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ADVANCED POWER AND ENERGY PROGRAM

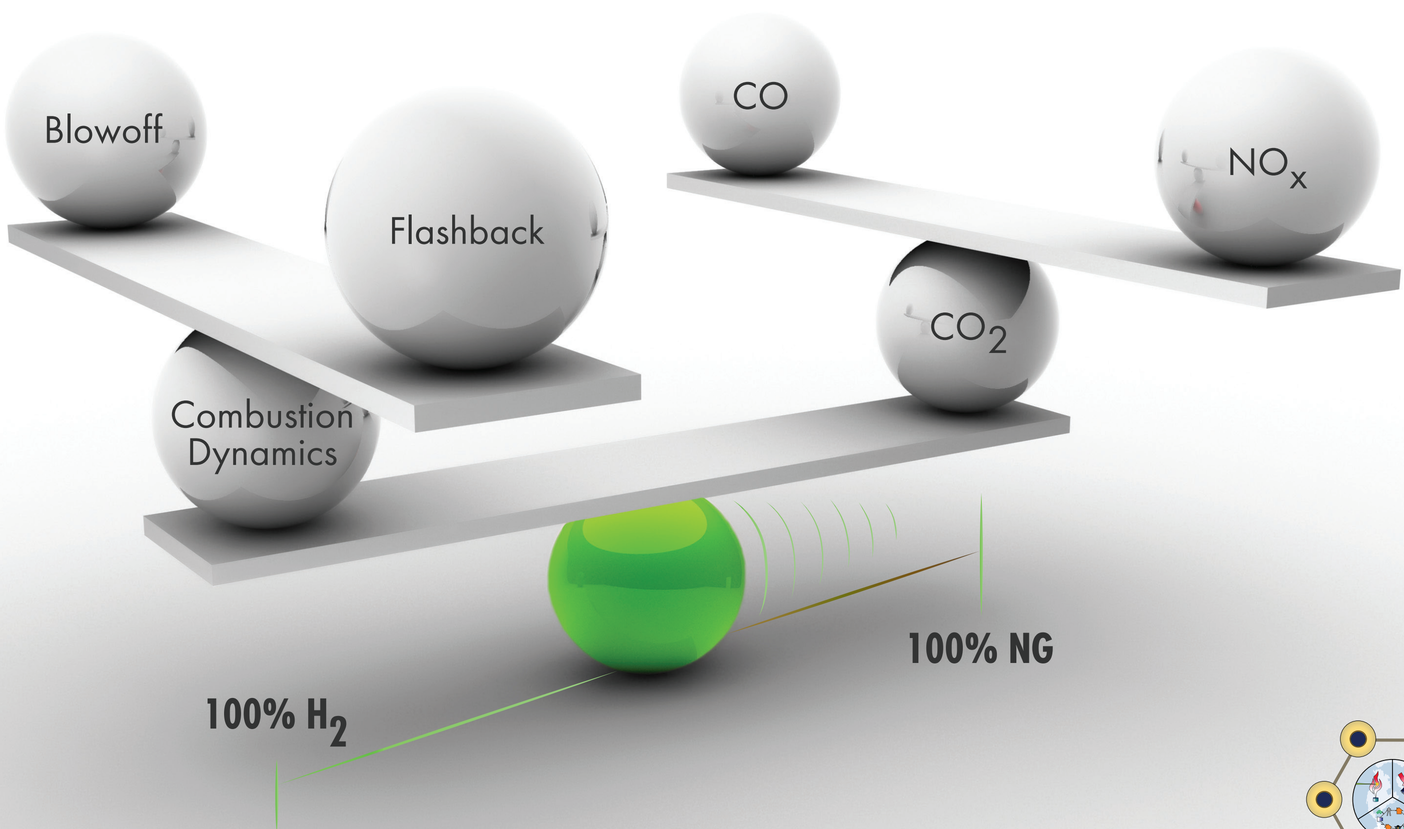
BRIDGING

ENGINEERING SCIENCE TO PRACTICAL APPLICATION

BLENDING HYDROGEN WITH NATURAL GAS

BALANCING

OPERABILITY EMISSIONS



Director's Message

Professor Scott Samuelsen, Ph.D.
Director, Advanced Power and Energy Program (APEP)

The transition to renewably generated fuels continues to garner momentum in the United States and around the world. APEP's research is at the forefront of this transformation. "Bridging" the gap between industry, national and international agencies, and laboratories has long been a hallmark of APEP. These critical relationships have become even more important in maintaining the momentum of the paradigm shift to renewably generated fuels in the United States and around the world.

In this seventh edition of our **BRIDGING** annual report, the featured article highlights the UCI Combustion Laboratory's (UCICL) continuing work on balancing combustion emissions and operability by quantifying how much renewable hydrogen can displace natural gas. The UCICL has conducted extensive research in this area over the past two decades through support of the **California Energy Commission**, the **US Department of Energy**, and the **California Air Resources Board**. The research carried out by the UCICL and others has led to technologies that, today, can attain low pollutant emissions using high hydrogen content fuels while maintaining operation free from blowoff or flashback from gas turbine engines to household appliances.

This issue of BRIDGING also summarizes a remarkable contribution of both funding and vision from the **HORIBA Group**. A long-time collaborator and supporter, Horiba last August generously committed $9 million to establish the "HORIBA Institute for Mobility and Connectivity^2 (HIMaC^2)" at APEP. Scheduled to open in February 2020, the institute will focus on certification and testing of zero-emission vehicles and electric drivetrain components, the evolving connection of clean mobility to the electric grid, and vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) connectivity. HIMaC^2 will combine our existing Grid Evolution Laboratory with a newly designed, state-of-the-art Vehicle Evolution Laboratory, providing a unique resource for both research and education at the nexus of transportation and the electric grid. UCI and the Samueli School of Engineering are matching a substantial portion of the HORIBA gift.

On another front, the National Fuel Cell Research Center (NFCRC), in partnership with **Microsoft Corporation**, has begun research to assess generating chilled water from the exhaust heat emanating from solid oxide fuel cells while assuring the dynamic effectiveness of the integrated system and system reliability. Projections show that the data center sector could consume 20% of all the electricity in the world by 2025. In addition, the NFCRC together with **Stone Edge Farm Microgrid** embarked on a new project to deploy hydrogen energy storage. This critical research will improve the efficiency of hydrogen energy storage systems and enable deployment in the future.

We are especially proud of the accomplishments of our students which for the 2018-2019 academic year includes 4 graduates, 5 internships with diverse entities such as: **174 Power Global, Bloom Energy, Irvine Valley College,** and the **California Energy Commission.**

We continue to be indebted to our long standing relationships that contribute in so many ways to our research, real world demonstration projects, students, and to "bridging" from needed research in engineering science to the ultimate goal of deployment in practical application.

Scott Samuelsen

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Blending Hydrogen into Natural Gas:

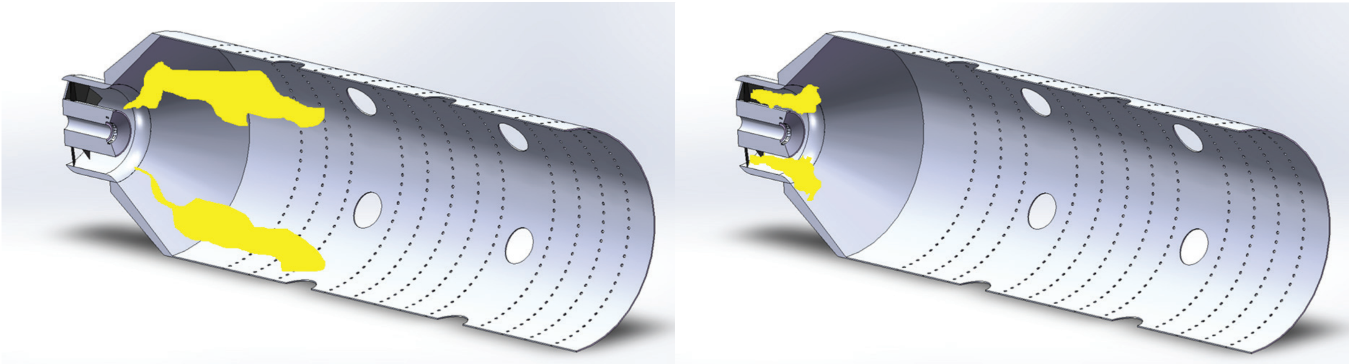
Balancing Emissions and Operability in Combustion Devices Enables the Pathway to Carbon Reduction

THE OPPORTUNITY AND CHALLENGE

Enabling a carbon free future to meet California's ambitious clean energy goals will require displacing fossil derived natural gas with renewable fuels such as renewably generated hydrogen. Blending hydrogen into natural gas is a logical transitional step towards operation on 100% hydrogen. Extensive work has been done to bring pollutant emissions levels from combustion devices to very low values. This has been attained through careful preparation of the fuel and air mixture and the use of "premixing" in which the fuel and air are combined prior to entry into the combustion chamber. Key pollutants such as carbon monoxide and unburned hydrocarbons are inherently reduced when adding hydrogen to natural gas, as this carbon free fuel will automatically eliminate these two pollutants. However, oxides of nitrogen (NOx), precursors to ozone formation in the urban region, remain an open question.

Additional considerations for low NOx systems fueled by high hydrogen content fuel streams are "operability" issues such as *flashback* (sudden movement of the reaction into the premixer, see Figure 1) or *blowoff* (sudden detachment and extinction of the stable reaction). Due to its high reactivity, hydrogen presents both an opportunity as well as a challenge for flashback and blowoff. The high reactivity makes hydrogen combustion more stable than natural gas (which is mainly methane) reactions. As a result, reactions can be stabilized at significantly lower temperatures when hydrogen displaces natural gas. These lower temperatures can result in a concomitant reduction in oxides of nitrogen which are known to form rapidly at high combustion temperatures.

To attain uniformly reduced temperature (and thus minimize NOx emissions), the fuel and air must be very well mixed prior to combustion as mentioned above. Yet with more reactive hydrogen added, the likelihood of flashback increases. As a result, current low emission systems that rely on careful fuel air mixing (e.g., gas turbines, ovens, water heaters, boiler burners, etc.) will become more susceptible to flashback if hydrogen is introduced. If flashback occurs, it will generally cause catastrophic failure of the premixer and ultimately, the burner itself. This is illustrated in Figure 1 and 2.



A) Stable B) Flashed Back

Figure 1. Comparison of Stable Reaction and Reaction Which Has Flashed Back into the Fuel/Air Premixer

THE PATH FORWARD

To facilitate adoption of hydrogen blending, the underpinning science to enable the balance between emissions and operability needs to be established. The UCICL has conducted comprehensive research in this area over the past two decades through support of agencies such as the California Energy Commission, US Department of Energy, and the California Air Resources Board. This research has systematically evaluated how hydrogen addition impacts emissions and operability of a wide range of combustion devices. Initial studies focused on gas turbine applications. Combustion systems designed by Capstone Turbine Corporation and Solar Turbines have been the subject of extensive experimental and numerical studies. In the early 2000's UCICL worked on retrofitting fuel injectors for a commercial Capstone natural gas fired gas turbine for the purpose of operating on hydrogen. This California Energy Commission sponsored study resulted in a demonstration study in which the 60kW gas turbine was successfully operated on 100% hydrogen over the full range of loads and from start to stop.[1, 2] The study was successful in demonstrating operability of the engine purely on hydrogen, but fell short of attaining low emissions performance despite apparent excellent premixing attained with the redesigned fuel injectors. As discussed in reference 2, the Capstone engine employed relatively complex internal exhaust gas recirculation to attain low emissions, which did not provide for an optimal configuration in which to allow a simple injector retrofit that can meet all performance goals.

> *"What remains is for the lessons learned from the gas turbine sector and the underpinning science developed to be applied to other end use sectors."*

Figure 2. Cooktop Burner Before and After Flashback Due to Hydrogen Addition to Natural Gas

Additional work was carried out with a Solar Turbines commercial engine as a target. This work, supported by the US Department of Energy, resulted in a partnership with UCICL and Parker Hannifin to adapt their liquid fuel "macrolaminate" injector technology for injection of hydrogen. Recognition of the need for very rapid mixing of the fuel and air, combined with the realization that minimizing the reaction time reduces NOx led to applying "micromixing" concepts.[3, 4] The technology was ultimately tested at Solar Turbines on a single injector test rig.[5] This research demonstrated that flashback free, low emission premixed hydrogen and air combustion could be attained at gas turbine conditions. These early studies laid the groundwork for a number of gas turbine manufacturers developing fuel injection systems that feature large numbers of small injectors. For example, Hitachi and GE have developed fuel injectors for high hydrogen content fuels that mimic the micromixing concepts shown in references 3, 4, and 5.

In the last ten years, a wide range of gas turbine products have already progressed significantly towards low emission performance with good overall operability using these strategies. Mitsubishi, Siemens and GE have developed full scale systems that can operate on high quantities of hydrogen (up to 30% by volume) with low emissions performance. While "cut and try" methods using concepts such as micromixing or rapid mixing have proven able to attain flashback free performance with low emissions, the UCICL has also conducted extensive fundamental research associated with predicting autoignition, stability, and flashback behavior for premixed injectors.

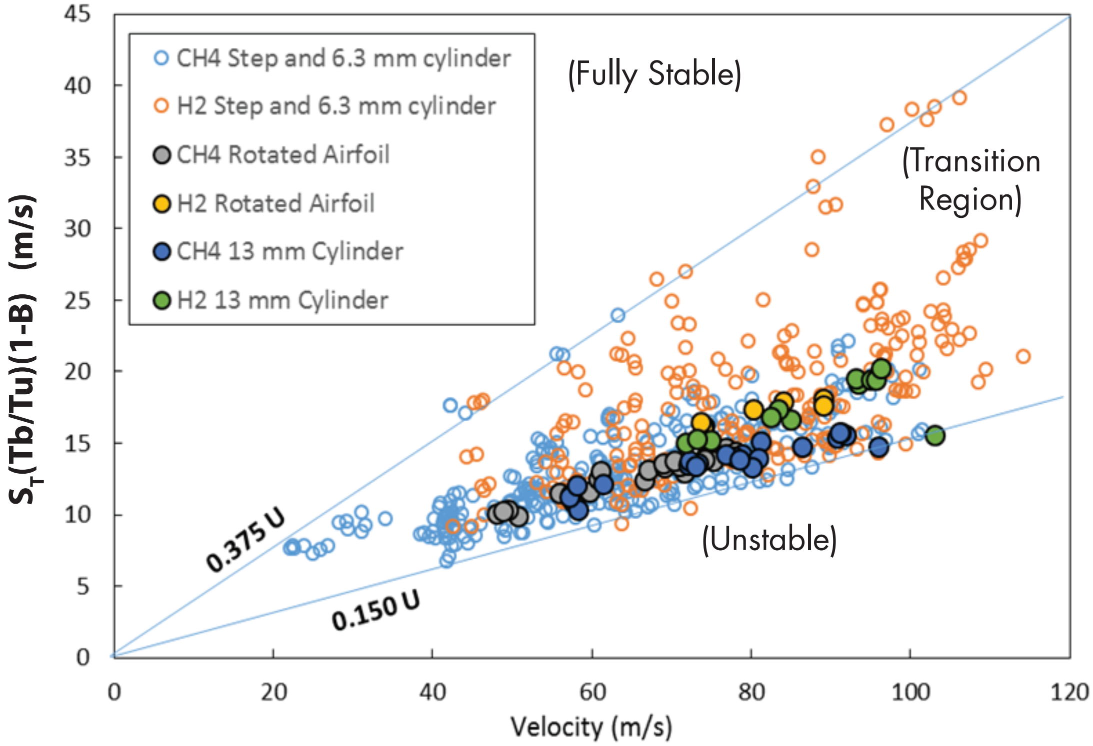


Figure 3. Design Correlation for Predicting the Onset and Absolute Blowoff Limit for Flameholders at Gas Turbine Conditions.[8]

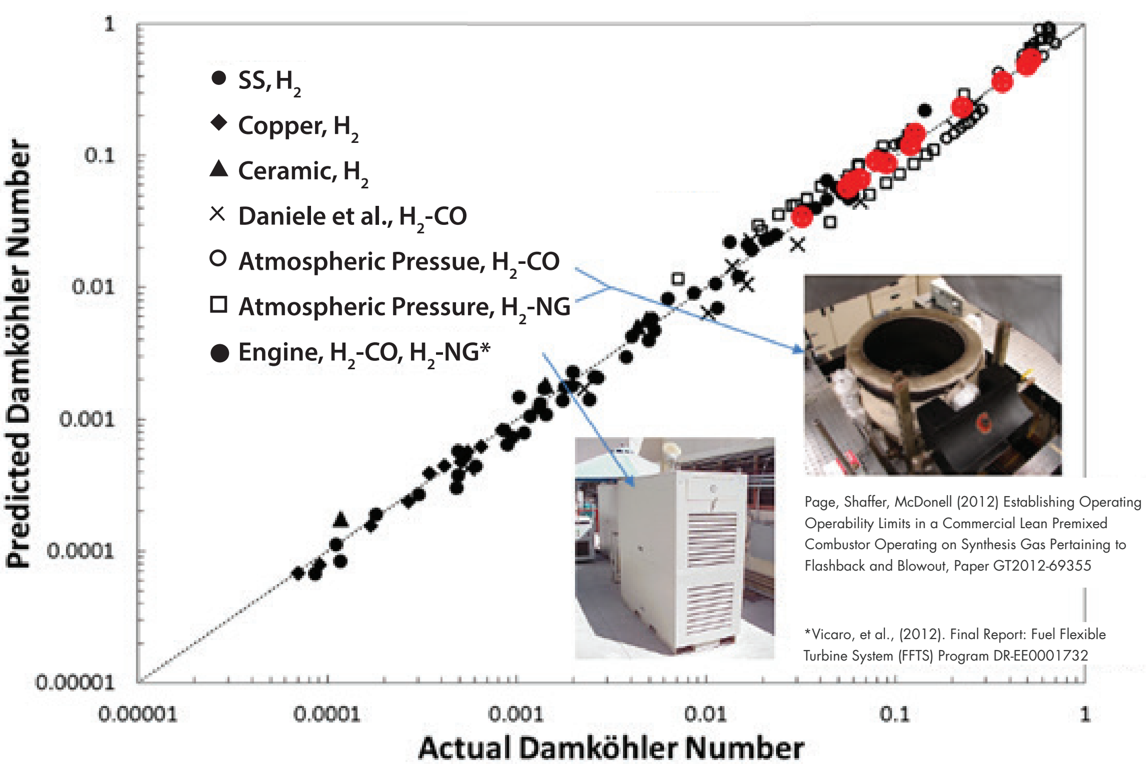


Figure 4. Summary of Predicted and Measured Flashback Conditions for a Wide Range of Conditions and Systems.

Autoignition (spontaneous ignition of a fuel air mixture) is possible when fuel and air are mixed to flammable conditions and exposed to high temperatures and pressures. With reactive fuels like hydrogen, the possibility of autoignition within the premixer must be considered. Work done by Beerer established that, for well-designed premixers (i.e., free from separation or other recirculating regions) autoignition should not be a limiting factor for gas turbine system.[6] This study also illustrated that predicting autoignition delay times for hydrogen/air mixtures using chemical kinetic methods could seriously overestimate the delay times.[7] Yet, when considering practical premixers with good design practice, the measured ignition delay times were still significantly longer than those expected in the premixer.

At the other end of the spectrum, predicting lean stability limits (or blowoff) of hydrogen/air flames has also been studied at the fundamental level by the UCICL. Resulting correlations for stability limits at actual engine conditions were developed by the UCICL using new data obtained at the appropriate conditions. This research, sponsored by the US Department of Energy, led to simple design tools that can be used to estimate when flame stability starts to degrade as shown in Figure 3.[8]

As mentioned previously, flashback issues have been overcome in practice through use of micromixing methods, but fundamentally understanding the details of the flashback phenomena, and that of boundary layer flashback is also quite valuable. A series of studies associated with premixed jet flames in which boundary layer flashback was the critical flashback mode have been carried out. Starting with atmospheric studies,[9, 10] and culminating with studies at elevated pressure[11] and subsequent application of a flashback model developed to actual gas turbine engine studies,[12] the ability to predict boundary layer flashback propensity for a wide range of applications and conditions was developed. The performance of this model is shown in Figure 4. Based on the research completed, a review of critical mechanisms and work was compiled in a review article on the subject.[13]

OUTLOOK

In summary, the UCICL has contributed significantly to 1) understanding and 2) addressing the tradeoffs associated with integrating hydrogen into the overall fuel mix as a means to significantly reduce the carbon signature of everyday fuels. In the gas turbine area, the research carried out by UCICL and others has led to technology that, today, can attain low pollutant emissions using high hydrogen content fuels while maintaining operation free from blowoff or flashback. The somewhat delicate balance and tradeoffs faced when operating combustion devices on hydrogen has been largely attained, at least for the gas turbine technology sector. What remains is for the lessons learned and the underpinning science developed to be applied to other end use sectors, such as industrial burners and residential and commercial appliances. With the experience developed from the gas turbine sector, the pathway forward for enabling high hydrogen content fuels to operate with reduced emissions and without operability issues is well in hand. It is a matter of simply applying what has been learned to these other application sectors and demonstrating the viability. This will lead to new and retrofitted technologies that can accommodate future low to zero carbon fuels.

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HORIBA Commits $9 Million to APEP for New Institute

Research to Focus on Connectivity Between Transportation and Energy Sectors

The Horiba Group, a leading global provider of analytical and measurement systems, has committed $9 million to the Advanced Power and Energy Program (APEP) to establish the "Horiba Institute for Mobility and Connectivity^2 (HIMaC^2)."

Horiba, a leading global provider of analytical and measurement systems, has a long standing relationship with APEP. Atsushi Horiba, the current chairman and CEO of the Horiba Group, was an undergraduate researcher in the UCI Combustion Laboratory (UCICL) in the mid 1970's. Since 1988, APEP has hosted over thirty Horiba young scientists for one-year research appointments, and Horiba was a pivotal cornerstone in the APEP Pacific Rim Consortium on Combustion, Energy, and the Environment (PARCON) that led to the National Fuel Cell Research Center (NFCRC) and the International Colloquium on Environmental Preferred Advanced Generation (ICEPAG).

In addition to Horiba's gift, UCI's Henry Samueli School of Engineering and Office of the Provost and Executive Vice Chancellor is providing funds for staffing and ongoing activities at the new entity. Overall, the investment in HIMaC^2 is in excess of $14 million.

HIMaC^2 will focus research and education efforts on combining the formerly disparate energy and transportation sectors into an integrated and complementary system. Its faculty, staff, and students will work to simultaneously address the environmental impacts of climate change and air quality, energy independence and security, and the affordability of fuel and electricity for consumers.

In particular, HIMaC^2 will pursue solutions to three grand challenges facing the future of energy and the environment. The first is to develop zero-emission mobility; namely vehicles and fuel supply chains that emit neither greenhouse gases nor pollutants that cause smog, acid rain, and other health hazards. The second and third reflect the "2" in HIMaC^2:

- To connect zero-emission modes of transport with an electric grid that incorporates renewable wind and solar resources at a much higher level than exists today, and
- To invent the next generation of conveyances that can sense their surroundings, "talk" with one another (V2V) and communicate with the infrastructure (V2I).

The majority of the Horiba donation will be invested in the design and construction of a state-of-the-art Vehicle Evolution Center (VEC) housed in UCI's Engineering Gateway building, HIMaC^2 will integrate the VEC with the existing Grid Evolution Center (GEC) developed in partnership with Schweitzer Engineering Laboratories in to a unified institute.

February 2020 is the projected date for initiating the commissioning of HIMaC^2, and May 2020 for the grand opening.

First Zero-Emission Bus Fleet in California with Mixed Technologies

The Innovative Clean Transit regulation – passed unanimously by the California Air Resources Board - requires public transit agencies to gradually transition to 100 percent zero-emission fleets by 2040. Among new clean technologies, Battery Electric Buses (BEBs) and Fuel Cell Electric Buses (FCEBs) are the most promising for widespread implementation.

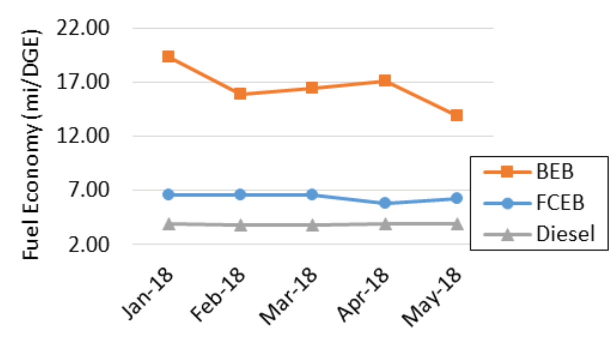
Over the past 5 years, UC Irvine's Anteater Express has collaborated with APEP to electrify its entire fleet, first with a FCEB, and then with 20 BEBs. This has led to a significant reduction in carbon and criteria pollutant emissions, a substantial increase in fuel efficiency, and a model for transit agencies in the state and nationwide.

UC Irvine Fuel Cell Electric and Battery Electric Buses

Through a grant from the South Coast Air Quality Management District, APEP is using this innovative fleet to evaluate and compare the performance of the two zero-emission bus technologies.

BEBs vs. FCEBs

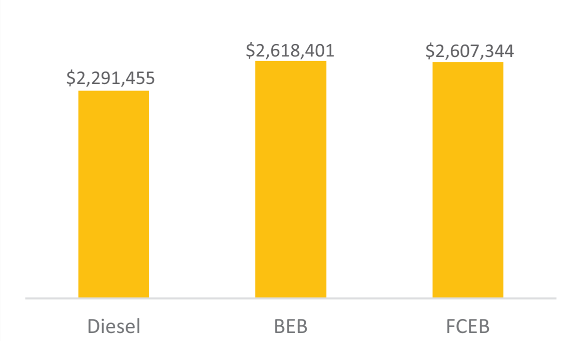
FCEBs have a 300 mile range with a similar durability, availability, and refueling process and filling-time to diesel buses. BEBs have a range of 150 miles and relatively long charging time. However, if the length of the routes is less than 150 miles, as in the case of the Anteater Express, a one-to-one comparison can be conducted using the following two factors: fuel economy and Total Cost of Ownership (TCO). Using data collected from Anteater Express in addition to developed models, the fuel economy improvement (miles/Diesel Gallon Equivalent) is 4 and 1.6 times improved when compared to diesel buses for BEBs and FCEBs, respectively.



Fuel Economy Comparison

> *"..the total cost of ownership that is virtually the same for BEBs and FCEBs...."*

TCO calculations include purchase cost, maintenance cost, fuel economy, fuel price, midlife overhaul, yearly miles, fueling station cost, and a twelve year lifespan. These costs in combination with collected operational data, resulted in the total cost of ownership that is virtually the same for the BEBs and the FCEBs despite the fact of a lower purchase price and a higher fuel efficiency of the BEB. This is due to the needed replacement of the BEB batteries at midlife.



Total Cost of Ownership per Bus

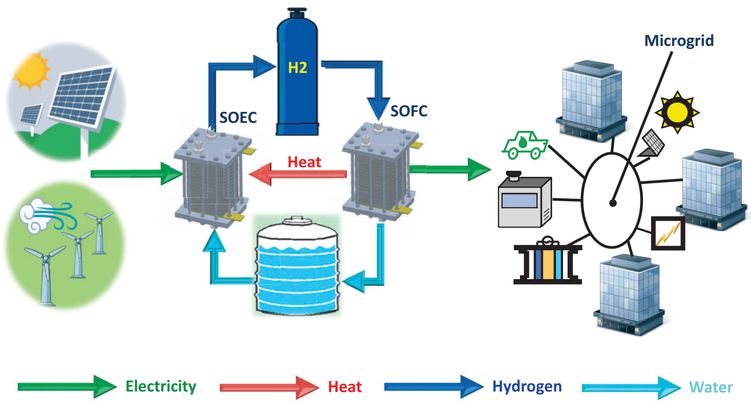
In conclusion, BEBs and FCEBs are complementary technologies that can be selected to map to the different needs (e.g., range) for a given transit agency.

Hydrogen Energy Storage for Renewable Islanded Microgrids

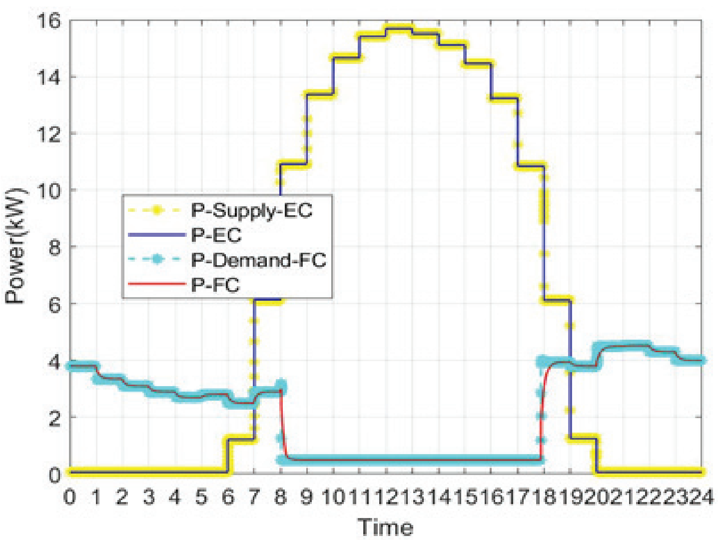
California is committed to obtain all of its electricity from zero-carbon sources by 2045. The intermittent and uncontrollable nature of these renewable energy sources (RES) requires complementary storage and dispatchable clean power generation to meet dynamic power demand. Increasing use of RES has prompted the investigation of electric energy storage (EES) technologies to manage the temporal and spatial mismatch between electricity supply and demand. Analyses consistently show that large-scale EES technologies play a pivotal role in the transition to a zero-carbon society by providing needed massive and seasonal shifting of electricity. Hydrogen energy storage is the most promising long duration EES technology for widespread use.

> *"The hydrogen produced is a clean energy carrier that can be stored for later use."*

Conversion of excess electricity from RES technologies to hydrogen through electrolysis produces a valuable zero carbon fuel that can be used for large-scale, long-term energy storage. High-temperature ceramic solid oxide electrolysis cells (SOEC) have been shown in the laboratory to have higher efficiency than low-temperature electrolysis (due to lower electrochemical losses, ability to use heat and electricity to make hydrogen, and better thermodynamic characteristics). In an SOEC system, H_2O, CO_2 or a combination of both are electrochemically reduced resulting in the production of H_2 and CO, respectively. The hydrogen produced is a clean energy carrier that can be stored for later use. Examples of later use include to produce zero emissions electricity in a fuel cell for power generation or transportation, and the use in industry for synthesis of chemical compounds such as methane, ammonia, and plastics.



A microgrid is an attractive platform to evaluate this strategy. To this end, the NFCRC is partnering with The Stone Edge Farm Microgrid (SEFM) which encompasses RES, storage, and controls to function as a renewable islanded microgrid. While the SEFM already deploys hydrogen energy storage, their support of this evaluation is to improve the efficiency of hydrogen energy storage. For the field demonstration, the NFCRC is combining a highly efficient SOEC, a highly efficient solid oxide fuel cell (SOFC), and the required balance of plant to serve as a stand-alone renewable energy system in the event that the microgrid is islanded (i.e., separated from the grid during a grid outage).



Under this scenario, the islanded microgrid is powered solely by solar and wind power. When the electricity production from the RES exceeds the microgrid demand, it can be supplied to the SOEC to convert steam to renewable hydrogen. Hence, the curtailment of excess electricity is avoided by storing it as valuable fuel and storage resource. The SOFC dynamically provides complementary power when solar and wind power are not available, and provides high quality heat for the microgrid.

A clever design of the heat exchanger network, controls, and other balance of plant is required to harness the high quality heat, offset the thermal mismatch of the system, follow dynamic loads, and keep the system warm when not in use. The NFCRC research is addressing these types of system challenges and working with a start-up, Hydroloop, to design and build a prototype solid oxide hydrogen energy storage system prototype in the 1-3 kW size class for the SEFM.

High Efficiency Integration of Solid Oxide Fuel Cells and Chillers for Data Centers

The rapid growth of data-driven machines and services is increasing the need for power. Today, data centers consume more than 3% of the world's energy (~420 terawatt-hours/year) and they are responsible for 2% of total greenhouse gas emissions.

Projections show that the data center sector could be using 20% of all available electricity in the world by 2025. With this significant increase, energy efficiency and low emissions are crucial for data centers. Information technology (IT) equipment and cooling infrastructure are the two major power consumers; the latter consuming 40% of the total energy delivered to the data center.

The implementation of solid oxide fuel cell (SOFC) technology for power generation in data centers has many advantages; fuel flexibility, lower emissions, higher production efficiency even at the server rack scale, and the production of high-quality exhaust heat for co-generation applications.

Microsoft Corporation is supporting NFCRC research to assess the achievable air conditioning from SOFC exhaust heat while assuring the dynamic effectiveness of the integrated system and maintaining system reliability.

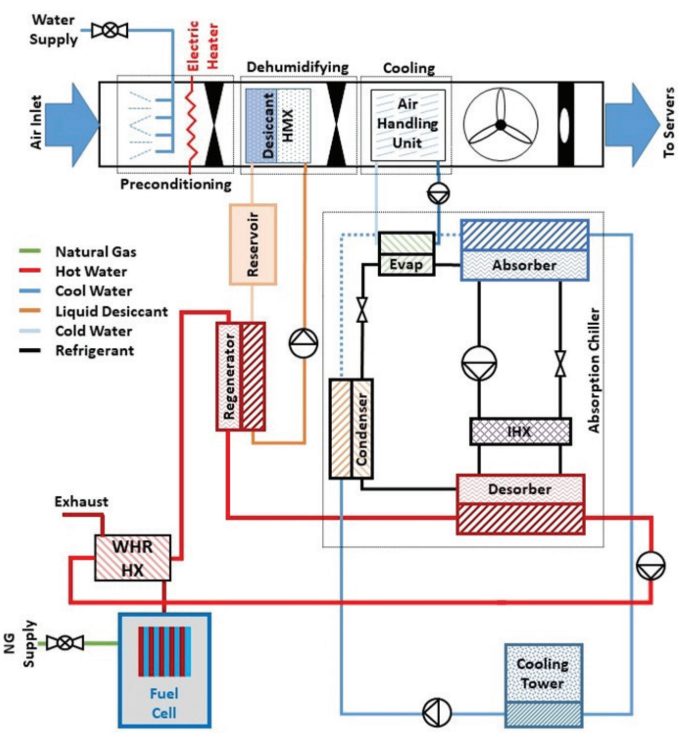
"By developing the appropriate high efficiency thermal integration in parallel, the SOFC can provide the clean, primary power production role in the architecture of future data centers."

A previous collaboration with Microsoft investigated the implementation of a SOFC in a data center by using a direct current (DC) to supply power from the fuel cell to the server rack. This investigation proved that a SOFC is capable of the dynamic load following required when powering active servers.

The current collaboration with Microsoft theoretically and experimentally investigates a SOFC integrated with bottoming cycles to produce air conditioning. A heat powered absorption cooling cycle utilizing lithium bromide (LiBr) is selected to provide cooling for the servers. By implementing supplemental cooling to the incoming air, data centers will be able to minimize their water demand in high temperature climates where water prices are high.

Similarly, a liquid desiccant regenerative cycle is selected to provide dehumidification to the incoming air. High humidity can cause corrosion within the servers leading to short circuits. Low humidity can cause the servers to develop electrostatic charges that can damage sensitive equipment.

In addition to dynamic simulation, NFCRC researchers are experimentally evaluating a small-scale SOFC, integrated with absorption chilling and dehumidification systems, for powering a rack of servers in the range of 6-15 kW. The SOFC exhaust heat produces hot water in a heat exchanger, the hot water is used in either a regenerator for dehumidification or desorber for cooling. A custom-built dehumidifier system and a commercial absorption chiller will be tested in the NFCRC laboratory for air conditioning purposes.



UCICL and NFCRC Welcome New Associate Directors

After an extensive search, the Advanced Power and Energy Program welcomed two additional faculty in the fall of 2018. Professor Bihter Padak as associate director of the UC Irvine Combustion Laboratory and Professor Iryna Zenyuk as associate director of the National Fuel Cell Research Center. Together they will help guide the future of the UCICL and NFCRC.

Professor Bihter Padak

UCICL Associate Director Bihter Padak joined UC Irvine as an assistant professor in the Department of Mechanical and Aerospace Engineering. Professor Padak received her Bachelor's degree from Istanbul Technical University in Chemical Engineering, Master's degree from Worcester Polytechnic Institute and earned her Ph.D. degree in Energy Resources Engineering at Stanford University. Her research focuses on combustion and emission control technologies, and aims to reduce the environmental impacts of generating electricity from fossil fuels. Prior to joining UCI, she was on the Chemical Engineering faculty at University of South Carolina, and associated with the SmartState Center for the Strategic Approaches to the Generation of Electricity (SAGE). She is the recipient of the 2017 American Institute of Chemical Engineers' (AIChE) 35Under35 Award in Energy, a Best Paper Award from the Geological Society of America's Frontiers in Coal Science, and the Centennial Teaching Assistant Award from Stanford University.

Professor Padak's group focuses on combustion, reaction kinetics, and emissions control technologies. Her laboratories are equipped with bench-scale experimental systems to elucidate the flame chemistry, combustion kinetics, and pollutant formation of practical burners. Her group also employs electronic structure calculations to investigate surface interactions and develop kinetic models validated by spectroscopic techniques. Areas of application include oxy-fuel combustion, chemical looping combustion, natural gas and high hydrogen content fuel combustion in gas turbines, selective catalytic reduction and mercury control technologies.

Professor Iryna Zenyuk

NFCRC Associate Director Iryna Zenyuk joined UC Irvine as an assistant professor in the Department of Chemical and Biomolecular Engineering. Professor Zenyuk received her Bachelor's degree in Mechanical Engineering from the New York University and the Master's and Ph.D. degrees focusing on fuel cells from Carnegie Mellon University. She was a postdoctoral fellow at the Lawrence Berkeley National Laboratory in electrochemistry and joined Tufts University in 2015 as a faculty in the Mechanical Engineering Department. In 2018, she served as a visiting professor at the Los Alamos National Laboratory, the University of New Mexico, and the Grenoble Institute of Technology in France. Professor Zenyuk's numerous awards include an NSF CAREER award, a Scialog Fellow award from the Research Corporation for Science Advancement, the Fraunhofer Award for Young Researchers from the International Society for Porous Media (InterPore), and a Toyota ECS award. She has published over 40 journal publications and delivered more than 50 invited presentations.

Professor Zenyuk's group works on enabling renewable energy solutions for transportation and stationary applications with emphasis on electrochemical systems. Her research focuses on low-temperature hydrogen fuel-cells, electrolyzers, and Li-metal batteries. She works on design strategies encompassing novel materials, diagnostic tools, and device-level testing. Her group is a leading expert in x-ray computed tomography imaging of operando devices, for which they use five DOE synchrotron user facilities. Her goal is to grow the fundamental electrochemistry aspect within the NFCRC and to strengthen the links between the fundamental and applied research programs.

2018-2019 Graduates

Jennifer Lee, M.S.

Substation Automation and Optimization of Distribution Circuit Operations

Gi Jung Lee, M.S.

Modeling Power Plant and Electric Grid Dynamics with High Renewable Use and Climate Change in California

John Stansberry, M.S.

Dynamic Analysis of a Proton Exchange Membrane Electrolyzer Integrated with a Natural Gas Combined Cycle Power Plant for Power-to-Gas Applications

Analy Munoz, Ph.D.

Technology Mix Optimization for Zero-Emission Fleets Adopting a Multi-Criteria Decision Analysis within a Life Cycle Assessment Framework

2018-2019 Internships

Maryam Asghari

California Energy Commission

Summer 2019

Zahra Heydarzadeh Sheykh

Irvine Valley College

2019-2020

Pegah Mottaghizadeh

Bloom Energy

Summer 2019

Alejandra Hormaza Mejia

California Energy Commission

Summer 2019

Alireza Saeedmanesh

174 Power Global

Summer 2019

Publications 1 July 2018 to 30 June 2019

JOURNALS

ASSESSING CLIMATE CHANGE IMPACTS ON CALIFORNIA HYDROPOWER GENERATION AND ANCILLARY SERVICES PROVISION (2018). Climate Change, Vol. 151, No. 3-4, pp. 395-412, (Brian Tarroja, Kate Forrest, Felicia Chiang, Amir AghaKouchak, Scott Samuelsen)

RESOURCE PORTFOLIO DESIGN CONSIDERATIONS FOR MATERIALLY-EFFICIENT PLANNING OF 100% RENEWABLE ELECTRICITY SYSTEMS (2018). Energy, Volume 157, pp. 460-471 (Brian Tarroja, Brendan Shaffer, and Scott Samuelsen)

A GENERIC MICROGRID CONTROLLER: CONCEPT, TESTING, AND INSIGHTS (2018). Applied Energy, Vol. 229, pp. 660-671 (Ghazal Razeghi, Fei Gu, Russell Neal, Scott Samuelsen)

LEAN FLAMMABILITY LIMITS OF SYNGAS/AIR MIXTURES AT ELEVATED TEMPERATURES AND PRESSURES (2018). Journal of Energy and Fuels, Vol. 32, No. 10, pp. 10964-10973 (Daniel Jaimes, Vincent McDonell, Scott Samuelsen)

COMPARING THE EMISSIONS BENEFITS OF CENTRALIZED VS. DECENTRALIZED ELECTRIC VEHICLE SMART CHARGING APPROACHES: A CASE STUDY OF THE YEAR 2030 CALIFORNIA ELECTRIC GRID (2018). Journal of Power Sources, Vol. 401, pp. 175-185 (Aaron Cheng, Brian Tarroja, Brendan Shaffer, Scott Samuelsen)

TRANSLATING CLIMATE CHANGE AND HEATING SYSTEM ELECTRIFICATION IMPACTS ON BUILDING ENERGY USE TO FUTURE GREENHOUSE GAS EMISSIONS AND ELECTRIC GRID CAPACITY REQUIREMENTS IN CALIFORNIA (2018). Applied Energy, Vol. 225, pp. 522-534 (BrianTarroja, Felicia Chiang, Amir AghaKouchak, Scott Samuelsen, Shuba Raghavan, Max Wei, Kaiyu Sun, and Tianzhen Hong)

ASSESSING FUTURE CLIMATE IMPACTS ON BUILDING ENERGY DEMAND CHARACTERISTICS IN CALIFORNIA (2018). Applied Energy, Vol. 226, pp. 49-60 (Brian Tarroja, Felicia Chiang, Amir AghaKouchak, Scott Samuelsen, Shuba Raghavan, Max Wei, Kaiyu Sun, and Tianzhen Hong)

A REVIEW OF SENSOR TECHNOLOGIES FOR AUTOMOTIVE FUEL ECONOMY BENEFITS (2018). SAE International Journal of Connected and Automated Vehicles, Vol. 2, Issue 1, pp. 5-16 (Van Wifvat, Brendan Shaffer, and Scott Samuelsen)

TURNING PARIS INTO REALITY AT THE UNIVERSITY OF CALIFORNIA (2018). Nature Climate Change, Vol. 8, pp. 183–185 (Victor, David G., Ahmed Abdulla, David Auston, Wendell Brase, Jack Brouwer, Karl Brown, Steven J. Davis, Carrie V. Kappel, Alan Meier, Mark Modera, Rebecca Zarin Pass, David Phillips, Jordan Sager, and David Weil)

NEED FOR A MARGINAL METHODOLOGY IN ASSESSING NATURAL GAS SYSTEM METHANE EMISSIONS IN RESPONSE TO INCREMENTAL CONSUMPTION (2018). Journal of the Air and Waste Management Association, Vol. 68, Issue 11, pp. 1139-1147 (Mac Kinnon, Michael, Heydarzadeh, Zahra, Doan, Quy, Ngo, Cuong, Reed, Jeff and Brouwer, Jacob)

DYNAMICS OF AN INTEGRATED SOLAR PHOTOVOLTAIC AND BATTERY STORAGE NANOGRID FOR ELECTRIC VEHICLE CHARGING (2018). Journal of Power Sources, Vol. 399, pp.166-178 (Loura Novoa, and Jack Brouwer)

OPTIMAL DESIGN OF A DISTRIBUTED ENERGY RESOURCE SYSTEM THAT ECONOMICALLY REDUCES CARBON EMISSIONS (2018). Applied Energy, Volume 232, Pages 119-138 (Robert Flores, and Jacob Brouwer)

CRITICAL EVALUATION OF MOMENTUM FLUX RATIO RELATIVE TO A LIQUID JET IN CROSSFLOW (2018). Atomization and Sprays, Vol 28 (7), pp. 599-620 (Scott Leask, Vince McDonell, and Scott Samuelsen)

NET-ZERO EMISSIONS ENERGY SYSTEMS (2018). Science, Vol. 360, Issue 6396 (Steven Davis, et. al.)

CONSIDERING FUTURE REGIONAL AIR QUALITY IMPACTS OF THE TRANSPORTATION SECTOR ENERGY POLICY (2019). Energy Policy, Vol. 124, pp. 63-80 (Michael Mac Kinnon, Shupeng Zhu, Marc Carreras-Sospedra, James V. Soukup, Donald Dabdub, G.S. Samuelsen, Jacob Brouwer)

SIMULATION OF ELEVATED TEMPERATURE SOLID SORBENT CO2 CAPTURE FOR PRE-COMBUSTION APPLICATIONS USING COMPUTATIONAL FLUID DYNAMICS (2019). Applied Energy, Vol. 237, pp. 314-325 (Qin Chen, Fabian Rosner, Ashok Rao, Scott Samuelsen, Ambal Jayaraman, and Gokhan Alptekin)

EMULSION JET IN CROSSFLOW ATOMIZATION CHARACTERISTICS AND DYNAMICS (2019). Journal of Engineering for Gas Turbines and Power, Vol. 141, pp. 041025-1 to041025-11 (Scott Leask, Vincent G. McDonell, and Scott Samuelsen)

INFLUENCE OF HYDROGEN ADDITION TO PIPELINE NATURAL GAS ON THE COMBUSTION PERFORMANCE OF A COOKTOP BURNER (2019). International Journal of Hydrogen Energy, Vol. 44, Issue 23, pp. 12239-12253 (Y. Zhao, V. McDonell, and S. Samuelsen)

PRIORITIZING AMONG THE END-USES OF EXCESS RENEWABLE ENERGY FOR COST-EFFECTIVE GREENHOUSE GAS EMISSION REDUCTIONS (2019). Applied Energy, Volume 235, pp. 284-298 (Sarah Wang, Brian Tarroja, Lori Schell, Brendan Shaffer, and Scott Samuelsen)

Highlights of the 2018-2019 Academic Year

SUMMER 2018

National Fuel Cell Symposium—June 2018

The National Fuel Cell Research Center held its annual National Fuel Cell Symposium and Pre-Symposium Fuel Cells 101 short course in Sacramento, CA. The 2018 Symposium focused on Stationary Fuel Cells, while FC 101 addressed the basics of fuel cell technology, fuel cell types, and the role of fuel cells in the electric grid.

APEP Hosts Student Tours—July and August 2018

Over the summer International students were hosted from SOKA High School, Tokyo, KAUST University, Saudi Arabia, and Yonsei University, South Korea. The visiting International students had the opportunity to learn about energy production, utilization and sustainability while visiting APEP's research laboratories.

UCI COSMOS Program—August 2018

The Advanced Power and Energy Program hosted high school students participating in the UCI COSMOS program, an academic experience for the next generation of scientists, engineers, and mathematicians. The group was presented overviews of APEP research on Autonomous Vehicles and on adding renewable hydrogen to the natural gas system.

FALL 2018

California Renewable Hydrogen Deployment Roadmap—September 2018

APEP received a CEC grant for the development of a deployment roadmap for renewable hydrogen production in California through 2050. The roadmap will provide details on the build-out necessary to serve the growing demand for renewable hydrogen to serve transportation, power generation, and other applications.

Shibaura Institute—September 2018

The Advanced Power and Energy Program hosted a group of electrical engineering students from the Shibaura Institute of Technology in Japan. The visit included APEP research presentations on the Advanced Energy Community in Huntington Beach, 100% Renewables and Energy Storage, Autonomous Vehicles, and a tour of the alternative fuels vehicle fleet.

AEE-SoCal Annual Conference—September 2018

APEP Graduate Students participated in the 2018 AEE—So Cal annual conference that covered the topics of Big Data in the World of Energy and The Future of Energy in Transportation. APEP graduate students presented on the future of Electric Vehicle Transportation and hosted an exhibit table featuring the research at APEP.

Netherlands Delegation—September 2018

A delegation from the Netherlands comprised of industry and government agencies visited APEP for a meeting and discussion on the important role of hydrogen in energy storage needs. The group toured APEP research facilities which included the connectivity lab, the fuel cell lab, and the Power-to-Gas demonstration site.

WINTER 2018

UCI H_2 Fueling Station Record Year—January 2019

For 2018, a total of 70,191 kilograms of hydrogen were dispensed, which is 44% more output than in 2017. Two hydrogen fuel cell electric buses also refueled at the station, but the majority of the output was into light duty fuel cell electric vehicles.

UCI Sustainability Students—February 2019

Undergraduate students from the UCI Sustainability Department visited APEP for research presentations on Plug-In Electric Fuel Cell Vehicles, Autonomous Vehicles, and future vehicle integration into the electric grid.

SPRING 2019

ICEPAG 2019: Microgrid Global Summit—March 26-28, 2019

This three-day summit hosted by APEP brought together global experts from Industry, Government, and Academia to examine and share cutting edge information on real-world, on-the-ground Microgrid developments. Major topics included the smart grid, mobility, and transportation electrification.

Atomization & Sprays Short Course—March 15-16, 2019

The UCI Combustion Lab Course provides an introduction to the theory of atomization and evaporation and how these concepts connect to practical devices used in various applications including fuel injection, coatings, and pharmaceuticals. Lectures and presentations were complemented with a hands-on experience that involved applying various diagnostic methods to representative sprays in the test cells of the UCI Combustion Laboratory.

Gas Turbine Combustion Short Course—March 11-14, 2019

The four-day course offered by the UCI Combustion Laboratory provides detailed instruction on the emissions, design, performance, theory, and regulations associated with gas turbine combustion systems. Special attention is paid to methods of minimizing pollutant emissions, regulatory forces, and the experimental and computational methods used to delineate combustor behavior.

Plug-In Prius Prototype Farewell—May 2019

APEP bid a fond farewell to the last of 21 Toyota Prius Plug-In Hybrid vehicles that joined the Advanced Power and Energy Program in 2010. The Plug-In Prius fleet were part of several research projects which included the Irvine Smart Grid Project. Toyota will retire the prototype Plug-In Prius vehicles which paved the way for mass production of Plug-In Hybrid vehicles today.

www.apep.uci.edu

Advanced Power and Energy Program
University of California, Irvine
Irvine, California 92697-3550

The Advanced Power and Energy Program (APEP) encompasses three organizational elements: the National Fuel Cell Research Center, the UCI Combustion Laboratory, and the Pacific Rim Consortium on Combustion, Energy, and the Environment.

APEP advances the development and deployment of efficient, environmentally sensitive, and sustainable power generation, storage, and conservation. At the center of APEP's efforts is the creation of new knowledge brought about through fundamental and applied research and the sharing of this knowledge through education and outreach.

The connection of APEP's research to practical application is achieved through our close collaboration with industry, national agencies, and laboratories to "bridge" engineering science and practical application.

APEP is affiliated with The Henry Samueli School of Engineering at the University of California, Irvine, and is located in the Engineering Laboratory Facility (Building 323) near East Peltason Drive and Engineering Service Road.

For additional information, please contact:

William Gary
Manager of Outreach & External Relations
Advanced Power and Energy Program
949 824.7302 x11131
wmg@apep.uci.edu.