

UNIVERSITY OF CALIFORNIA  
**UCRIVERSIDE** | **CE-CERT**  
BOURNS COLLEGE OF ENGINEERING  
CENTER FOR ENVIRONMENTAL RESEARCH AND TECHNOLOGY



**25**

**YEARS** OF INNOVATIVE  
RESEARCH

2016 ANNUAL REPORT  
(Published May 2017)

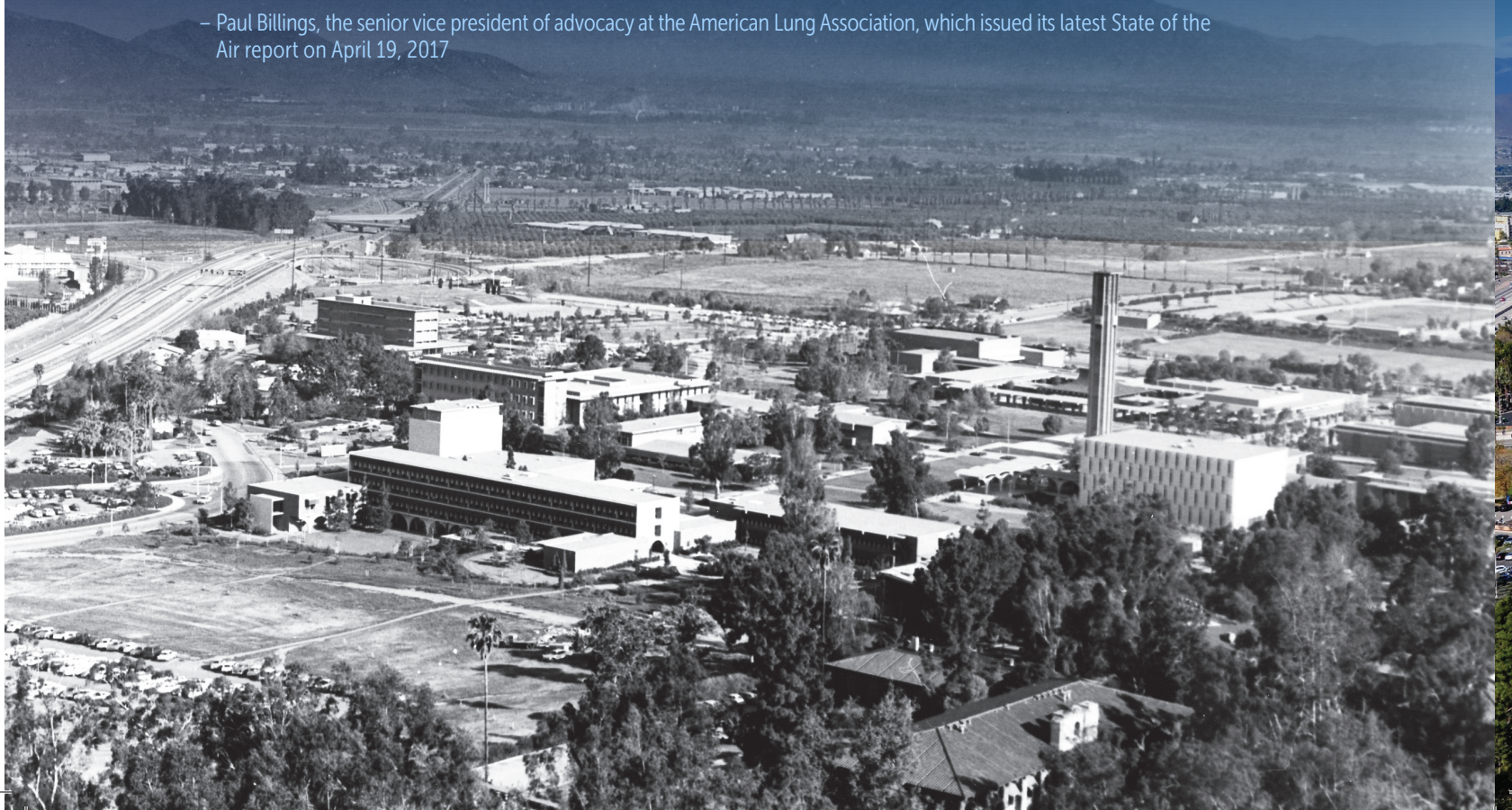


# CE-CERT 25 YEA

The collective efforts of regulatory agencies, industry and academia over the last three decades have resulted in monumental improvements to our nation's air quality, greatly reducing the health impacts from smog, including asthma, cancer, diseases such as Alzheimer's, and premature death. Our region in particular has arguably had some of the most impactful contributions to and benefits from cleaning up our air, in a large part due to the support from our community, the hard work of our state and local agencies, and groundbreaking research from academic institutions like ours. UC Riverside has certainly played a critical role, particularly in improving our understanding on how smog impacts our environment, beginning with the citrus experiment station over 60 years ago and more recently in understanding the detailed chemical mechanisms in the atmosphere that create ozone and secondary particles.

**"NO STATE HAS DONE MORE TO ADDRESS AIR POLLUTION THAN CALIFORNIA HAS DONE OVER THE LAST 50 YEARS. BUT THEY ALSO HAVE THE BIGGEST PROBLEMS,"**

– Paul Billings, the senior vice president of advocacy at the American Lung Association, which issued its latest State of the Air report on April 19, 2017





# RS OF HISTORY

Today our air quality is greatly improved, providing spectacular views of our local mountains that were not so visible in past years. However, our air quality is still far from healthy. In April 2017, Riverside County, with a population of over 2 million, received the unhealthiest air quality rating of an "F" for both ozone and particulate matter from the American Lung Association's National State of the Air report. Only through additional research, development, regulation, technology implementation and community engagement will we be able to meet the long elusive goal of clean air in our region. In the following pages, you will learn how CE-CERT at UCR is continuing to do our part to accelerate viable sustainable solutions in the energy and transportation sectors that will also promote cleaner air and improved quality of life for our community.

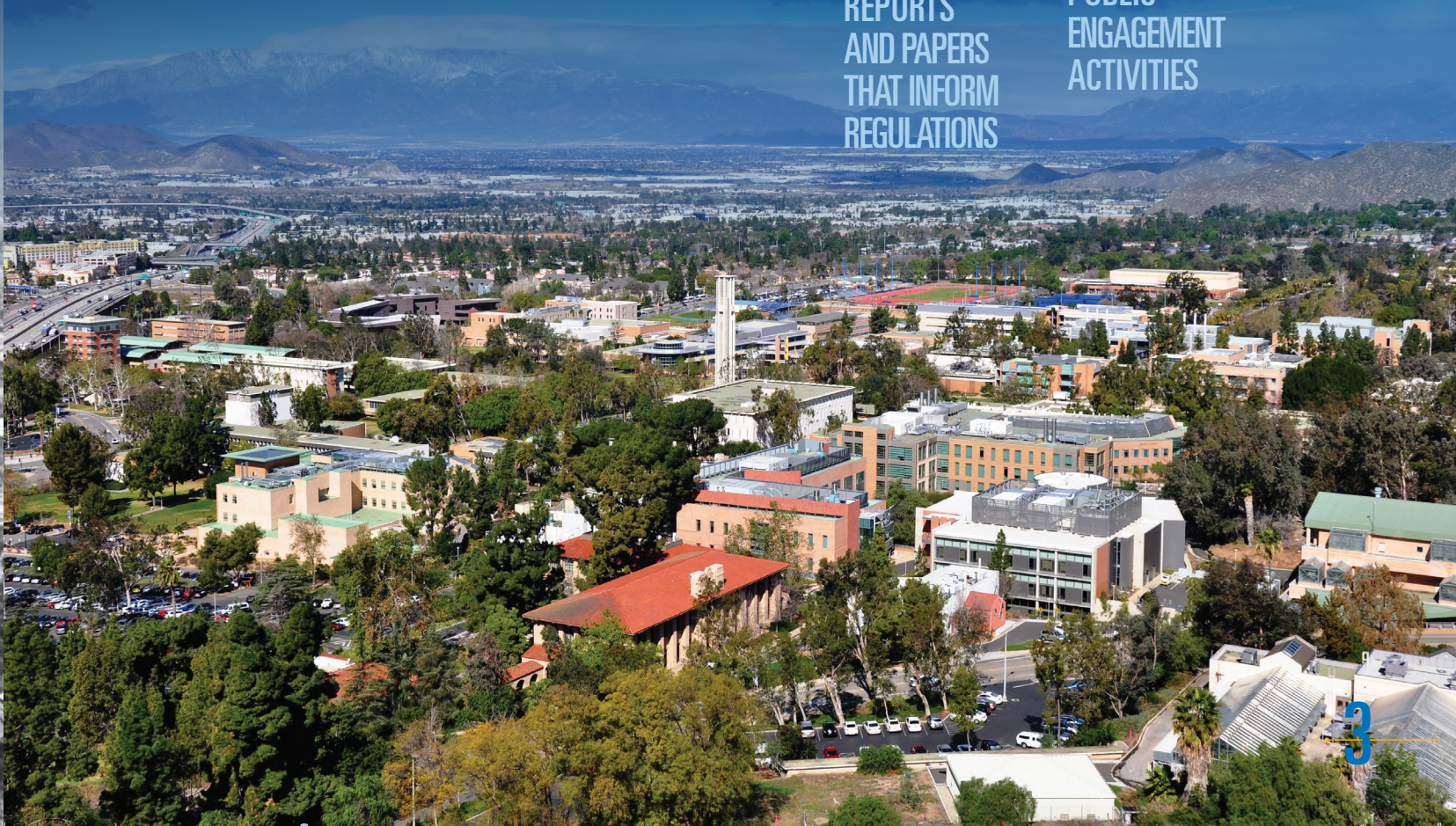
CE-CERT is proud to reflect on our modest role in this process, from our humble beginnings of our first year with \$300,000 in support to now over \$18 million dollars in active awards in 2016. Let's take a moment to look at CE-CERT's impact by the numbers:

**>150**  
EDUCATED  
GRADUATE  
STUDENTS

**>300**  
EDUCATED  
UNDERGRADUATE  
STUDENTS

**>1300**  
TECHNICAL  
REPORTS  
AND PAPERS  
THAT INFORM  
REGULATIONS

**>625**  
PUBLIC  
ENGAGEMENT  
ACTIVITIES





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# WELCOME TO THE COLLEGE OF ENGINEERING CENTER FOR ENVIRONMENTAL RESEARCH AND TECHNOLOGY



## MISSION

The distinctive mission of the University of California is to serve as a center of higher learning, providing long-term societal benefits through transmitting and discovering advanced knowledge and functioning as an active working repository of organized knowledge. CE-CERT's mission addresses all three aspects of UC's overarching mission: research, education, and public service in the areas of air quality, transportation, and energy.

## FOCUS

CE-CERT's research focus is on using technology to achieve environmental sustainability, an ambitious goal that requires innovation in many different areas. From working to understand how emissions impact air quality to developing the technologies needed to improve solar and other renewable energy sources, our research teams are currently engaged in supporting one or more of the five focus areas listed below:



### CLEAN AIR

Understanding how emission sources react in the atmosphere to form toxics, ozone (smog), and particulates that impact human health



### RENEWABLE FUELS

Life-cycle analysis ranging from creating renewable fuels from landfill waste and biomass (e.g. green waste) to improving technologies that use these fuels to run efficiently and safely



### SUSTAINABLE TRANSPORTATION SYSTEMS

Environmentally-friendly intelligent transportation systems, eco-driving applications, and advanced vehicle integration



### RENEWABLE ELECTRICITY AND SMART GRIDS

Advanced solar energy production, energy storage, energy distribution and management



### CLIMATE CHANGE IMPACTS

Measuring and predicting impacts of man-made emissions (e.g. power plants) and natural emissions (e.g. wildfires) on greenhouse gases and cloud formation

In this report, we highlight research areas and notable CE-CERT accomplishments in 2016.



# SUSTAINABLE INTEGRATED GRID INITIATIVE (SIGI)

## Intelligent Energy Management – Moving Research to Market

CE-CERT works with schools, government agencies and private industries to assist in installing efficient energy systems that provide renewable electricity, support electric vehicle operations, and minimize costs and disturbances to the electric grid.

Our SIGI research testbed, now operational for over two years, is one of the most versatile systems of its kind, allowing for the testing and demonstrating of interchangeable technology prototypes, highly reconfigurable systems, and an open source energy management platform. The testbed continuously collects a wide array of data on the performance and characteristics of each component – for example, the efficiency of the inverters, the state of health and aging of the batteries, and the surface temperature of the solar panels – to help evaluate the benefits of various strategies under different conditions and building types. The researchers at UCR use the information from our testbed and other deployments to study the many configurations and technologies that can comprise efficient microgrid systems. The SIGI testbed has now spawned several new systems across the state.

**TRANSFORMING  
EXISTING BUILDINGS TO  
NET ZERO BUILDINGS  
COST EFFECTIVELY  
USING THE LATEST  
TECHNOLOGIES**



### SIGI SYSTEMS THROUGHOUT CALIFORNIA

#### **Chemehuevi Hotel & Casino**

AZ/CA Border

#### **Cucamonga Valley Water District**

9029 Archibald Avenue, Rancho Cucamonga, CA 91730

#### **Inland Empire Utilities Agency Regional Plant 4**

12811 6th Street, Rancho Cucamonga, CA 91739

#### **Olivenhain Municipal Water District**

19090 Via Ambiente, Rancho Santa Fe, CA 92067

#### **UCR Main Campus**

900 University Avenue, Riverside, CA 92507

#### **Victor Valley Wastewater Reclamation Authority**

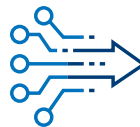
20111 Shay Road, Victorville, CA 92394





## THE SIGI TESTBED HAS THE FOLLOWING KEY FEATURES, SITUATED THROUGHOUT RIVERSIDE:

- 4 megawatts of photovoltaic generation
- 2 megawatt-hours of battery energy storage
- 27 electric vehicle charging stations
- Monitoring of 7 building loads



- An electric-powered trolley
- Energy monitoring and smart dispatch to buildings and EVs
- Open architecture designed for expansion

### WHAT MAKES THIS TESTBED UNIQUE?



#### Renewable Solar Generation

- D** Solar arrays
- B** Provides renewable generation to offset utility usage



#### Energy Management System Algorithms

- D** Can be configured for net zero applications, or minimizing cost, or minimizing carbon
- B** Open source software that overlays on an existing system to provide cost effective conversion



#### Storage

- D** Li-ion battery or other battery storage, hydrogen, RNG or other fuel source
- B** Reduces electricity bill by up to 40%



#### EV Charging

- D** Can provide level 2 or level 3 charging
- B** Can provide workplace charging at no cost to the employer
- B** Enables Vehicle-to-Grid Research

INDUSTRIES AND UTILITIES HAVE THE UNIQUE OPPORTUNITY TO PUT SIGI TO USE TO ADDRESS NEEDS IN:

1

Renewables and Distributed Energy Resources (DER) integration

2

Grid modernization, including control, optimization, and communications

3

Customer-focused products and services enablement

**“SIGI OFFERS A GREAT DEGREE OF FLEXIBILITY IN TECHNOLOGY EVALUATION”**



# RENEWABLE NATURAL GAS (RNG)

## Reducing Greenhouse Gases by Developing California's RNG Market

**T**he mission of CE-CERT's latest Center for Renewable Natural Gas (CRNG) is to facilitate the adoption of renewable natural gas technologies by developing and validating proof of concepts through design, modeling, construction, and demonstration of pilot scale testbeds.

The Center leverages on-going research and collaborations to address the technologies, processes, and policy issues around the commercialization of renewable natural gas. Each of these will undergo a holistic analysis on issues such as resource availability and utilization, infrastructure availability and challenges, life cycle and techno-economic analysis, and market and policy analysis to ensure success in the marketplace.

The Center also recognizes the importance of education and outreach, and actively works toward these goals by providing the latest research-based information to help utilities, policy makers, and the public update their existing paradigms around RNG.

**"RNG IS AN IMPORTANT ALTERNATIVE FUEL THAT CAN HELP THE STATE OF CALIFORNIA MEET SEVERAL GREENHOUSE GAS (GHG) AND RENEWABLE ENERGY TARGETS. AS A TRANSPORTATION FUEL, RNG CAN RESULT IN APPROXIMATELY 90% REDUCTION IN GHG EMISSIONS"**

**RNG IS FULLY INTERCHANGEABLE WITH FOSSIL FUEL NATURAL GAS BUT IS PRODUCED FROM RENEWABLE FEEDSTOCK AND CAN BE USED AS A 100% SUBSTITUTE FOR, OR BLENDED WITH, CONVENTIONAL NATURAL GAS.**

### CORE BENEFITS OF RNG



GHG Reduction



Energy Storage  
Solution



Improved  
Public Health



Vehicle Emissions  
Reduction



Economic/  
Job Development



Sustainable Waste  
Management



## CRNG FOCUS AREAS

### 1 HIGH YIELD THERMOCHEMICAL RNG PRODUCTION

Develop cost-effective technologies to commercially produce fuel-grade RNG from carbonaceous waste (e.g. forest biomass, agricultural residue); Address wide-scale adoption barriers such as feedstock logistics/pretreatment challenges, tar formation, gas cleanup, and high capital costs

### 2 POWER-TO-GAS PRODUCTION

Develop cost-effective systems to convert excess renewable electricity into hydrogen or methane as a means to increase the renewable energy content of the pipeline infrastructure while addressing grid capacity and storage issues

### 3 METHANATION PATHWAYS

Optimize hydrogen conversion to methane, especially in the power-to-gas context where direct hydrogen injection into pipeline or long term hydrogen storage is not viable

### 4 LIFE CYCLE AND TECHNO-ECONOMIC ANALYSIS

Conduct systems-level analyses of RNG production pathways to evaluate greenhouse gas and criteria pollutant emissions, material and energy balances (efficiencies), and commercial viability (economics)

### 5 ANAEROBIC DIGESTION

Optimize digestion pathways and technology options and address logistic and cost issues associated with feedstock collection and conversion

CURRENTLY, CALIFORNIA  
PRODUCES LESS THAN  
**1%** OF THE U.S. NATURAL  
GAS SUPPLIES

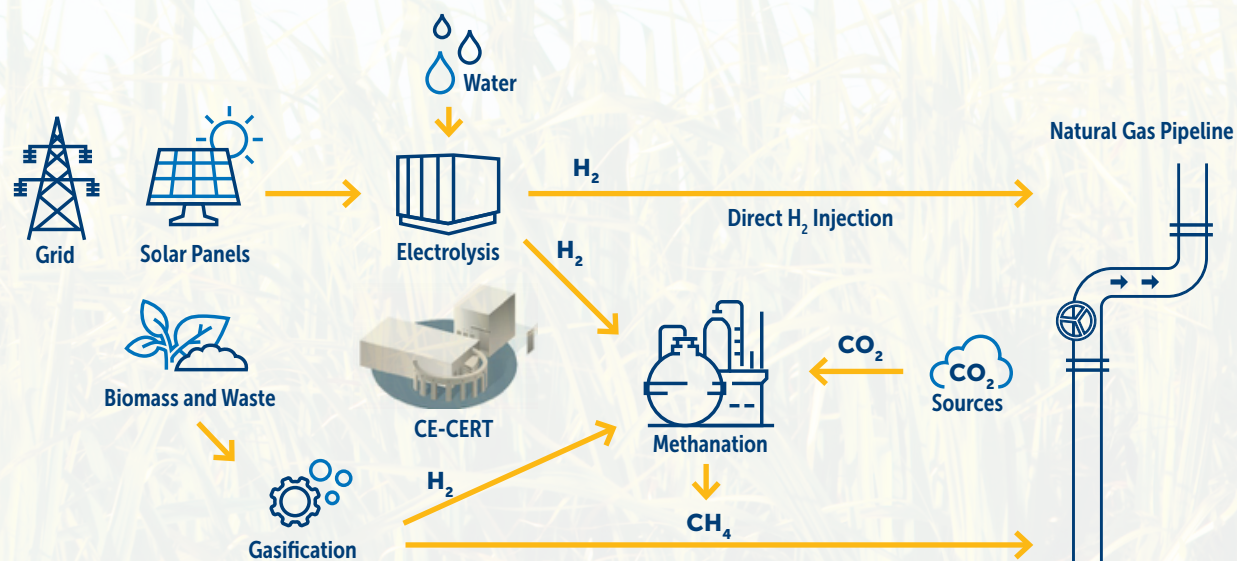
AND IMPORTS MORE THAN  
**90%** OF ITS SIGNIFICANT QUANTITIES OF  
NONRENEWABLE NATURAL GAS.



#### Accomplishment

Developing the steam hydro-gasification process from the conceptual phase to an operational process demonstration unit is a key example of improving commercial waste to energy technologies. The process, which is the culmination of the work of many researchers and students and has resulted in multiple patents, supports the goal of converting biomass into clean fuel in an efficient, cost-effective manner.

## RNG PRODUCTION





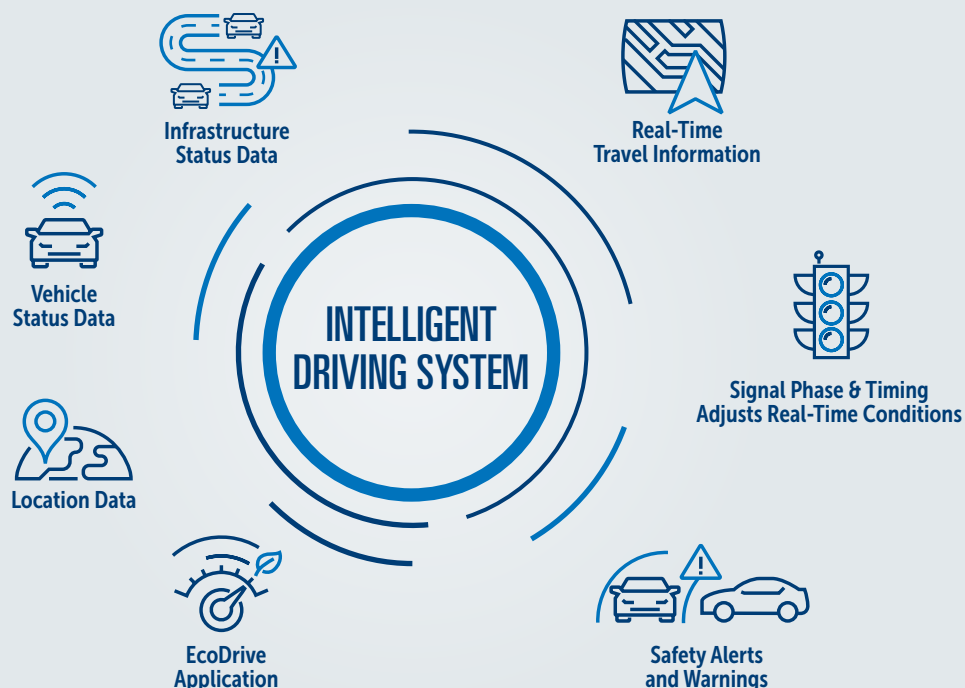
# TRANSPORTATION SYSTEMS RESEARCH

Building Smarter Cities by Improving Efficiency and Reducing Environmental Impacts through Intelligent Vehicles and Advanced Transportation Infrastructure

CE-CERT's Transportation Systems Research group is breaking new ground in the move toward intelligent transportation systems that use automation and communication to make the transportation of both people and goods safer, faster, and more fuel efficient.

Connected and automated vehicles use sensors and communicate with each other, and with advanced roadway infrastructure (e.g. traffic signals), to share information about traffic and road conditions and to automate vehicle operations to create the most energy efficient trip conditions possible. Dynamic eco-driving techniques utilize vehicle connectivity to improve user behaviors to achieve "green" trips that maximize fuel efficiency and minimize emissions.

CE-CERT researchers are now carefully examining the impacts of route, roadway characteristics, and traffic conditions on vehicle powertrain operations. This is particularly important for hybrid electric and other new types of vehicles. CE-CERT is using innovative testing technologies such as their dyno-in-the-loop setup (see inset) to identify the most efficient way to operate a vehicle.





This year, we are combining vehicle dynamics and powertrain controls in a project that will have a transformative impact on the fuel efficiency of one of the most widely used modes of public transportation. A team of CE-CERT researchers was awarded \$2.8 million by the U.S. Department of Energy's Advanced Research Projects Agency-Energy (ARPA-E) to create an "innovative powertrain eco-operation system" to increase the efficiency of plug-in hybrid electric buses. Data from on-board sensors and wireless communications will allow for a global optimization of vehicle dynamics and powertrain parameters (e.g., vehicle speed and acceleration, engine speed and torque, gear ratio, power split between internal combustion engine and electric motors) together in response to external system states in order to achieve optimal system energy efficiency. The target for the new generation buses is to achieve an energy consumption reduction of at least 20%, while maintaining existing performance characteristics and meeting stringent emissions and low NOx (oxides of nitrogen) standards in effect today.

**THE PROPOSED VEHICLE-  
POWERTRAIN ECO-OPERATION  
SYSTEM IS EXPECTED TO ACHIEVE  
THE ENERGY CONSUMPTION  
REDUCTION TARGET OF AT LEAST  
20% RELATIVE TO A 2016  
BASELINE VEHICLE.**



## DYNO-IN-THE-LOOP

CE-CERT researchers have recently developed a "dyno-in-the-loop" concept that allows for more realistic and cost effective vehicle performance and emissions testing. The concept takes advantage of vehicles being "connected" in the real world, and using data transmitted from an on-road probe vehicle to "drive" a vehicle on a dynamometer, thus eliminating the need for on-site testing in geographically distant locations. This concept also avoids limitations of "driving cycles" by linking high fidelity traffic simulation models in which the speed and associated loads of individual vehicles on a detailed roadway are translated to the test vehicle on the dynamometer. CE-CERT is currently carrying out both approaches in their ARPA-E Connected Eco-Bus project and in their Connected Vehicle Pilot Deployment (CVPD) project.



# SUSTAINABLE FREIGHT

## The Impact and Importance of Sustainable Goods Movement

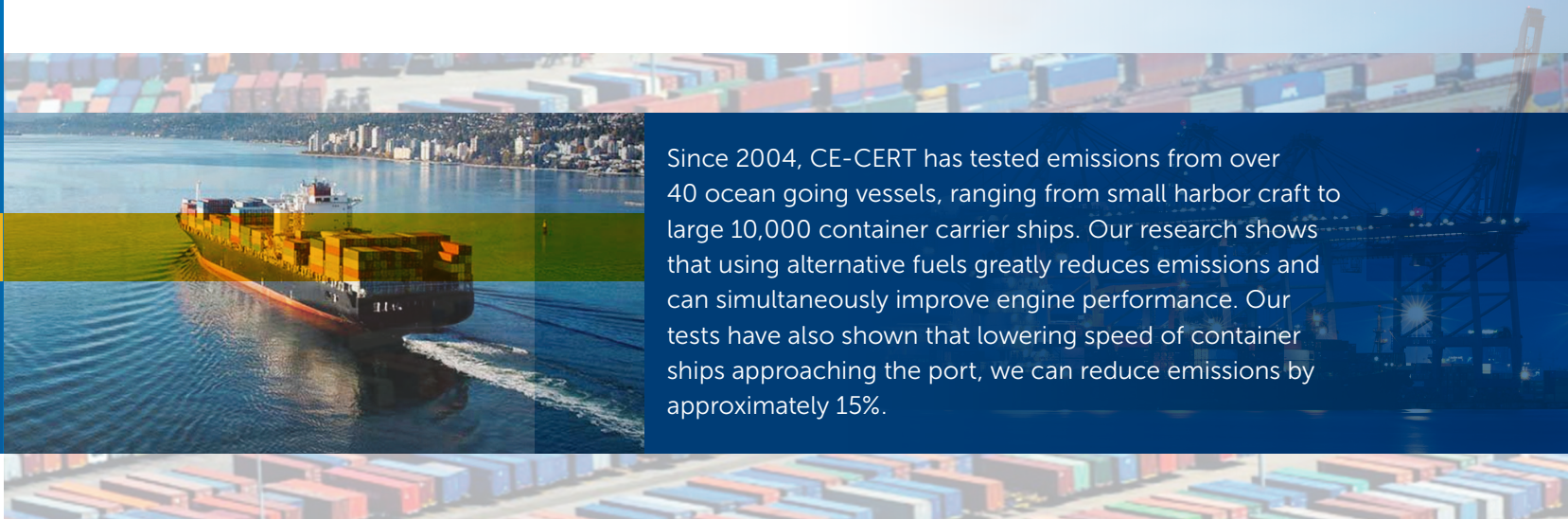
America's seaports generate more than \$4.6 trillion in economic activity, support the employment of more than 23 million people and handle some 2.2 billion tons of import, export and domestic cargo annually, which leads significant and energy consequences. Heavy-duty trucks (HDT) are a critical component of the U.S. freight movement system to deliver goods from ports to communities; however, these trucks consume a large amount of fuel and emit significant emissions, namely greenhouse gases (e.g., CO<sub>2</sub>) and air pollutants PM and NOx. In order to combat these issues, the freight industry is continuing to evolve where more recent efforts are focused on intelligent and efficient logistic centers. At CE-CERT, we are addressing how to make freight movements more sustainable through research and projects in the following areas:

- Integrated transportation air quality modeling at the regional scale to quantify future impacts from transportation growth and recommendations for smart growth
- Health benefit and cost analysis of accelerating heavy duty fleet turnover in the Inland Southern California region
- Application of modeling tools to accurately estimate transportation and air quality impacts at the local (neighborhood) scale
- Developing advanced heavy-duty truck routing algorithms for congestion and emission mitigation
- Validation of new heavy-duty engine technologies such as the new natural gas engine (right insert) and fully electric trucks
- Innovative freight-ramp control with merging assistance
- Development of cooperative freight intersection management systems for urban arterial networks
- Innovative managed lane system solutions for mitigating traffic impact
- Measurement of emissions from ocean going vessels and marine engines (top right)



**SHIPS USE FUEL WITH HIGH SULFUR PRODUCING AIR POLLUTANTS AND BLACK CARBON, WHICH DEplete ICE CAPS AND CONTRIBUTE TO GLOBAL WARMING. CURRENT TECHNOLOGIES REMOVE ONLY PARTICLES, BUT THE NEWEST TECHNOLOGIES TESTED AT CE-CERT (PICTURED) PROVIDES REMOVAL OF GAS AND PARTICLE PHASES OF SULFUR OXIDES IN EXCESS OF 95%.**





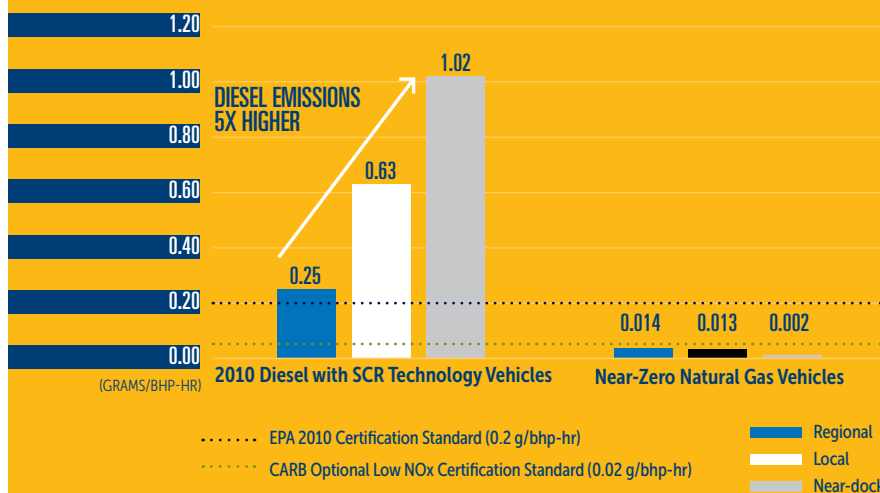
Since 2004, CE-CERT has tested emissions from over 40 ocean going vessels, ranging from small harbor craft to large 10,000 container carrier ships. Our research shows that using alternative fuels greatly reduces emissions and can simultaneously improve engine performance. Our tests have also shown that lowering speed of container ships approaching the port, we can reduce emissions by approximately 15%.

## 42% OF OUR NATION'S GOODS ARE RECEIVED AND DISTRIBUTED TO THE REST OF THE UNITED STATES THROUGH THE PORTS OF LOS ANGELES AND LONG BEACH.



With the near-zero emissions, natural gas vehicles are now available to move goods across the nation from our local ports. It is expected that these vehicles will play an important role in providing much needed emissions reductions required for the South Coast Air Basin and California to reach federal air quality attainment standards.

### COMPARING NO<sub>x</sub> EMISSIONS IN PORT TRUCK OPERATIONS



#### » NATURAL GAS VEHICLES EMITTED LOWER NO<sub>x</sub>:

Our research has shown that the ISL-G natural gas engine emits lower NO<sub>x</sub> emissions than its EPA certification standard. Emissions decreased as the duty cycles decreased (i.e., slower speeds, idling, stop-and-go traffic).

#### » DIESEL VEHICLES EMIT UP TO 5X HIGHER NO<sub>x</sub>:

2010 diesel engines with SCR technology emitted up to 5 times higher NO<sub>x</sub> emissions than its EPA certification standard. Emissions increased as the duty cycles decreased.

While port applications are illustrated in the figure above, CE-CERT also tested refuse and transit applications and found that they provided similar comparative results. These duty cycles represent a significant majority of heavy-duty vehicle trips in the South Coast Air Basin and in other urbanized areas.



CE-CERT's role as an independent and objective engineering research center has had a broad impact in improving the environment we live in and the air we breathe. We remain committed to helping accelerate our clean energy future. In our laboratories and in real-world settings, researchers test and evaluate proposed environmental policies for regulatory agencies prior to the rules being introduced into the public domain.

# CELEBRATING 25 YEARS OF

## UNDERSTANDING EMISSIONS PRODUCED FROM NEW TRANSPORTATION FUELS AND VEHICLES

### Leading Research on Emissions and Performance in Vehicles, Trucks and Ships

Early on, CE-CERT pioneered advanced testing technologies in our fully mobile emissions laboratory and portable emission measurement systems for criteria pollutants and greenhouse gases from all types of modes of transportation.

We have shown new ultra-low NO<sub>x</sub> natural gas heavy-duty vehicles are cleaner than their certification standards during a full range of duty cycles; CE-CERT is also a key leader in the measurement of ocean vessels emissions, which has been shown to dramatically impact the Southern California region.

CE-CERT now houses one of the best-equipped university emissions laboratories in the world, where researchers are continuing the study of energy and environmental impacts of advanced emission controls, reformulated and alternative fuels.

## RESEARCHING THE CRITICAL ROLE OF SECONDARY AEROSOL FORMATION

### Ground Breaking Atmospheric Research

In the late 1990s, CE-CERT revolutionized how we study SOA's by being one of the first to demonstrate the critical role of gas phase chemistry in the formation of secondary organic compounds.

Since then, CE-CERT developed a "next-generation" chamber for studying the atmospheric processes that form ozone and fine particulate pollution. Over 4600 experiments have been conducted in this chamber, each providing new data to understand the processes by which hydrocarbons and nitrogen oxides photochemically react in the atmosphere to produce secondary gaseous and particulate emissions.

We now realize that the atmosphere is even more complicated and even smaller particles (so small these particles can pass through to the inside of cell walls) are impacting human health and the environment. CE-CERT continues to investigate inhalable particles and are teaming with UCR's School of Medicine to help better understand what happens with long-term exposure.



Largest indoor chamber in the world is completed



1992

CE-CERT  
Established



Mobile Emissions Laboratory:  
on-road testing of heavy-duty vehicles



The future of CE-CERT lies in bringing new technologies to the marketplace, including finding a way to make technology more cost-effective. A key question is "How do we scale these technologies up affordably?"

Looking to the next 25 years, we will continue to focus on clean energy and cost effective energy storage. We will maintain a strong focus on innovative transportation solutions as well as alternative fuels research, renewable natural gas and cellulosic ethanol production through processes of renewable food sources. Finally, we will pursue new ways of collecting in-use emissions data from vehicles and other sources, to ensure new technologies do not have adverse health and environmental impacts.

# INNOVATIVE RESEARCH

## VANGUARDS OF INTELLIGENT TRANSPORTATION SYSTEM TECHNOLOGIES

**Focusing on making transportation more efficient, intelligent, safer and better for the environment**

In the 90's, CE-CERT demonstrated what was then a new concept of "carsharing" called "UCR IntelliShare". This system evolved and provided several key patents to the deployment of various automated shared-use vehicle systems using all kinds of environmentally friendly vehicles.

CE-CERT pioneered modal emission modeling tools for predicting instantaneous emissions based on vehicle type, traffic conditions, roadway configuration, and even driver habits. This modal approach was used in defining EPA's new generation of regulatory models.

The Center also uses these models and real time data to develop innovative connected and automated vehicle applications that include eco-driving, integrating predictive cruise control, and predicting optimal vehicle acceleration and deceleration to minimize fuel consumption.

## ESTABLISHING INNOVATIVE BIOENERGY TECHNOLOGIES

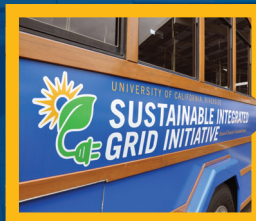
**Helping Bring to Market Viable, Affordable, Renewable Transportation Fuels**

CE-CERT has been advancing technologies to lower the cost of producing renewable fuels over the 10 years of funding from the Bioenergy Science Center. The objective of the program is to promote sustainable commercialization of renewable fuels that will compete with mature technologies in the current market.

CE-CERT created a patented method of converting raw agricultural and forestry residues and other plant matter to help solve the long elusive goal of producing fuels from biomass at high enough yields to become a cost effective alternative for petroleum-based fuels and chemicals.

Recently, CE-CERT has employed an advance biomass-conversion technology in a modular and scalable system to efficiently produce electricity and liquid fuels from virtually any plant matter. With our renewable energy solution, we can enable communities the potential to grow their own power locally, create jobs, and generate revenue within the community to foster further economic growth and societal development.

CE-CERT becomes founding member of BioEnergy Science Center BESC: a center viable ethanol transportation fuel industry based on non-food sources



Sustainable Integrated Grid Initiative: successful integration of intermittent renewable energy, energy storage and all types of electric and hybrid electric vehicles

2017



CE-CERT demonstrates the value of connected and automated vehicles at the Federal Highway Administration

CE-CERT  
Turns 25

For a more complete timeline see <http://www.cert.ucr.edu/25th/>



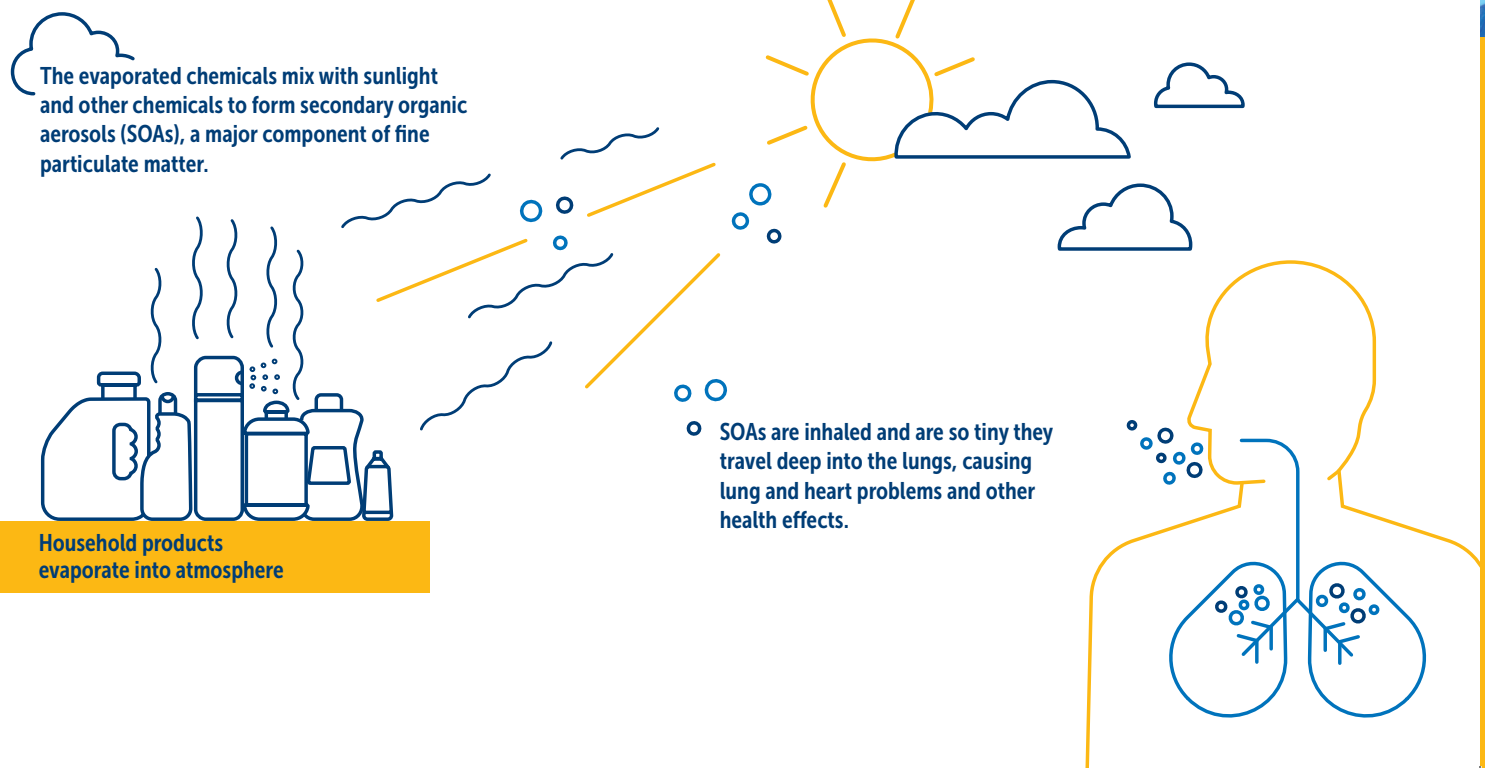
# ATMOSPHERIC PROCESSES RESEARCH

## Using Science to Create More Cost Effective Regulations

**W**ith access to one of the largest and most technologically-advanced atmospheric chamber in the country, it should come as no surprise that the Atmospheric Processes Research group has produced an impressive body of work to characterize how air pollution is formed from emissions of major sources - everything from transportation to forest fires to cattle. What may be surprising, is that this year much of the activity in the chamber focused on a seemingly innocuous source - consumer products.

Consumer products include products that individuals households and businesses use on a daily basis, including cleaning solutions, paint, and solvents. When used, some of the chemical components evaporate into the atmosphere, where they react with other chemicals and sunlight to create air pollutants such as ozone and secondary particulate matter. These air pollutants cause a myriad of health concerns, such as cancer and respiratory and cardiovascular diseases. The state has developed regulations based on current science (predominately vapor pressure) to minimize these health impacts.

### VOLATILE ORGANIC COMPOUNDS (VOCs) LEADING TO LONG-TERM ADVERSE HEALTH EFFECTS





Recognizing that better science is needed, the California Air Resources Board sponsored CE-CERT's research team to determine what other factors should be considered to reduce health impacts. Researchers tested each chemical in the chamber to measure if it evaporates into the atmosphere and once there, how much it contributes to pollutant formation. Surprisingly, results show that some currently permitted chemicals (based on vapor pressure) make a significant contribution to pollutant formation, while some currently prohibited chemicals do not show significant pollutant formation. This data can be used to improve future regulations.

**CONSUMER PRODUCTS  
ACCOUNT FOR OVER**

**12%**

**OF ALL VOLATILE ORGANIC  
COMPOUNDS (VOCs)  
EMISSIONS IN THE STATE.**

**THE RESEARCH INFORMS  
REGULATORS TO CREATE IMPROVED  
POLICIES THAT LEAD TO HEALTHIER  
AND ECONOMICAL CONSUMER  
PRODUCT USE IN CALIFORNIA.**



Studying secondary aerosol formation from a variety of fuels in the Portable Chamber.

In addition to consumer product research, the atmospheric processes team is currently working with the South Coast Air Quality Management District to study how different varieties of fuel sold in Southern California (such as gasoline and diesel) form secondary organic aerosols. This project will also measure how fuel evaporation will impact smog forming behavior in the future (e.g. our future atmosphere will have lower NO<sub>x</sub> levels, which changes the chemistry of smog formation).



# AQUEOUS BIOMASS PROCESSING

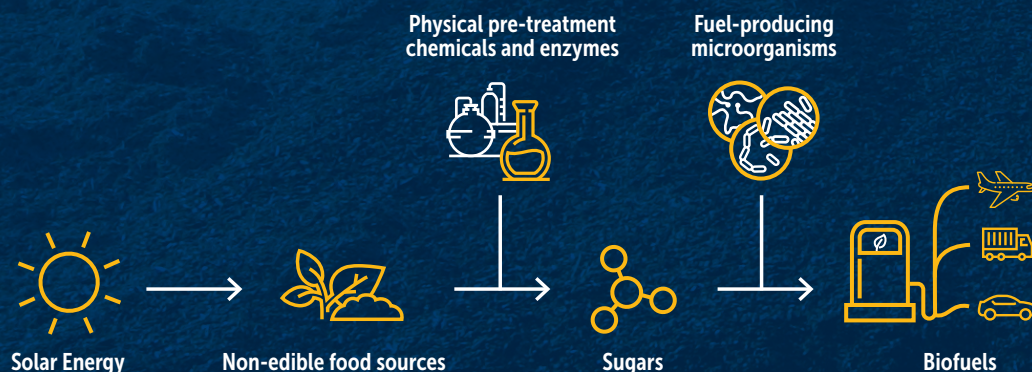
## Taking Biofuels from Lab to Market

Over the 10 years of the BESC Program (BioEnergy Science Center is a multinational, Department of Energy-funded research organization focused on creating sustainable cellulosic biofuels), the Aqueous Biomass Processing (ABP) research group advanced the state of conversion of biomass into commercially viable biofuels.

In 2016, the group has built this previous work to create integrated biorefineries to produce ethanol, high value polymers, and chemicals from through the Biomass Research and Development Initiative (BRDI) program, a joint program funded by the USDA's National Institute of Food and Agriculture and the Department of Energy. The ABP research group is using its \$1.3 million share to explore technologies that have the potential to change the world by increasing its energy supply, reducing its emissions, and developing new economic markets. One of these technologies is Co-solvent Enhanced Lignocellulosic Fractionation (CELf), a process that involves the addition of the co-solvent tetrahydrofuran (THF) to augment the aqueous pretreatment of biomass. CELf addresses one of the more difficult steps in the conversion process; the dissolution of lignin, which acts as a glue in plant cell walls and is traditionally resistant to breakdown.

**LIGNOCELLULOSIC BIOMASS INCLUDES WOOD CHIPS, GRASSES, CORN WASTE PRODUCTS, AND SIMILAR ITEMS. THESE WASTE PRODUCTS ARE ABUNDANT, RENEWABLE, AND NOT COMPETITIVE WITH FOOD PRODUCTS, BUT VERY EXPENSIVE TO PROCESS IN TERMS OF BOTH MONEY AND ENERGY**

### BIOFUEL LIFE-CYCLE



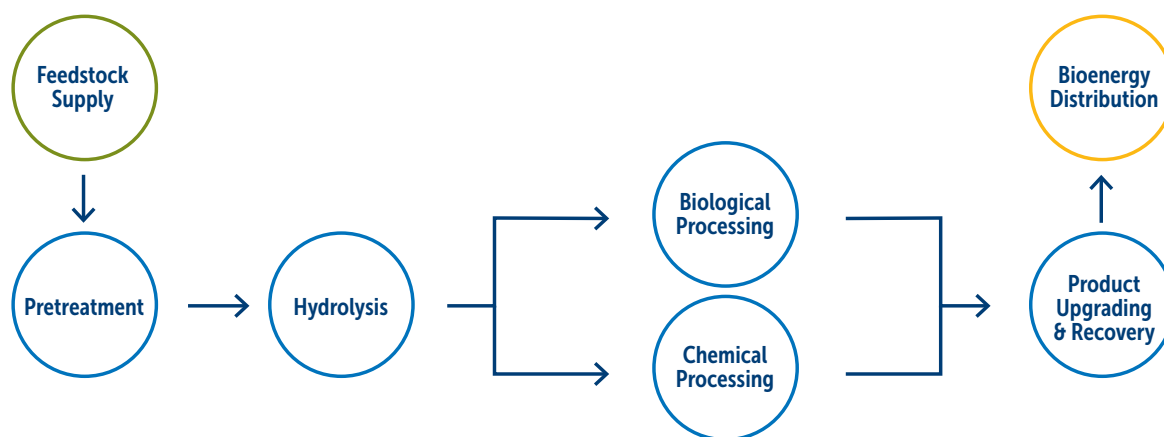




## STUDENT DISCOVERY HAS THE POTENTIAL TO BREAK THE BIOFUELS COST BARRIER

A major factor in the prohibitive cost of commercializing biofuels is the enzymes required to break down the biomass into products that ferment to produce fuels. The enzymes are expensive, and have a limited lifetime after which they 'deactivate' and stop the conversion process. Samarth Bhagia, along with the ABP group, helped discover the mechanism that causes these enzymes to deactivate at low loadings. This information will enable researchers to disable this mechanism, dramatically improving the longevity of the enzymes and lowering costs of one of the most expensive steps in biomass conversion.

**THE ABP GROUP, WITH THE GENEROUS SUPPORT OF ITS SPONSORS, IS WORKING TO MAKE THE WASTE BIOMASS TO ENERGY MANUFACTURING PROCESS AND ITS PRODUCTS MORE EFFICIENT, QUICKLY, AND LESS EXPENSIVE.**



Current CELF research has provided critical information about the amount (load) of enzymes needed to generate fuel, and its compatibility with existing processes such as consolidated bioprocessing (CBP). Researchers found that a very high concentration of ethanol can be achieved at moderate enzyme loadings by applying CELF fractionation technology, and that CBP is highly synergistic with CELF in terms of biomass deconstruction rates compared to the benchmark dilute acid pretreatment technology.



# OUR DONORS: MAKING AN IMPACT ON THE WORLD



## GRADUATE STUDENT HIGHLIGHT

**JIACHENG YANG**

**WILLIAM R. PIERSON/FORD GRADUATE FELLOWSHIP RECIPIENT**

### RESEARCH FOCUS

Understanding different categories of emissions (small off road diesel engines, light duty vehicles, heavy duty trucks, and ocean going vessels), and the impact of aftertreatment technologies on the reduction of emissions and fuel efficiency.

### AWARDS AND ACCOMPLISHMENTS

- Two-time Best Student Poster at the 26<sup>th</sup> and 27<sup>th</sup> Coordinating Research Council (CRC) Real World Emissions Workshop
- Reviewer for Journal of Air & Waste Management Association (AWMA) and Society of Automotive Engineers (SAE)
- Published 5 peer reviewed journal articles in 2016

### HOW HE'LL CHANGE THE WORLD

Jiacheng's research will help ocean going vessels do their part to keep our air clean. His work has provided critical information to agencies such as the US Environmental Protection Agency, the California Air Resources Board, and the International Maritime Organization for use in regulation design. He is currently developing better methods of measuring emissions such as black carbon, and improving existing scrubbing (filtration) technologies.

## 2016 AWARD WINNERS

- William R. Pierson/Ford Graduate Fellowship:  
Jiacheng Yang, Chemical and Environmental Engineering
- Ford Undergraduate Scholarship:  
Robert Espinoza, Chemical Engineering
- Colin E. Hackett Endowed Engineering Research Award:  
Partho Roy, Chemical and Environmental Engineering
- Esther F. Hays Graduate Fellowship:  
Yu Jiang, Chemical and Environmental Engineering
- Salim Khan Graduate Award:  
Paul Van Rooy, Chemical and Environmental Engineering

**DONORS SUPPORT APPROXIMATELY 10% OF CE-CERT'S RESEARCH**

Our donor's generous support provides students with research and conference opportunities and the freedom to use their imagination to create the visionary research that will make them industry leaders and global problem-solvers.



## UNDERGRADUATE STUDENT HIGHLIGHT

### ROBERT ESPINOZA FORD UNDERGRADUATE SCHOLARSHIP RECIPIENT

#### RESEARCH FOCUS

Utilizing nanotechnology to improve air filtration systems

#### AWARDS AND ACCOMPLISHMENTS

- Benjamin A. Gilman International Scholarship
- UC Education Abroad Program Promise Award
- Hispanic Scholarship Fund Scholar designation
- Three UC Riverside Hispanic Serving Institution Undergraduate Fellowship awards
- NSF Scholarship in Science, Technology, Engineering, and Mathematics
- UCR's STEM Exploration Day for Engineers
- Outreach Club Officer for Change in Scientific Importance for Youth (Delta SIFY)
- UCR Advancement Ambassador

#### HOW HE'LL CHANGE THE WORLD

During his recent travels, Robert has seen firsthand how many people across the world need help. His goal is to improve people's lives for the better through discovering new and improved ways to apply nano-enhanced devices and materials to daily life, as well as for the purpose of space flight and exploration.

## LIST OF DONORS AND AWARDS

- |                                                             |                                                              |                                               |
|-------------------------------------------------------------|--------------------------------------------------------------|-----------------------------------------------|
| • Colin E. Hackett Endowed Engineering Research Award       | • Jacques and Eugene Yeager Families Endowed Chair           | • Tanfeng Cao Award                           |
| • USA Waste of California and the County of Riverside       | • Jim Guthrie Research Award                                 | • CE-CERT Regional Properties, Inc. Endowment |
| • Esther F. Hays Graduate Fellowship Award                  | • Joseph Norbeck Memorial Fund for Student Success           | • Advanced Engine Technology (AET) Endowment  |
| • G. Neal Richter Student Support Fund in Energy Innovation | • Packard Foundation Fellowship in Environmental Engineering | • Johnson Ruel                                |
| • William Pierson & The Ford Foundation                     | • Salim Khan Award                                           | • Roberta Nichols                             |

**ARE YOU READY TO CHANGE THE WORLD?**

Learn more about how you can make an impact.  
<http://www.cert.ucr.edu/donations/giving-1.html>



# LEADERS IN COMMUNITY ENGAGEMENT

## Helping Inspire the Next Generation of Innovators

Our youth should be prepared to think deeply and to think holistically so that they have the chance to become the next generation of innovators, educators, researchers, and leaders who will solve the most pressing challenges facing our nation and our world. But right now, many of our youth do not have access to quality STEM learning opportunities and too few students see these disciplines as springboards for their careers.

**OUR GOAL:** Provide a program that supports students with more personalized learning experiences and hands-on activities in a laboratory setting with top researchers in STEM fields.

**OUR MISSION:** To inspire and provide avenues for our youth in science, technology, engineering, and math to reach their full potential.



### "INSPIRE HER MIND" PROGRAM

Motivating Women to Become Engineers

**Women remain underrepresented in the science and engineering workforce at 29% even though women make up half of the total U.S. college-educated workforce. At CE-CERT, we are helping to bridge this gap with providing programs catered to inspire women to pursue science and engineering fields.**

The *Inspire Your Mind Program* aims to inspire and motivate female students to pursue and stay engaged in STEM subjects in high school, a time when girls often lose interest in those fields.



### ANNUAL SCIENCE TECHNOLOGY EDUCATION CONFERENCE

Stimulating the Future STEM Generation

CE-CERT hosted nearly 300 high school students at the 5<sup>th</sup> Annual Science and Technology Education Partnership (STEP) Conference for high schools throughout the Riverside County School District.

"The STEP conference is a chance to give back to the community and inspire future scientists and engineer. By inspiring the younger generation, it allows me to vicariously relive the wonder and amazement that made me pursue the field of science in the first place. This experience invigorates me to continue researching, teaching and motivating the next generation of innovators". (Rany Tith, CE-CERT Undergraduate Researcher)



### SUSTAINABLE TRANSPORTATION AND SUSTAINABLE ENERGY SUMMER SCHOOL PROGRAM

First of its kind Summer International Lecture Program

This 5-week international short-course summer program focused on sustainable energy and sustainable transportation. This short course was tutorial in nature, but also demonstrated some of the latest cutting-edge research in air pollution, alternative fuels and smart grid technology. **This unique program allowed the visiting students to exchange ideas and skillsets with research faculty and work in a world-class laboratory while making new relationships with fellow UCR and summer program students.**

# WHO'S WHO?

Our impact is a direct result of the hard work from our dedicated research, staff and students.

## 2016 FACULTY AND RESEARCH STAFF

Richard Arnott, Professor of Economics	Rajeev Kumar, Associate Researcher
Akua Asa-Awuku, Associate Professor of Chemical and Environmental Engineering	Ji Luo, Postdoctoral Scholar
Kelley Barsanti, Assistant Professor of Chemical and Environmental Engineering	Alfredo Martinez-Morales, Managing Director, Southern California Research Initiative for Solar Energy
Matthew Barth, Professor of Electrical and Computer Engineering	Wayne Miller, Managing Researcher & Adjunct Professor of Chemical and Environmental Engineering
Kanok Boriboonsomsin, Assistant Research Engineer	Chan Seung Park, Associate Researcher & Adjunct Professor of Chemical and Environmental Engineering
Charles Cai, Assistant Researcher & Adjunct Professor of Chemical and Environmental Engineering	John Pisano, Development Engineer
Bill Carter, Emeritus Research Chemist	Marko Princevac, Professor of Mechanical Engineering
David Cocker, Professor of Chemical and Environmental Engineering	Xuwei Qi, Postdoctoral Scholar
Tom Durbin, Research Engineer & Adjunct Professor of Chemical and Environmental Engineering	Hamed Rad, Associate Professor of Electrical and Computer Engineering
Jay Farrell, Professor of Electrical and Computer Engineering	Arun Raju, Director of Center for Renewable Natural Gas
Dennis Fitz, Recalled Researcher	Robert Russell, Assistant Researcher
Peng Hao, Assistant Researcher	George Scora, Assistant Project Scientist
Wendy Goliff, Assistant Researcher	Mike Todd, Principal Development Engineer
Kent Johnson, Associate Researcher & Adjunct Professor of Chemical and Environmental Engineering	Sadrul Ula, Managing Director of Winston Chung Global Energy Center
Heejung Jung, Associate Professor, Mechanical Engineering	Akula Venkatram, Professor of Mechanical Engineering
Georgios Karavalakis, Associate Researcher & Adjunct Professor of Chemical and Environmental Engineering	Guoyuan Wu, Assistant Researcher & Adjunct Professor of Electrical and Computer Engineering
Zak Kassas, Assistant Professor of Electrical and Computer Engineering	Charles Wyman, Professor of Chemical and Environmental Engineering
	Nanpeng Yu, Assistant Professor of Electrical and Computer Engineering
	Qi Zhu, Assistant Professor of Electrical and Computer Engineering

## 2016 GRADUATE STUDENTS

Isaac Afreh	Jiyong Kim	Mayling Lu	Patrick Roth	Ziran Wang
Christian Alcaraz	Ninad Kothari	Ayla Moretti	Partho Roy	Nigel Williams
Devin Cavero	Chengguo Li	Aakash Parikh	Priya Sengupta	Hao Xin
Rachna Dhir	Weihua Li	Abhishek Patri	Michele Simkins	Yun Xue
Emmanuel Fofie	Weixia Li	Wei Han Peng	Priyanka Singh	Jiacheng Yang
Fei Gu	Yang Li	Xinze Peng	Christos Stamatis	Fei Ye
Yu Han	Yaqiong Li	Liem Pham	Glen Svenningsen	
Jia Jiang	William Lichtenberg	Pedro Piqueras	Danyang Tian	
Yu Jiang	Taehoon Lim	Xuwei Qi	Ashley Vizenor	
David Kari	Yue Lin	Minerva Robles	Chao Wang	

## 2016 UNDERGRADUATE STUDENTS

Kang An	Ryan Cheng	Albert Ha	Shunhua Lin	Marco Rubio
Ruben Ashkyan	Toyeung Cheung	Michael Han	Dana Maxie	Molovi Shuba
Lauren Aycock	Jackson Dulla	Angie Hua	Laura McAllister	Taylor Stenehjem
Mario Cazares	Ian Dunn	Ryo Huntamer	Shawn Miata	Rany Tith
Aaron Chan	Jaydeep Dutta	Ramon Jauregui	Taymour Mohammed	Ryan Trang
Onesimus Chan	Matthew Ealy	Ho-Ren Kang	Alex Moore	Joanna Vasquez
Stanley Chang	Robert Espinoza	Sultan Khan	Chio Ng	Maher Zaher
Daniel Chao	Angelica Franco	Pegdwende Kologo	Kevin Ortega	
Alan Cheng	Antonio Godoy	Jennifer Le	Brian Rountree	



# SELECTED PUBLICATIONS

## 2016 FACULTY, RESEARCHER, AND AFFILIATE FACULTY PUBLICATIONS BY THE NUMBERS

Journal Articles

63

Conference Proceedings and Symposia

53

Technical Reports

68

Book Chapters

2

GROWTH IN THE NUMBER OF CONTRACTS AND GRANTS AWARDED TO THE CENTER HAVE ALLOWED CE-CERT'S RESEARCHERS AND FACULTY TO INCREASE THEIR PUBLICATIONS SIGNIFICANTLY SINCE LAST YEAR; OUR SPONSORED AWARDS ACTIVE IN CALENDAR YEAR 2016 TOTALED \$18 MILLION.



#### Advanced Thermochemical Research Group

Z. Liu, J. M. Norbeck, A. Raju, S. Kim and C. S. Park, "Synthetic Natural Gas Production by Sorption Enhanced Steam Hydrogasification Based Processes for Improving CH<sub>4</sub> Yield and Mitigating CO<sub>2</sub> Emissions," *Energy Conversion and Management*, pp. 256-265, 2016.

C. S. Park, A. Raju, S. A. Franco, P. Roy and H. S. Jung, "Development of a Fuel Sensor Technology for a Variable-blend Natural Gas Vehicle," *Journal of Natural Gas Science and Engineering*, pp. 149-155, 2016.

#### Aqueous Biomass Processing Research Group

B. Mostofian, C. M. Cai, M. D. Smith, L. Petridis, X. Cheng, C. E. Wyman and J. C. Smith, "Local Phase Separation of Co-Solvents Enhances Pretreatment of Biomass for Bioenergy Applications," *Journal of the American Chemical Society*, vol. 138, no. 34, pp. 10869-10878, 2016.

T. Y. Nugyen, C. M. Cai, O. Osman, R. Kumar and C. E. Wyman, "CELF Pretreatment of Corn Stover Boosts Ethanol Titrers and Yields from High Solids SSF with Low Enzyme Loadings," *Green Chemistry*, vol. 18, pp. 1581-1589, 2016.

#### Atmospheric Processes Research Group

C. Clark, M. Kacarab, S. Nakao, A. Asa-Awuku, K. Sato and D. Cocker, "Temperature Effects on Secondary Organic Aerosol (SOA) from the Dark Ozonolysis and Photo-Oxidation of Isoprene," *Environmental Science and Technology*, vol. 50, no. 11, pp. 5564-5571, 2016.

L. Li, P. Tang, S. Nakao and D. Cocker, "Impact of Molecular Structure on Secondary Organic Aerosol Formation from Aromatic Photo-Oxidation Under Low NO<sub>x</sub> Conditions," *Atmospheric Chemistry and Physics*, vol. 16, pp. 10793-10808, 2016.

#### Emissions and Fuels Research Group

K. C. Johnson, Y. Jiang and J. Yang, "Ultra-Low NO<sub>x</sub> Natural Gas Vehicle Evaluation ISL G NZ," Final Report for SCAQMD Contract No. 15626 with Cummins Westport, Inc. 2016.

K. C. Johnson and R. Russel, "Measurement of Criteria Pollutant Emissions from Carnival's PM Reduction System," Final Report for the International Maritime Organization. 2016.

#### Sustainable Integrated Grid Initiative Research Group

M. Gostein, B. Stueve, B. Brophy, K. Jung, A. Martinez-Morales, S. Zhang, Y. Jin and J. Xu, "Soiling Measurement Station to Evaluate Anti-Soiling Properties of PV Module Coatings," in *Proceedings of the 43<sup>rd</sup> IEEE PVSC*, Portland, OR USA, 2016.

Y. Xue, M. Todd, S. Ula, M. Barth, and A. Martinez-Morales, "A Comparison Between Two MPC Algorithms for Demand Charge Reduction in a Real-World Microgrid System," in *Proceedings of the 43<sup>rd</sup> IEEE PVSC*, Portland, OR USA, 2016.

#### Transportation Systems Research Group

D. Tian, W. Li, G. Wu, K. Boriboonsomsin, M. Barth, S. Rajab and S. Bae, "Evaluating the Effectiveness of V2V-based Lane Speed Monitoring Application: A Simulation Study," in *Proceedings of the 2016 IEEE Intelligent Transportation Systems Conference (ITS2016)*, Rio de Janeiro, 2016.

X. Qi, G. Wu, K. Boriboonsomsin, M. Barth and J. Gonder, "A Data-Driven Reinforcement Learning-Based Real-Time Energy Management System for Plug-in Hybrid Electric Vehicles with Charging Opportunities," in *Transportation Research Record: Journal of the Transportation Research Board*, 2016.

#### Book Chapters

C. S. Park and A. Raju, "Current Developments on the Thermochemical Conversion of Biomass to Fuels and Chemicals," in *Valorization of Lignocellulosic Biomass in a Biorefinery: From Logistic to Environmental and Performance Impact*, Kumar, Singh and Balan, Eds., Nova Science Publishers, 2016.

T. D. Durbin, G. Karavalakis and K. C. Johnson, "Environmental and Performance Impacts of Alternative Fuels in Transportation Application," in *Biomass Pretreatment and Conversion Processes*, Kumar, Singh and Balan, Eds., Nova Science Publishers, 2016.

#### PATENTS

C.S. Park, K. Johnson, A.S.K. Raju. Lean Combustion with Renewable Natural Gas.

Z. Kassas and J. Morales. Signals of Opportunity Aided Inertial Navigation System.

Z. Kassas, K. Shamaei, and J. Khalife. Software-defined Radio for Navigation with LTE Signals.

Z. Kassas, J. Khalife, and K. Shamaei. Software-defined Radio for Navigation with Cellular CDMA Signals.

#### DISSERTATIONS & THESES

Samarthya Bhagia. "Factors Contributing to Recalcitrance of Poplar to Deconstruction," Ph.D. dissertation, Department of Chemical and Environmental Engineering.

Mary Kacarab. "Impacts of Controlling Reactivity and Temperature on Advanced Study of Secondary Organic Aerosol Formation," Ph.D. dissertation, Department of Chemical and Environmental Engineering.

David Kari. "Adaptive/Optimal Vehicle Infrastructure Integration with Intelligent Vehicles & Complex Networked Control Systems," Ph.D. dissertation, Department of Electrical and Computer Engineering.

Lijie (Sara) Li. "Insights into Predicting Secondary Organic Aerosol Formation from Anthropogenic Volatile Organic Compounds: Impact of Molecular Structure and NO<sub>x</sub> Concentration," Ph.D. dissertation, Department of Chemical and Environmental Engineering.

Tae-hoon Lim. "Nanoengineering of ZnO Electrical and Optical Characteristics by Controlling its Morphology and Defects via Reaction Kinetics, Fluid Dynamics, and Stoichiometry in Low-Pressure CVD Synthesis," Ph.D. dissertation, Department of Materials Science and Engineering.

Thanh Yen Vuong Nguyen. "Integration of a Novel Co-solvent Enhanced Lignocellulosic Fractionation (CELF) Pretreatment with Biological Conversion to Ethanol," Ph.D. dissertation, Department of Chemical and Environmental Engineering.

Vanessa Ann Thomas. "Understanding Synergies Between Pretreatment, Feedstock, and Consolidated Bioprocessing for Lignocellulosic Biomass Conversion," Ph.D. dissertation, Department of Chemical and Environmental Engineering.

Xuwei Qi. "Real-time On-line Intelligent Energy Management for Plug-in Hybrid Electric Vehicles," Ph.D. Dissertation, Department of Electrical and Computer Engineering.





## IN MEMORY OF FOUNDING DIRECTOR, JOE NORBECK

Dr. Joe Norbeck joined UC Riverside in 1992 as a Professor of Chemical and Environmental Engineering, and as the Founding Director of the Bourns College of Engineering Center for Environmental Research and Technology (CE-CERT). Under Joe's visionary leadership, CE-CERT grew to become an innovative and globally respected environmental research center, serving as an "honest broker" on a number of important regulatory, scientific, and economic questions surrounding environmental and energy policy.

In addition to founding CE-CERT, Joe helped shape the College of Engineering from its early beginnings, having a hand in hiring many key faculty throughout the years, as well as serving as faculty advisor and making a lifelong impact in the lives of dozens of graduate students.

In his tenure, Joe served as CE-CERT's Director and held the Yeager Families Chair from 1992 to 2004, and then held the W. Ruel Johnson Chair until his retirement. From 2004 through 2010 he served as the Director of UCR's Environmental Research Institute. Joe retired from full time service in 2013, becoming Emeritus Professor and continuing his research at CE-CERT.

In mid-2016, Joe passed away at the age of 72 from medical complications. Joe will be remembered at UCR for many things, including his positive spirit, kind heart and love for interacting with students (he received the Chancellor's Student Mentoring Award in 2003), his innovative research (he received a Clean Air Award in 1995), and for inspiring many who were fortunate to know him. He will be truly missed.

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### Joseph Norbeck Memorial Fund for Student Success

Joe regarded the opportunity for students to have laboratory experiences as one of the most rewarding aspects of his career. This award provides support to full-time graduate and undergraduate students in environmental engineering who are engaged in experimental research at CE-CERT.



<http://www.cert.ucr.edu/donations/giving-1.html>





## 2016 SELECTED CE-CERT FACTOIDS

Charles E. Wyman  
named one of the  
**Top 100**  
People in the Advanced  
Bio-economy in 2016

TSR research team receives  
prestigious international  
research award for  
**"Eco-Intelligent  
Transportation  
Systems Technology"**

(see <https://ucrtoday.ucr.edu/43022>)

**CE-CERT is  
UCR's 1st  
Energy Star  
Building**

### **Black Carbon and Water**

**Emissions and Fuels**  
Research team pioneered  
the development of on-  
board testing systems to  
evaluate ocean-going ship  
emissions

In 2016, UCR ranked in the  
**Top 15%**

in sustainability rankings,  
No. 27, of all U.S. schools.  
UCR demonstrated a strong  
commitment to upholding high  
environmental standards.

**Charles Cai  
named to  
Forbes 30  
under 30 list**

(see <https://ucrtoday.ucr.edu/43752>)





# 25

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