Center for Applied Energy Research
working for you.

www.caer.uky.edu
Energy has been described as one of the future’s Grand Challenges. How will we satisfy our insatiable appetite for energy that fuels the global economy and our way of life? The world employs a mix of energy resources - oil and gas, coal, sun, wind, hydro, geothermal, biomass, and nuclear. We harness, burn, produce heat and electricity, liquid fuels, chemicals and gases from these energy resources. In turn, they contribute to our quality of life, health, nutrition, comfort, convenience, leisure, transportation, communication and productivity.

The University of Kentucky Center for Applied Energy Research serves these higher purposes. Among our most important aims is to assure that the benefits of investigations, research and study are applied, made available to the public and brought into the widest possible use. The Center, through its technology innovation and service to the community, contributes to improving the lives of Kentuckians by creating jobs and economic opportunities; by sustaining vital industries and public services; and by improving energy efficiency and protecting the environment.
What does energy research mean for the state?

Through our research we are bringing technologies into practices, which are needed to:

- Position the coal industry, electric utilities and heavy industry to respond to a carbon-constrained economy and the technical challenges of capturing and storing carbon dioxide.
- Extend the life and improve the environmental performance of the state’s fleet of coal-fired electric power plants, which provide some of the lowest-cost electricity found anywhere in America.
- Address problems associated with the accumulation of coal by-products and support a growing industry devoted to the use of these materials for sustainable construction.
- Develop a coal-to-liquids and coal-to-gas industry in Kentucky as an alternative to transportation fuels, chemicals, and gases derived from imported petroleum.
- Enable a developing biofuels industry to benefit from the strength of Kentucky’s agriculture and forest-product industries for cleaner, renewable fuels and chemicals.
- Advance distributed power generation and storage technologies to harness the sun and wind; and for cleaner alternative fueled vehicles (fuel cells, batteries, and capacitors).
- Develop higher value-added carbon materials derived from coal (pitch, coke, binders, fibers, and composite materials) that serve the nation’s defense, aerospace, automotive, and manufacturing industries.
- Advance the monitoring, clean-up, and remediation of legacy radioactive and chemical wastes associated with the nation’s nuclear power and weapons industries.
Bioreactor tubes containing algae culture at CAER’s greenhouse.
As global energy demand increases, along with concerns about greenhouse gases, it is imperative that we expand the use of carbon-neutral processes and reduce our dependence on fossil fuels. Any solution must be sustainable, reliable and economical at scale. Algal biomass shows characteristics that make it both a promising sink for recycling carbon dioxide (CO2) from power plants and a source of bio-oil for clean transportation fuels.

Algae are the fastest growing, photo-synthesizing organisms on the planet, possessing growth rates far superior to conventional crops. Also, algae have higher-oil-content per mass than other biomass, with some species containing over 50% oil. This fast growth rate and high-oil-content make them potentially ideal for CO2 uptake and as a source of bio-oil. CAER’s investigations range from selecting superior algae; to engineering combustion, bioreactor, separation and processing systems; to upgrading the oil to useful fuels. Future work will include a 10 megawatt slip-stream study at a coal-fired electric power plant to demonstrate the benefits of algae systems for CO2 capture and recycle.
We are exploring many technology needs for power generation in the carbon-constrained world of the future.
There are significant technology needs to re-tool and improve the environmental performance of coal-fired electric power plants, including technologies to make them capture-ready for carbon emissions. CAER has teamed with major power producers, government entities, and research organizations to form the Carbon Management Research Group to advance near-term technologies. The only commercial technology now available for CO2 capture is amine scrubbing; however, the process can de-rate the plant’s output by nearly 30%, potentially equating to a 60-70% increase in electricity costs. CAER’s research is directed at finding ways to minimize the de-rate and to reduce the capital cost associated with carbon capture. In addition, we are investigating other liquid/solid sorbents, post-scrubbing solution dehydrate, membranes, and absorption processes. Building on CAER’s 0.1 megawatt laboratory-scale plant, the next step will be a series of slip-stream investigations hosted and sponsored by DOE and CMRG’s member utilities using a portable 1 megawatt unit. The field studies represent a critical step in developing and demonstrating practical technologies for reducing CO2 emissions.
Researchers explore processes to transform unusable coal combustion by-products into marketable products.
Sustainable materials from coal ash

Coal combustion byproducts (CCBs) are created when we burn coal to generate electricity. The U.S. produces 125 million tons per year. About 40% is recycled and finds its way into everyday construction materials including: Portland cement components; masonry cinder blocks; road aggregate and fill sand; roofing shingles; wallboard; and polymer fillers. The remaining 60% was mainly disposed of in ash ponds and landfills adjacent to the nation’s power plants. Disposal costs are high, and landfill and pond space is limited, particularly in urban areas. Environmental and safety concerns have been raised about disposal practices. CAER’s investigations focus on finding, recovering, and separating combustion by-products, and processing them into useful materials.

Among our newer projects is one that could save lives. A technology developed by CAER and Minova North America called Tekcrete Fast™ and Tekcrete Fast M™ (with a specific application for mining safety), has been licensed by Minova, and can be used by engineers to stabilize damaged structures. It can be sprayed to reinforce the structure almost immediately, before it fails catastrophically. It is a high-strength, quick-setting concrete (which uses CCBs) and achieves set and structural strength in minutes. Original work was funded by the U.S. Department of Homeland Security, Science & Technology Directorate.
Research includes developing novel, asymmetrical capacitors employing ‘green’ materials and chemistries.
Batteries and capacitors for distributed power and hybrid electric vehicles

To harness the sun and wind for distributed power and to make electric-powered vehicles a reality, there is an urgent need to develop long-lasting and reliable electrochemical power sources like batteries and capacitors. We are investigating power sources with greater energy and power densities but also improved safety, low environmental impact and enhanced performance. Our research focuses on electrochemical capacitors, which are complimentary to batteries. Batteries store more energy and deliver it over longer periods whereas capacitors release quick bursts of energy. Our researchers use cheap sources of carbon to build the next generation of capacitors. The goal is to increase the specific energy density of activated carbons by using low-cost materials and simple, environmentally-benign activation schemes.

Other research includes the development of novel, asymmetric electrochemical capacitors also employing ‘green’ materials and chemistries. Under investigation are capacitors based on low-cost, aqueous electrolytes and advanced cathode materials taken from Li-ion battery technology.

CAER’s researchers collaborate closely with the Kentucky-Argonne Battery Manufacturing R&D Center located adjacent to CAER. We stand ready to assist the state’s goal of developing a viable battery manufacturing industry to serve a future market for hybrid electric vehicles.
Synthesis gas can be produced from a plethora of sources, including either fossil fuel or renewable resources.
Synthesis gas for clean fuels and chemicals

The Clean Fuels and Chemicals Group is a strong and well-established program at CAER with longstanding ties to the catalyst manufacturing and petrochemicals industries. The program concentrates on catalytic technologies for converting synthesis gas derived from fossil fuels and biomass to hydrocarbons, which can be upgraded to produce ultra-clean diesel, jet fuel, and other transportation fuels, as well as feedstocks for chemical synthesis. The group has built one of the foremost open-access catalyst testing labs in the world and is so strongly supported by industry, that in 1997 the CAER created a subsidiary - the Center for Catalysis Research and Testing. Interactions with companies striving to commercialize new or improved Fischer-Tropsch technologies ensure that CAER’s work remains highly relevant to their needs. With numerous highly-cited works of scholarship in the field, CAER’s work is also an exemplary model of academic research leading to practical results.

In the cutting edge area of hydrogen production for fuel-cell applications, the group has also made important contributions in light-alcohol reforming for hydrogen production, and has worked with companies on low temperature water-gas shift, a critical step in fuel processor technology for hydrogen purification.
At 100 feet, our bench-scale multifilament, continuous-tow, wet-spinline is one of the most robust in the country for developing novel precursors for carbon fiber.
Advanced carbon materials

Carbon fibers are the world’s strongest materials and have become a lighter, stiffer alternative to fiberglass. They are widely used in applications where high strength and stiffness, as well as low weight are critical such as in satellites, aircraft, and race cars. Our research, including carbon-fiber processing, structure and properties, encompasses the production of high-value carbon materials such as pitches, binders, cokes, active carbons, fibers and composites. These materials find applications ranging from adsorption to thermal management to structural components. Among the achievements of CAER was its recent commissioning of the largest carbon fiber spinline found in an academic setting. It is capable of producing enough fiber for prototyping near-finished carbon products (composites, foams, etc.) of great interest to commercial and government clients.

CAER also pursues cutting edge technologies related to synthesis and application of carbon nanotubes, which represent a whole new class of materials - 400 times stronger than steel but four times lighter. We seek to advance the scientific understanding of these materials as well as their practical application in energy, nanotechnology, medical, defense, aerospace and other industries.
Co-firing biomass with cleaned waste coal is an economical way to generate electric power, while reducing wasted resources.
Engineered fuels from waste materials

Our research shows that fine-coal waste that is discarded in slurry impoundments and gob piles can be combined with nearby biomass from hardwood forests, reclaimed surface mines, or energy crops to form a low-cost, cleaner-burning fuel. In briquetted form, these engineered fuels can be transported, stored, and processed in existing equipment without expensive capital modifications. Of equal importance, they provide an economical way to move biomass from regions where it is abundant to industrial or utility sites where it can be used in existing coal-fired boilers to generate heat and/or power. University research coupled with industrial collaboration has been instrumental in transitioning this technology from the laboratory to commercial readiness. It’s a win-win proposition for the environment: a clean-burning boiler fuel from materials that would otherwise be wasted.
The solar laboratory in the new building is designed to investigate manufacturing and commercialization aspects of low-cost PV technology, along with other thin-film technologies.
Solar energy research, prototyping and evaluation

A critical component in the design of the new CAER laboratory building includes expanded collaboration with UK’s solar energy faculty in the Department of Chemistry. The solar laboratory in the new building is specifically designed to investigate manufacturing and commercialization aspects of low-cost PV technology, along with other thin-film technologies such as solid-state lighting. Photovoltaic (PV) refers to the technology which a solar panel uses to produce electricity. Wet labs have been constructed to create new materials, including high-performance semiconductor inks, while clean rooms will be available for early PV module manufacture. Most importantly, several labs are equipped to allow the screening of these new PV technologies to determine power conversion efficiency, module stability, and weathering durability of the low-cost solar cells. These facilities are available to industry, to assist in establishing a PV manufacturing infrastructure in central Kentucky.

The key factor preventing widespread adoption of solar technologies for power generation is the cost of purchasing and installing the necessary photovoltaics. Researchers are investing a method to reduce PV cost by simplifying and accelerating manufacturing using high-speed printing techniques and low-cost electronic inks to produce light-weight, flexible and low-cost arrays. Converting these inks into paints, we have spray-painted solar cells onto surfaces, which could prove useful for temporary power generation in emergencies. PV cost reductions will also make it a viable technology in regions not typically considered for solar energy production, since the low cost of the panels will be paid off more quickly even with lower power output. While Kentucky is not an ideal location to use solar technologies to generate grid-level power, its renowned manufacturing infrastructure makes it an ideal location to manufacture PV technologies.
Studies provide information on ecological impacts of contaminants at the Paducah Gaseous Diffusion Plant.
Environmental remediation

Uranium enrichment for nuclear power generation and weapons production resulted in a legacy of contaminated waste sites at the U.S. Department of Energy’s civilian nuclear facilities, including the Paducah Gaseous Diffusion Plant in western Kentucky. Clean up challenges there include the contamination of water, soil and ecological resources from radioactive waste, metals, chlorinated solvents, and PCBs. Through an annual grant from DOE, the CAER is advancing the monitoring, clean-up, and remediation of the waste site, in addition to assisting the community in the “end-state” plan for the facility. Through the Kentucky Research Consortium for Energy and Environment (KRCEE), expertise and support is provided through university and industrial channels, continuing education, and development and application of technical advances. Since it was established in 2003, KRCEE has completed 22 projects to support DOE’s cleanup efforts. Completed projects include the development of GIS-based environmental data storage and retrieval systems; field characterization and remediation methodologies; and groundwater flow and transport models.
Public services demonstrate commitment to environmental stewardship and social responsibility.
Services and solutions for the state

CAER goes to great efforts in engagement, public service and outreach for Kentucky’s people, communities and industries through:

- Engaged research, technical consulting, and analytical and testing services that are applied, problem-focused, and solution-driven.
- Technology transfer, new-business development and job creation associated with emerging and advanced technologies.
- The provision of vital public information services.
- Targeted labor-force development and community-based learning, such as adult professional development and experiential education for K-12.
- Service in areas of professional expertise on community/company boards, commissions, study panels, and advisory committees.
- A commitment to environmental stewardship and social responsibility for the people and communities we serve.
Each year we service over 150 requests for basic analyses, technology evaluations, product tests and field studies from industry.
Applied research, engineering, and service to industry

Successive deployment of pioneering energy technologies creates a “learn-by-doing” or “learn-by-using” scenario. Experience leads to improvements in operating efficiencies and reductions in cost. CAER pursues its niche as an applied research institution by putting technology into practice. Our focus is on engineering scale-up, cost reduction, and production efficiencies; and on supporting at-scale demonstrations, technology maturation, and deployment. Our work often takes us to the field, the mine, the plant or the refinery.

CAER’s private sector interactions can also be measured by the extent of testing, consulting, and analytical services provided to industry. The Industrial Support program extends the Center’s analytical capabilities to include near-term, problem-solving research and testing for industry. Experienced professionals, along with cutting edge instrumentation and analytical services, combine to provide exceptional problem-solving capabilities tailored to specific client needs. Each year we service over 150 requests for basic analyses, technology evaluations, product tests and field studies.
The Center promotes UK’s objective of developing and benefiting from its intellectual property.
From ideas to reality: technology transfer and business development

Among our most important aims is to ensure that the benefits of investigations, research, and study are made available, applied, and used. Therefore, technology transfer and business development, along with the job creation that comes with it, are paramount objectives. The Center promotes UK’s objective of developing and benefiting from its intellectual property (IP) - its patents, inventions and trade secrets, which are the tangible results of CAER's research.

Developing and commercializing IP involves several steps, from an invention disclosure, to establishing proprietary rights through patents and trade secrets, to a license to use or practice the know-how. Finding licensees and demonstrating the efficacy of a particular innovation requires wide ranging technical discussions with client-industries. Samples and materials are often exchanged for testing, prototyping and cost-engineering. The licensee often requires collaboration in the early stages of process scale-up and product qualification. By common measures of technology transfer - invention disclosures, patents, licenses, and business start-ups - CAER's performance ranks well among peer institutes. A continuing effort to pursue collaborations with industry is also illustrated by the large number of companies that work with CAER under confidential disclosure, research, service and testing, and materials transfer agreements.
The Mine Map Repository is believed to be the largest collection of mine maps in the world.
Vital public information services

The Mine Map Repository [and its public GIS] has over 185,000 ‘paper’ coal mine maps dating to 1884, and is believed to be the largest collection of coal mine maps in the world. For over 25 years CAER has operated the repository for the Kentucky Office of Mine Safety and Licensing. The group helps to avoid disturbing oil and gas wells, aquifers, and other hazards below the surface, as well as buildings, highways and transmissions lines above ground. They also support mine safety and rescue, blasting, abandoned mines, reclamation, and environmental issues.

CAER staff also supports the Kentucky Division of Oil and Gas’ Risk Based Data Management System - a nationwide database serving the oil and gas industry and regulatory agencies. The system, which was conferred DOE’s prestigious “Energy 100 Award,” is intended to better focus domestic oil and gas exploration and production; safeguard the environment; and streamline permitting and reporting.
Our employees are involved in programs in their communities and professional organizations that are designed to interest young people in science.
Workforce development and community-based learning experiences

In addition to performing research, Center staff members teach, train, and provide experiential education for students at all levels – pre-college to post-graduate. At collegiate and post-graduate levels, we’re interested in targeted labor force development to address our nation’s critical shortage of scientists and engineers; skilled operators; and industrial specialists that will be needed to sustain energy industries. Our professional staff contributes to teaching; serves on advising committees; and mentors students. We are proud that our laboratory has served as the proving ground for hundreds of today’s best trained and skilled professionals.

We are keenly interested in the pipeline of tomorrow’s professionals. We are all about community-based learning experiences for adult professional development, and experiential education for K-12 and groups traditionally underrepresented in STEM disciplines. CAER offers a wide range of extended campus and specialized learning activities from short courses and conferences, to educational web sites and energy learning materials, to experienced-based internships and co-ops. Our employees are involved in their communities and professional organizations in programs to interest young people in science and to support vocational guidance and training. The staff is also involved in the local schools through participation on school councils, as organizers and judges of science fairs, and other extra-curricular activities.
Relationships matter

Organizations we have worked with have this to say about us . . .

Süd-Chemie Inc. is a leading producer of catalysts and has a major production facility in Louisville, Kentucky. The Center for Applied Energy Research has worked with Süd-Chemie for over 25 years in developing new and novel catalytic materials. Süd-Chemie’s commercial success has been a result, in part, of these materials innovations that have significantly improved our products and production methods.

Jürgen Ladebeck
Global Manager, Research & Development
Catalytic Technologies

LG&E and KU have worked closely with CAER over the last several years to initiate and expand a consortium of industry, government, and academia advancing carbon capture and management technologies. The consortium develops and demonstrates technologies to reduce and manage CO₂ in coal-fired electric power plants through carbon capture, utilization, storage, and plant efficiency improvements. These efforts are part of our larger long-term dedication and partnership with CAER.

Paul W. Thompson
Senior Vice President, Energy Services
LG&E and KU
Efforts are underway to examine the Center’s energy consumption and find ways to reduce it.
Energy efficiency and sustainability

It’s important that we practice what we preach. Our 1970s-era original laboratory building was not built using today’s energy conservation standards. However, recent efforts have examined the building’s energy consumption and found ways to reduce it. Among the conservation efforts are: re-lamping with more efficient lighting, using exhaust hood fans more efficiently, eliminating personal ink jet printers and replacing with fewer, larger laser printers at stations, and reducing lighting in areas that are overlit.

We are also working to ‘green’ UK’s main campus through installation of wind and solar demonstrations. Finally, the CAER is working closely with UK’s Office of Sustainability to help educate the university community on energy conservation to establish an institutional culture of sustainability.
UK College of Design models illustrate a 150 year plan for the Paducah, Kentucky Gaseous Diffusion Plant.
Lending our energy efficiency and sustainability expertise

Kentucky’s Houseboat to Energy Efficient Residences (HBEER) project directly responds to the impact the economic downturn had on the state’s houseboat manufacturing industry. With technical input from CAER, students and faculty from the UK College of Design developed models of energy-efficient, affordable housing that could be produced by the region’s houseboat manufacturers.

The estimated energy costs are about $1.65 per day, which is one-half to one-sixth of energy bills for other housing alternatives. More than 80 percent of the homes’ materials are derived from products made in Kentucky with Kentucky labor. The next phase of the project will include a prototype for multifamily housing as well as classroom space for energy efficient schools and more durable alternatives to portable classrooms. This partnership includes the Kentucky Highlands Investment Corporation (KHIC), and the Kentucky Housing Corporation (KHC).

In another joint College of Design enterprise, the CAER’s KRCEE (Kentucky Research Consortium on Energy and Environment), which oversees the cleanup of the Paducah Gaseous Diffusion Plant, is working with the UK CoD on sustainable possibilities and opportunities for the area in the future.

Students developed scale models of the site’s geographical features, its subsurface conditions, and the groundwater contaminant plumes. The models will be used as a tool to provoke conversation and debate among scientists and the public, with the hope of progressing toward removing and abating the groundwater contamination and its sources, and enabling a regeneration of the site and region.
The new building uses 54% less energy than similar buildings.
A Living Laboratory

The newest addition to the CAER campus is a 43,000 square foot laboratory that houses the renewable energy and energy storage research groups. The building is special for several reasons, including its many energy-saving features. These features include:

• An overall energy use reduction of 54% compared to a similar facility;
• Exterior walls and roof with twice the insulation normally used;
• Offices with active light sensors that automatically adjust fluorescent lights depending on available daylight;
• Geothermal heating and cooling system; and
• Monitors in the lobby that show current energy use and savings.

The living laboratory houses the research groups whose concentrations are: Biofuels and Bioenergy; Solar Energy Research Prototyping and Evaluation; and Electrochemical Energy Storage Research. The Electrochemical Group works closely with the Kentucky-Argonne Battery Manufacturing R&D Center through the development of new cell fabrication and manufacturing processes for advanced lithium-ion batteries for portable and bulk storage, as well as for the transportation sector. The Center is a collaboration among UK, the University of Louisville, Argonne National Laboratory and the Kentucky Energy and Environment Cabinet.
We pursue a multidisciplinary approach to research, and benefit from a wide range of university faculty, resources and departments.
The University Advantage

CAER’s research is applied and developmental, yet we pursue essentially the same objectives as UK’s colleges and departments: to encourage scholarship and a spirit of inquiry; generate knowledge and contribute to the body of literature; advance the state-of-the-art; and support the training and education needs of students. We pursue a multidisciplinary approach to research, and benefit from a wide range of university faculty, resources and departments throughout the physical and life sciences, and the applied sciences of agriculture and engineering. Among our most important objectives is to assure that research and investigations are carried out with a high degree of integrity, independence and objectivity that is expected of a first class academic institution.

There is a continuing effort to foster collaborations throughout the nation and internationally. CAER sponsors a number of study-abroad and other exchange programs for students, post-doctoral scholars, and visiting scientists from universities and research institutions spanning the globe, including participants from South America, Europe, the Middle East, Africa, Australia and Asia.
The University of Kentucky
Center for Applied Energy Research (CAER)

Welcomes opportunities to work with related businesses, associations, and government organizations. These partnerships leverage our scope of work, while introducing our expertise to new audiences.

To visit our center or find out more about CAER, please contact us:

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