot formation and effects on climate forcing, nano-material synthesis, characterization and modeling, and transport theory of nanomaterials.

## **Oil**

**Key research:** Computer technologies to improve oilfield development and fluid applications for tertiary oil recovery.

**Activities:** Research and Academic Training on Interactive Smart Oilfields. Research areas include:

- Integrated asset management

- Well productivity improvement
- Robotics and artificial intelligence
- Embedded and networked systems
- Reservoir management
- Data management tools
- Immersive visualization

Development of aqueous fluids consisting of water-soluble (acrylic) polymers to give very high molecular weight assemblies that effectively viscosify water at very low polymer concentrations. The fluids may have uses in tertiary oil recovery.

## 2. CLIMATE CHANGE

### Science

**Key research:** Climate research at USC seeks to understand how the Earth's climate system responds to internal and external forcings and to assess the environmental impacts associated with changing climatic conditions.

**Activities:** Research to document the coupled ocean and atmospheric responses to higher/lower atmospheric temperatures. Exploring how the climate system responded to higher and lower concentrations of atmospheric CO<sub>2</sub> and other greenhouse gases in the past. Region-scale hydrologic studies (in California, SE Asia, India and the Caribbean) designed to assess the frequency and magnitude of recurring drought or extreme rainfall. Studies to understand what controls variable marine productivity and carbon cycling along the California coast and in the Gulf of California.

**Activities:** Tropical ocean and climate variability, the history of changing marine productivity and carbon cycling in the oceans of the California coast, and in the area California rainfall variability (atmospheric science) study ocean-climate change in the Gulf of California over the last 8000 years. Studying climate change as recorded in lake sediments over the last few thousand years, how animals respond to heat stress at the genome level, including how long an animal is likely to survive at different temperatures and how flies in particular can be engineered to be more resistant to heat. Studies of the genetics of adaptation for climatic factors like temperature in plants, biological adaptation in the context of environmental science including animal physiology and developmental and molecular biology.

### Carbon sequestration

**Key research:** Models for understanding transport of liquids and gasses in aquifers; sequestration in the ocean

**Activities:** Develop mathematical models and efficient and accurate numerical algorithms for solving large-scale problems of flow and reactive transport in highly heterogeneous porous media such as petroleum reservoirs and water bearing aquifers. Advance the mathematical and geoscience foundations necessary to enhance the predictive capabilities of simulators through an improved understanding of the physical processes that govern subsurface phenomena on multiple spatial and temporal scales.

Carbon sequestration in the ocean and ocean responses to climate change with regard to concentrations of greenhouse gases.

## Carbon separation

**Key research.** Develop high temperature membranes for the separation of CO<sub>2</sub> from flue-gas and other gaseous mixtures.

**Activities:** Nanoporous inorganic membranes are being developed which can be used for the separation of CO<sub>2</sub>. Both conventional and reactive separations are being investigated using these membranes. For example, in an ongoing project these membranes are used to improve the efficiency of the water gas shift (WGS) step in an IGCC power plant. The membrane-based WGS reactor produces two streams, a pure hydrogen permeate product to be used for clean energy generation, and a sequestration-ready, CO<sub>2</sub>-rich retentate effluent.

## Carbon trading

**Key research:** Cap and trade model for estimating implications of reducing emissions in terms of minimizing costs, projecting permit price, estimating the size of the market and identifying sellers and buyers.

**Activities:** Refining a mathematical programming emissions permit trading model and applying it to new contexts, including the Western States Initiative, of which California is the lead; and expanding the range of trading partners, including the European union and developing countries in the Pacific Rim. Advising Mid-Western and Southeastern States on designing and implementing cap and trade initiatives. Also examining the application of permit trading to energy conservation targets in China

## Policy

**Key research:** Understanding different policy alternatives and addressing the implications of alternative solutions to reducing greenhouse gas emissions.

**Activities:** Developing a comparative framework for understanding the emergence and implementation of climate change (greenhouse emissions reduction) policies across major nations with initial focus is on CA as a first mover. Environmental justice implications of different policy approaches to reducing emissions and the role of policy in contrasting reducing emissions and sequestration.

## 3. ENVIRONMENTAL IMPACTS:

### Impact of air pollution on health

**Key Research:** Epidemiological studies on children's health and assessment of exposure to air pollution.

**Activities:** Investigating environmental exposures, studying who might be most susceptible, and linking research efforts with communities. Involves the study of cancer, respiratory disease and adverse reproductive outcomes, as well as developing new methods to design studies and evaluate exposures. Includes studies of long-term exposure to local and regional air pollutants from outdoor origin, which promotes atherogenesis in early life, leading to differences in carotid intima media thickness (CIMT) in 10-12 year old children participating in the Children's Health Study from 13 Southern California communities. Special focus on near-roadway exposures and health impacts.

Determine how the toxicity of ultrafine particles depends on the concentration and characteristics of the semi-volatile and non-volatile fractions of PM emitted from vehicles and other sources. Understanding the mechanism of toxic action of freshly-emitted combustion aerosols and identifying fractions of the aerosol causally related to health effects.

Special focus on health and community impacts in harbor communities and along the global supply chain. Also special focus on land use and zoning with regard to siting of port/rail/freeway/distribution centers in close proximity to homes and schools, as well as siting of schools and homes near freeways and busy roads.

### **Particulate Matter: Monitoring, Characterization, Evaluation and Interpretation**

**Key Research:** Air quality research with an emphasis on the characterization of particulate matter associated with vehicular traffic.

**Activities:** Observe, evaluate and interpret the chemical composition, physical properties and toxicological characteristics of atmospheric particulate matter across the entire size spectrum from ultrafine (< 100 nm in diameter) to coarse (> 2500 nm in diameter). Measurements are obtained using both commercially-available equipment and novel approaches developed at USC. Data are obtained primarily through field projects throughout the Los Angeles basin, although laboratory-based observations – particularly to validate new experimental methods, characterize emissions or evaluate personal exposures – are also performed. Ambient data have been collected in “source” (e.g. adjacent to freeways near the coast) and “receptor” regions (e.g. in Riverside) in order to characterize the contribution of secondary atmospheric formation to observations. Individual source profiles and the Chemical Mass Balance method are used to determine sources of atmospheric particulate matter in Los Angeles. Differences in observations adjacent to light-duty gasoline powered and heavy duty diesel vehicles have been explored and characterized. Pollutant loading adjacent to freeways can be up to a factor of 10 times higher than downwind, although the distance required for concentrations to return to urban background levels varies by season, time of day, and vehicular profile. Toxicological characteristics of collected aerosol are evaluated by a variety of methods in order to explore the dependence upon particle size and chemical composition.

**Activities:** Evaluate the chemical composition, physical properties and toxicological effects of particulate matter. Research on physical and chemical characterization of air pollutants via intensive monitoring studies of the Los Angeles Basin. Developed continuous monitors for measurement of physical and chemical properties of air pollutants, and characterized the formation and dynamics of air pollutants near freeways and demonstrated increased (~10-fold) exposures to these toxic pollutants in the vicinity of freeways and busy thoroughfares.

Studies of aerosol chemical and microphysical properties, processes leading to aerosol formation and transformation, and individual exposure to specific particulate properties.

### **Life-cycle Environmental Impacts**

**Key research:** Meta-analysis comparing conventional versus future truck fuels.

**Activities:** Alternative fuels and new energy technologies will be needed to support the goods movement economy. However, it is not yet clear what alternatives will have the least environmental impacts, when analyzed on a life-cycle basis. We have been collecting up-to-date information on the Life-Cycle Assessments for alternative energy systems such as: wind, solar, hydrogen, ocean, and biofuels. Comparisons have been made between these alternative fuels and the conventional fossil-based ones (diesel, LNG, CNG) using LCA methodologies.

**Key research:** Comparing pre-fabricated concrete blocks versus Contour Crafting

**Activities:** Life-cycle analysis of conventional cement blocks (pre-fab) buildings versus those built by automated (robotized) concrete buildings. Standard Portland Cement is the main additive to the mix. All phases of the life-cycle impacts are included based on their CO<sub>2</sub>-equivalent emissions.

### **Land Use and Environmental Implications**

**Key research:** Understanding green space in Los Angeles and the region.

**Activities:** The Center for Sustainable Cities' Green Visions Plan project focuses on southern California's landscape in terms of target species habitat, watershed assets, and parks and open space, as a means to promote multi-purpose planning for, and to target investments in, water quality, open space, and habitat conservation projects. In addition to extensive data development and analysis, the GVP will provide a sophisticated web-based dynamic mapping and analysis tool for project planners. Such web-based tools, built and enriched with real-time data on parameters associated with climate change, are critical to understanding how climate changes may influence species distributions, stream network functionality, and provision of ecosystem services to local populations.

### **Coastal and marine environmental studies**

**Key research:** Evaluation of coastal and oceanic ecosystems and ocean acidification.

**Activities:** Carbon sequestration in the ocean and ocean responses to climate change with regard to concentrations of greenhouse gases. Developed software for mapping ocean parameters such as temperature, circulation, and water quality, that are used to monitor climate change.

### **Environmental justice**

**Key research:** Environmental impacts on low-income and minority communities.

**Activities:** Focus on issues of environmental justice, regional inclusion, and the economic and social conditions facing low-income urban communities including issues of demographic change, economic inequality, and community empowerment. Current project looking at the environmental justice implications of options CA might use to reduce greenhouse gas emissions with an emphasis on cap and trade solutions.

### **Transportation planning**

**Key Research:** Relationships between land use and transportation, transportation policy evaluation, and impacts of information technology on transportation and travel behavior.

**Activities:** A major focus of research is increasing the efficiency of the transportation system. Research activities in goods movement include port simulation and truck routing for more efficient port operations and reduced vehicle traffic in metropolitan areas; freight rail system routing and utilization efficiency and freight cargo routing efficiency; impacts of regulatory policies on urban freight flows and congestion. Research activities in passenger transport include increasing use of transit and non-motorized modes through urban design, more efficient transit service and examining transit use among target population subgroups. Also developing a guideline for integrating inland ports into the intermodal goods movement system based on the containers originating and terminating at the ports of Los Angeles and Long Beach. A mathematical optimizations model for a generic inland port location allocation problem is being developed. In addition to VMT, we will calculate the reductions in fuel usage and truck/train emissions for the improved network.

## Policy and regulatory analysis

**Key Research:** Analyzing policy alternatives and providing solutions to policy makers with emphasis on infrastructure, energy and environmental policies.

**Activities:** Investigate issues in alternative fuels policies and impacts on energy markets, as well as associated agricultural and environmental concerns. Assess renewable and energy efficiency policies, including portfolio standards, addressing questions of the impacts of different policies on utilities and consumers. Related to this is understanding consumer behavior in terms of their use of energy and reaction to environmental problems.

Research, outreach, and education activities to further understanding and awareness of infrastructure challenges facing the state and country. This includes compiling, evaluating, and disseminating data and research pertaining to California's infrastructure trends, mechanisms and implications of investment spending, linkages between infrastructure investment and state and local economic activity, and related infrastructure issues.

Understanding the public debate in complex policy conflicts, especially environmental conflicts. An analysis of the role of stakeholder groups in the ongoing debate about the "Bay-Delta" estuary, the centerpiece of California's water system.

## 4. ENERGY ISSUES AND IMPACTS

### End Use Energy Efficiency Analysis:

**Key Research:** Various efforts have shown that energy utilities can help their customers reduce energy consumption with no loss of quality of life or economic performance.

**Activities:** Econometric analyses of the 200 largest US electric companies over 15 years demonstrate that both energy savings and the amount spent to improve energy efficiency increase when regulators include financial incentives in their mandates to reduce energy use and/or to reduce green house gas emissions. These incentives vary across time and space. That said, revenue or income decoupling to adjust for lost sales, direct financial incentives and indirect cost recovery mechanisms are statistically correlated with high achievements in energy efficiency programs incrementally and on a sustained inter temporal basis. This research combines regulatory policy analyses and benefit cost analyses of external benefits to determine target levels of energy efficiency improvements and how much each stakeholder should pay to achieve such results.

### Energy Security

**Key research:** Development of advanced models and tools for the evaluation of the risks, costs and consequences of terrorism and to guide economically viable investments in homeland security.

**Activities:** Model to analyze the regional economic impacts of a terrorist strike against the electric power systems. This includes incorporating features of disequilibrium and risk into the models. It also includes parametric adjustments for resilience by utility customers, including conservation, use of distributed generation, and business relocation.

## **Economics and Modeling**

**Key research:** Economic impacts of environmental problems and alternative technologies.

**Activities:** Cap and trade model for estimating costs of reducing greenhouse gas emissions. Program package to estimate the regional economic impacts of alternative electricity generating technologies. Developing theory and algorithms for predicting viability and broader socioeconomic impacts. The objective is to enable rapid prototyping without expensive and sometimes impossible experimentation. Also working on refining state of the art methodology of computable general equilibrium modeling to evaluate impacts of federal global warming legislation.

## **Geographic Information Systems**

**Key Research:** GIS Tool Development.

**Activities:** Development of new terrain analysis techniques; modeling of soil erosion, vegetation, and water quality processes and problems; modeling of spatial patterns of urban growth and habitat change and impact of land use change, urban growth, and conservation policies on these patterns; description of environmental and socio-economic characteristics and their impacts on selected health and quality of life outcomes; and the development of web-based map and gazetteer services for digital libraries and archives. Areas include:

- Spatial Analysis
- Environmental Modeling
- Development of New Terrain Analysis Techniques
- Development of Web-based Map and Gazetteer Services for Digital Archives
- Modeling Recreational Boat Traffic in the Sacramento-San Joaquin Delta
- Place-Based Decision Support for Spatial and Temporal Transference of Risk and Hazards
- Quantifying the Impact of Nature's Services in Urban Landscapes
- Rapid Integration of Geospatial and Online Data for Unexpected Events

## **Sustainable planning**

**Key Research:** Sustainable Enterprise Executive Roundtable.

**Activities:** Bringing together the Port of Los Angeles and large firms engaged in manufacturing, shipping, waste handling, and retailing, to develop key tools to adapting to a carbon-constrained environment. These tools include analysis of carbon footprints of products, packaging and supply chains.

## **Energy and Environmental Governance**

**Key Research:** Gateway Mega-Regions Program.

**Activities:** A program devoted to understanding and fostering the range of public policies and governing institutions for the greater Los Angeles region and similar trade and gateway regions around the globe. The program is premised on the core assumption that the needed governing and business strategy for gateway mega-regions will be viable only to the extent that they address simultaneously the environmental and economic requisites of a sustainable community.

## **International Issues**

**Key research:** Political economy and development in Latin America.

**Activities:** A study on the development of newly found natural gas reserves in the Andean region of South America, which compares the political and economic context for radically different policy approaches adopted by Bolivia and Peru.

## **Information Sciences**

**Key Research:** Innovative technologies and application in the use of information technologies.

**Activities:** New core technologies, along with supporting architectures, toolkits, and test beds for deployment in real-world applications, leading to fully integrated practical prototypes that can be employed as is, or adapted for national defense, commercial, or academic use. Intensive design development of systems and technologies to improve robustness, scalability, and versatility and integration of heterogeneous systems and technologies for synergistic performance.