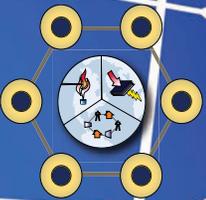


ADVANCED POWER & ENERGY PROGRAM

# BRIDGING

Engineering Science to Practical Application



# DIRECTOR'S MESSAGE



**Professor Scott Samuelsen**  
**Director**  
**Advanced Power and Energy Program**

Bridging the gap between engineering science and practical application has never been more important. The close collaboration with industry, national and international agencies, and laboratories has long been a hallmark of the Advanced Power and Energy Program (APEP), the umbrella organization for the National Fuel Cell Research Center (NFCRC) and the UCI Combustion Lab (UCICL). These critical relationships have become even more valuable in maintaining the momentum of the paradigm shift to clean energy in the United States.

For this fifth edition of our BRIDGING annual report, the featured article highlights APEP's continuing work on Power to Gas (P2G) as an ultimate energy storage solution, and the utilization of excess renewable power that would otherwise be curtailed. This project is significant not only because it is the first power-to-gas hydrogen pipeline injection project in the United States, but also because it is (1) demonstrating the value of surplus renewable electricity that would otherwise go to waste, (2) showing that end-use technologies can operate on a mixture of natural gas and hydrogen, and (3) establishing the importance of P2G in enabling a high use of renewable power in the future.

APEP has teamed with the cities of Huntington Beach and Santa Monica on two Advanced Energy Community (AEC) projects with support from the **California Energy Commission (CEC)**. AEC technologies seek to reduce energy demand through efficiency measures, reduce emissions through the use of renewable and sustainable generation, and increase energy service reliability. Partners in the Huntington Beach project include **Altura Associates**, **Southern California Edison**, **Southern California Gas**, and the **National Renewable Energy Laboratory**. Santa Monica partners include **Arup**, **Energy and Environment Economics**, and **ICLEI-Local Governments for Sustainability**.

The new APEP Connectivity Laboratory has become invaluable for testing and validation of advanced power technologies and in supporting courses that include a new Department of Electrical Engineering and Computer Science course on Power Systems. The laboratory was established in collaboration with industry partners **Schweitzer Engineering Laboratories (SEL)**, **Southern California Edison (SCE)**, **OPAL-RT**, and **MelRok**. The lab is furnished with the latest instrumentation donated by SEL, enabling the evaluation and testing of advanced energy systems, and supporting the education of the next generation of power engineers.

In the past year, the National Fuel Cell Research Center in partnership with **Southern California Gas**, has researched and evaluated the benefits of integrating thermal storage with a Solid Oxide Fuel Cell (SOFC), and a Micro-CHP system for Zero Net Energy (ZNE) residential applications. Also being investigated are the energy balance and economic analysis of a mixed-fuel ZNE home using an SOFC system as compared to an all-electric ZNE home. Under the sponsorship of the **U.S. Department of Energy**, researchers are also developing integration schemes to maximize the potential of integrating a SOFC with a Gas Turbine. The resulting SOFC/GT "hybrid" substantially reduces combustion related pollutant emissions in heat engines.

Continuing its cutting edge research in the area of clean combustion, the UCI Combustion Laboratory (UCICL) with funding provided by the CEC is studying the performance of appliances when the percentage of renewable natural gas is increased in the fuel supply. In another CEC funded study, the UCICL with supporting partners **Horiba**, **Capstone Turbine Corporation** and **CoorsTek Sensors** is examining the use of Solid-State Electrochemical Sensors for continuous monitoring of Nitric Oxide (NO) emissions produced by Distributed Generation resources.

We are especially proud of the accomplishments of our students which for the 2016-2017 academic year includes 5 graduates, 7 internships with diverse entities such as: **Southern California Edison**, **Capstone Turbine**, **the Stone Edge Farm Microgrid Project**, and **Solar Turbines**, and a Fulbright Fellowship at the **Paul Scherrer Institute** in Switzerland.

In summary, 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.

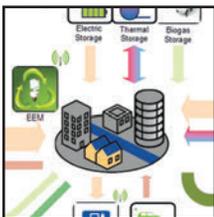
A handwritten signature in black ink that reads "Scott". The signature is stylized and cursive.

Scott Samuelsen

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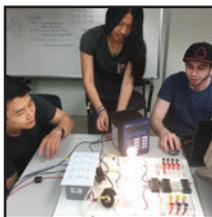
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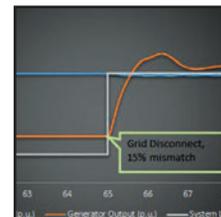
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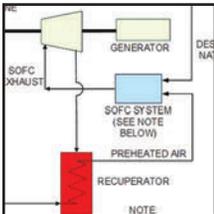
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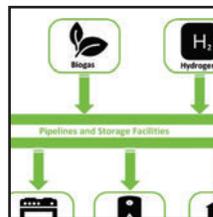
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Also included in this issue:

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# Renewable “Power-to-Gas” Proof of Concept is a Success



Photo by Paul Kennedy

## UCI Parking Structure Solar Panels

Massive daily, weekly, and even seasonal amounts of energy storage will be required to utilize the high levels of renewable power now being mandated. In California for example, 50% renewable power utilization is required by 2030. The Advanced Power and Energy Program at UC Irvine with support from the Southern California Gas Company and collaborator Proton Onsite, has successfully launched the first U.S. research and development project to create, demonstrate, and evaluate a carbon-free renewable “power-to-gas” (P2G) system.

In this pioneering project APEP has successfully used an electrolyzer to create hydrogen and safely inject it into an existing UCI Microgrid natural gas line for both storage and transmittal to the University’s combined cycle power plant at concentrations of up to 0.78%. Hydrogen production data, the natural gas hydrogen mixture flow rate, and the emissions of the combined cycle plant are all being closely monitored during this project. After a smooth launch, all continues to go well for this first U.S. proof of concept power-to-gas project.

Specifically APEP research is being conducted with SoCalGas and the National Renewable Energy Laboratory to:

- Advance the dynamic operation of DC electrolysis.
- Advance hydrogen natural gas mixing concepts.
- Investigate pipeline hydrogen storage capabilities.
- Demonstrate efficient hydrogen production and injection into an existing natural gas pipeline—a U.S. first.
- Develop integrated P2G system concepts.
- Analyze the cost effectiveness of massive energy storage via P2G.

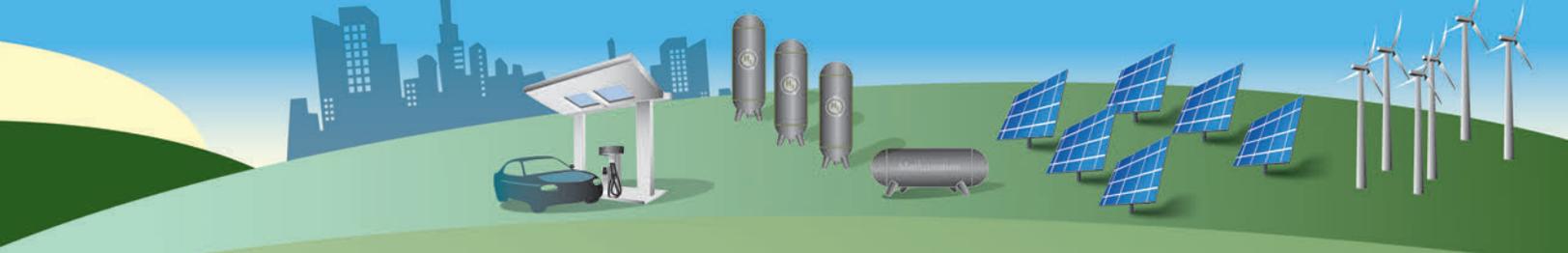
The APEP P2G process produces carbon-free hydrogen gas by using the highly dynamic and intermittent electricity derived from renewable sources such as solar and wind in electrolyzer-based methods to break down water into hydrogen and oxygen. The hydrogen can then be directly and safely introduced into existing natural gas pipelines at low levels, converted to synthetic methane — a renewable natural gas, used to dynamically dispatch gas-fired power plants with net zero carbon emissions, and used to fuel zero emission fuel cell electric vehicles

The U.S. natural gas system includes transmission and distribution pipeline networks and existing underground gas storage facilities that are sufficient to store enormous amounts of energy. In the SoCalGas service territory alone, more than 12 terawatt-hours of electric equivalent storage can be accommodated.

Smart Grid integration of P2G followed by direct injection of renewable gas into the natural gas system provides a massive energy storage buffer that can be used to manage the electric



Graduate Student John Stansberry Describing the P2G Electrolyzer



grid when very high levels of renewable power are used. No other technology offers the readily available and existing means for storing such massive quantities of energy, while at the same time delivering renewable energy from remote locations of production to urban areas—without the environmental impact of additional overhead power lines that must run through pristine or populated environments.

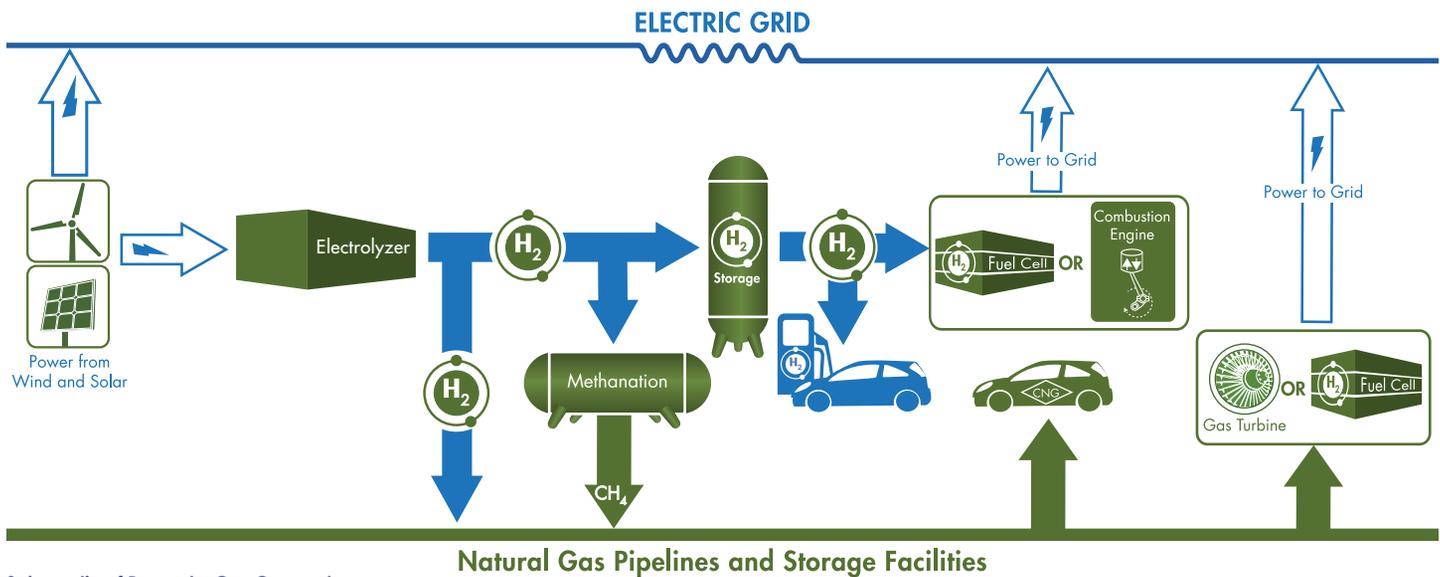
At this point in the project, some of the major research findings include:

- During partially cloudy conditions, failure of the electrolyzer to achieve part-load conditions of around 35% of full power was found to significantly contribute to lost opportunities for P2G to capture solar power.
- Solid Oxide Electrolysis technology was tested and evaluated in the laboratory, and achieved electric energy input as low as 30 kWh/kg-H<sub>2</sub>. State-of-the-art PEM Electrolyzers and Alkaline Electrolyzers require more electrical input, on the order of 50 kWh/kg-H<sub>2</sub>.
- P2G modeling of the UCI Microgrid showed that the fraction of renewable energy that could be used could be increased to 35% compared to the current use of 3.5% by implementing a Power-to-Gas strategy.
- Full-scale hydrogen production and injection into an existing 400 psi natural gas pipeline that feeds the UCI Central Plant was successfully accomplished.

- Combustion of this P2G hydrogen gas in a Solar Turbines Titan 130 natural gas combined cycle plant, typical of all major natural gas power plants around the world, was accomplished.
- An economic model was developed to evaluate the levelized cost of returned energy via multiple P2G pathways that included:
  - Returned energy as electricity (i.e., electricity in and electricity out).
  - Natural gas pipeline injection and subsequent legacy plant operation.
  - Battery energy storage.
  - Production of hydrogen fuel.
- For all the pathways investigated, the most valuable use of hydrogen is as hydrogen fuel for fuel cell vehicles.

When fueled with renewable hydrogen, Fuel Cell Electric Vehicles (FCEV's) are not only emission free but also carbon free, while providing many of the conveniences drivers are accustomed to with conventional internal combustion powered vehicles such as long-range, rapid fueling, and large vehicle capabilities that are unmatched by any other zero emission transportation option.

APEP plans to continue operating the P2G system at the UCI Central Plant to study the impacts of operating on other intermittent renewable power sources such as wind farms, and to study the long-term impacts of hydrogen injection and mixing. Also being studied is the possible installation of a larger electrolyzer to capture additional otherwise curtailed electricity and enable higher concentrations of hydrogen.



Schematic of Power-to-Gas Concept

# Advanced Energy Communities to Support **Renewable Power Generation**

California state law requires that 33% of all electricity generated in 2020, and 50% in 2030, be from renewable resources, which will likely drive integration of renewable technologies at the community level. However, to enable high renewable use, there currently is a lack of understanding and integration of:

- Smart grid technologies.
- Combined cooling heat and power generation with high temperature fuel cells.
- Electrical, thermal, and chemical energy storage.
- Energy efficiency measures.
- Dynamics of renewable generation.
- Dynamics and control of community loads.
- Electric vehicle integration.
- Local gas and electricity utility constraints.

When better understanding and integration of these technologies is accomplished in a community it creates an Advanced Energy Community (AEC). The Advanced Power and Energy Program at UCI has teamed with the Cities of Huntington Beach and Santa Monica on two AEC projects. Figure 1 graphically represents the components of an Advanced Energy Community.

In Huntington Beach APEP has partnered with Altura Associates, Southern California Edison, Southern California Gas, and the National Renewable Energy Laboratory to develop tools to optimally design and operate an AEC. Using these tools, the team will develop and propose a master AEC plan for the Oak View community located in Huntington Beach. This community

consists of single- and multi-family residences, an elementary school, commercial businesses, and industrial operations, including municipal waste collection and processing facilities. By installing AEC technologies in the community:

- Energy demand will be reduced through efficiency measures.
- Emissions will be reduced through the use of renewable and sustainable generation.
- Energy service reliability will be increased for critical community loads.

The Huntington Beach AEC will support local utility and state goals of environmentally and economically sustainable development. The goals of this AEC project are to produce:

- Advanced Energy Community design and operation tools.
- An AEC master plan for the Oak View community.
- Outreach strategies and business models to educate and empower Oak View residents.

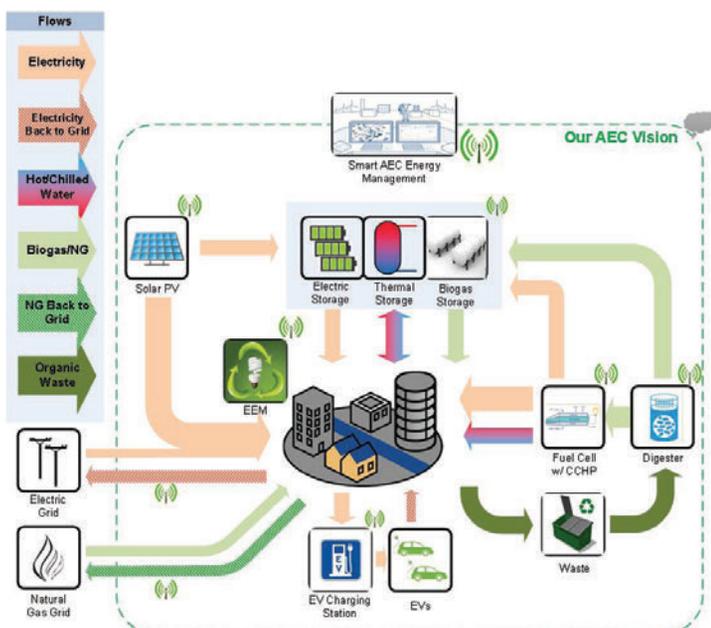
Successful completion of the project tasks will not only result in an AEC roadmap for the Oak View community, but also tools for the development of Advanced Energy Communities in similar communities throughout the state and the world.

In Santa Monica APEP is partnering with Arup, Energy and Environment Economics, and ICLEI-Local Governments for Sustainability. To meet the City of Santa Monica's extensive set of sustainability and low-carbon energy targets as applied to the "City Yards Microgrid Project," this project will evaluate:

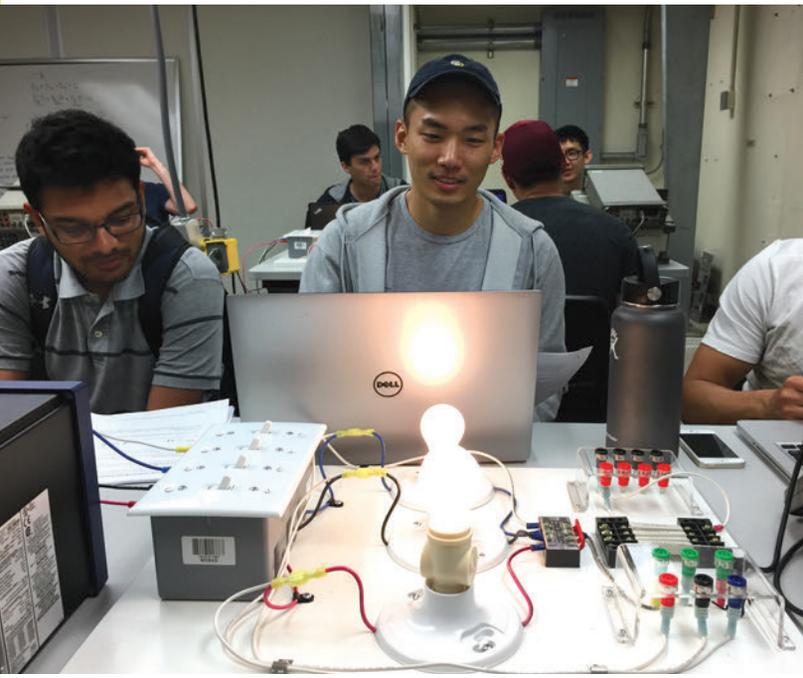
- Different energy technology solutions.
- Governance structures.
- Business models.
- Financing options.

"City Yards" currently houses the City's facilities maintenance, custodial services, street maintenance, fleet maintenance, traffic operations, resource recovery and recycling, water and wastewater operations, hazardous waste storage, and a Fire Department training area.

In January 2015, the City Council voted to move forward with a \$115 million redevelopment of the industrial site to better align the operational relationships and improve the functionality of the spaces used by the City's 9 departments and agencies that occupy this site. The City Yard Microgrid will serve as a relevant and replicable model for other cities in California and will showcase a variety of viable and attractive Advanced Energy Community Concepts to other cities.



**Figure 1:** APEP's Vision of the Components of an Advanced Energy Community



# State-of-the-Art **Connectivity** **Laboratory** Opens its Doors

The new Advanced Power and Energy Program (APEP) Connectivity Laboratory, initiated in April 2017, serves as a valuable resource for research and instruction. Furnished with the latest instrumentation, this facility enables evaluation and testing of advanced energy systems such as smart grids, microgrids, photovoltaics, battery systems, plug-in electric vehicles, and fuel cells, as well as serving as a state-of-the-art platform to educate the next generation of power engineers.

The laboratory was established in collaboration with industry partners Schweitzer Engineering Laboratories (SEL), Southern California Edison (SCE), OPAL-RT, and MelRok, with the state-of-the-art instruments donated by SEL. The lab has been designed to be rugged yet flexible enough for general instruction, and amply equipped to support advanced power engineering research and cutting edge smart grid and microgrid research. The laboratory provides a flexible plug-and-play environment that can be rapidly configured to create a broad range of AC and DC electrical networks with capabilities that include:

- Testing next-generation renewable and distributed energy resources and power electronics systems.
- Creating hardware-in-the-loop and real-world models of current and future electrical systems.
- Providing a key teaching tool for hands-on training of the next generation of power engineers.

The lab consists of two main components: The Experimental Research Platform and the Command and Control Center.

The Experimental Research Platform is a flexible plug-and-play structure that allows for the rapid interconnection of distributed energy resources such as microturbines, photovoltaic inverters, batteries, electric vehicle chargers, and fuel cells. The backbone of this platform consists of multiple electrical networks that can be independently connected to the utility grid or self-supported on individual microgrids. The platform is equipped with advanced industrial monitoring and control equipment allowing students to familiarize themselves with devices that are used in Industry.

From the Command and Control Center, devices in the Experimental Research Platform as well as the entire UCI microgrid can be monitored and studied. An OPAL-RT 5600 real-time hardware-in-the-loop simulator allows researchers to recreate, in simulation, a variety of operating scenarios, and allows researchers and students to quickly explore a wide range of power system configurations.

The APEP Connectivity Laboratory has proven indispensable in the testing and validation of advanced power technologies, and is invaluable in supporting several UC Irvine courses including a Power Systems Laboratory course offered by the Department of Electrical Engineering and Computer Science.

# The Advanced Power and Energy Program Accelerates its Work on a Generic Microgrid Controller

With funding from the Department of Energy, the Advanced Power and Energy Program in collaboration with Southern California Edison and project partners ETAP, and MelRok have developed functional specifications for a Generic Microgrid Controller (GMC). These specifications will provide easy adaptation by various developers of microgrids of different sizes and with different resources. This flexibility will reduce the engineering and up-front cost required to design and develop microgrid controllers, and support the integration of microgrids into future smart grids.

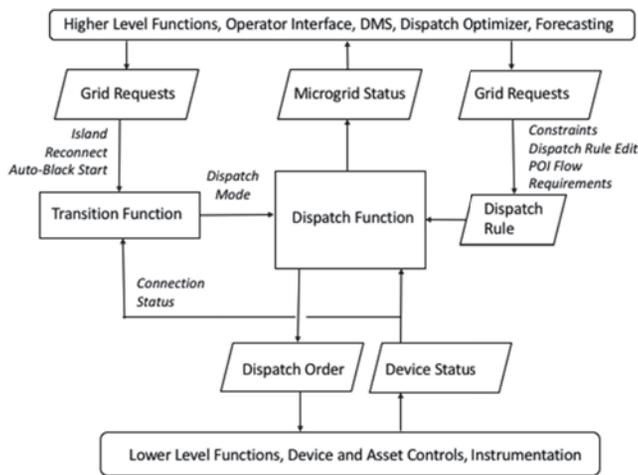


Figure 1: Master Microgrid Controller (MMC) Core Functions

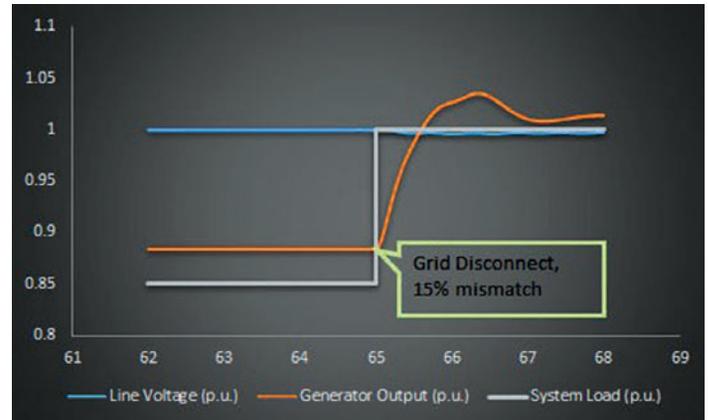


Figure 2: Unintended Island Response

The GMC specifications developed by APEP were applied to the UCI Microgrid, a controller was developed, and is being tested on the OPAL-RT platform where a detailed model of the UCI Microgrid was developed and simulated. A field test of the controller will also be performed on the UCI Microgrid which will include islanding and transition back to grid-connected mode. To facilitate transition between islanded and grid-connected mode, a 2MW/500kWh battery energy storage device has been deployed at a UCI substation as a part of this project. It will also be used to help minimize imports from the grid during grid-connected operations. Minimizing imports will help maximize the financial benefits provided by the UCI Microgrid.

APEP continues to work with its microgrid partners and other stakeholders to determine policies and standards needed to enable microgrid participation in the electricity wholesale and distribution markets, and to solidify the role of microgrids in increasing community resiliency and response to emergency situations.



UCI Microgrid Battery Energy Storage Device

# The Water-Energy Nexus in Electric Power Generation

Fuel cell power plants can substantially contribute to achieving air quality and climate goals through several high value attributes including high efficiency, ultra-low pollutant emissions, zero demand for water, and near zero acoustic emissions. When integrated into a Brayton cycle, the resultant "hybrid" technology:

- Releases the Carnot Efficiency constraint that is due to material limitations in heat engines.
- Substantially reduces combustion related pollutant emissions of the heat engine.

This results in a high efficiency generation of electricity from coal, natural gas, and/or biogas in both central plant generation and distributed generation. A suitable fuel cell for this application is the Solid Oxide Fuel Cell (SOFC). A basic integration scheme of the SOFC/gas turbine hybrid (SOFC/GT hybrid) is illustrated in Fig. 1.

Researchers at the Advanced Power and Energy Program at the University of California, Irvine under the sponsorship of the U.S. Department of Energy, and in coordination with the Research Center for Energy and Power of the Chinese Academy of Sciences, and the National Engineering Research Center of Clean Coal Combustion at Tsinghua University, are developing integration schemes to fully realize the potential of SOFC/GT hybrid systems. The integration is applicable for both central plant and distributed generation applications, and seeks to maximize thermal efficiency and minimize the environmental impact. In addition, post combustion water recovery techniques are being investigated as part of evolving the integration schemes for these advanced power plants.

Central plant Integrated Gasification Fuel Cell/GT hybrid (IGFC) technology that combines coal and/or biomass gasification, is suitable for deployment for large scale (~100 MW) generation.

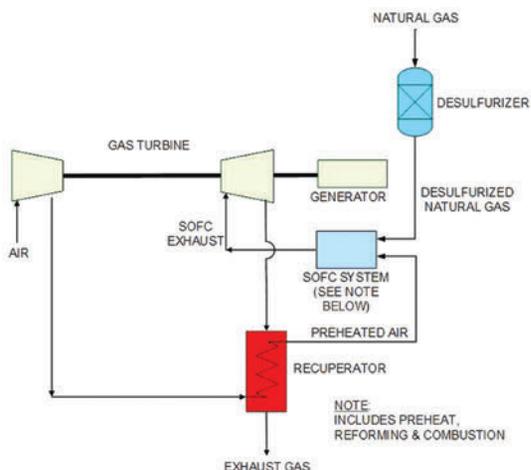


Figure 1: A Natural Gas Based SOFC/GT Hybrid

IGFC has the potential to generate electricity at efficiencies approaching 60% on a coal Higher Heating Value (HHV) basis, while capturing more than 90% of the evolved CO<sub>2</sub> with substantially reduced water demand. When the fuel cell is operated on natural gas (NGFC) in the absence of gasification, the NGFC hybrid has the potential for efficiencies approaching 75%. The higher overall plant thermal efficiency of SOFC/GT hybrid power plants leads to a lower amount of heat rejection requiring a lower amount of makeup water to the wet cooling towers that are typically used in current power plants. In addition, by keeping the anode and the cathode exhaust gases separate, the water vapor entering via the fuel, and the water vapor formed by oxidation of the fuel, may be more easily recovered by cooling the anode exhaust gas. This further reduces the net water consumption of the plant. A basic integration scheme of the IGFC/GT hybrid is illustrated in Fig. 2.

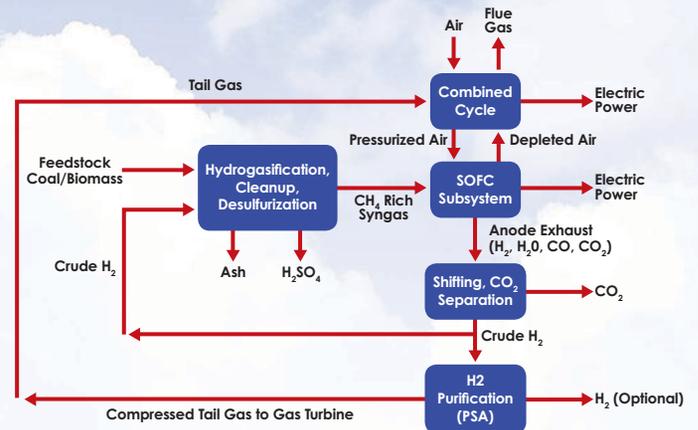


Figure 2: A Coal/Biomass Based IGFC Power Plant

The attributes of the SOFC/GT hybrid technology also makes it ideal for distributed power generation fueled either by natural gas or biogas derived from sources such as waste water treatment facilities and landfills. The increasing demand on electric grids to support high penetration of intermittent renewables, enhance power quality, increase reliability and resiliency, and provide ancillary services, is leading to local power generation on both sides of the meter in the U.S., and in the future, may also be expected in other parts of the world such as China. Clusters of SOFC/GT hybrids in the size range of 10 to 100 MW, referred to as Transmission Integrated Grid Energy Resource (TIGER) Stations are ideal to enable electric grid support by providing baseload power and load following capability.

# Solid Oxide Fuel Cells Support California 2020 Zero Net Energy Home Standards

New California Title 24 building codes require that beginning in 2020 all new single-family homes built must meet Zero-Net-Energy (ZNE) standards through a combination of energy efficiency and on-site renewable energy technologies. Solid Oxide Fuel Cell (SOFC) systems are emerging as the singular ideal, clean, 24/7, power generation technology for residential ZNE homes. The appealing and sought after attributes of these fuel cells include:

- Remarkably efficient operation.
- Compact scalable distributed generation on the customer side of the meter.
- Distributed generation on the utility side of the meter.
- Proven potential to be the most efficient source for distributed power generation for natural gas utilization.
- Operation at high temperatures that provide, high quality heat for generating additional electricity, heat, steam, or chilled water with recorded overall efficiencies exceeding 90% in well-designed commercial applications.
- Emission of virtually zero criteria pollutants.
- Virtually zero water consumption.
- Acoustically benign.



2016 Green Building Expo Display of a 1.5kw Combined Heat and Power System

These outstanding features enable the SOFC technology to be an ideal power generation technology in ZNE homes.

The National Fuel Cell Research Center (NFCRC) in partnership with SOLIDpower Group, has demonstrated a mixed-fuel ZNE home utilizing their BlueGen integrated SOFC system. The 1.5kW SOFC Micro-CHP system was designed for, and is being tested to evaluate the system's steady state performance characteristics. Results are being used in a thermodynamic analysis to evaluate the benefits of integrating thermal storage with a Solid Oxide Fuel Cell and a Micro-CHP system for ZNE residential applications. Also being investigated are the energy balance and economic analysis of a mixed-fuel ZNE home using an SOFC system, versus an all-electric ZNE home.



NFCRC 1.5kw Combined Heat and Power System

# UCICL Evaluates the Use of **Automotive Solid-State Electrochemical Sensors** in Emissions Monitoring for Distributed Generation



**Electrochemical Sensors (UniNOx® and NTK)**

The University of California, Irvine Combustion Laboratory (UCICL) is involved in an ongoing California Energy Commission funded research project with supporting partners Horiba, Capstone Turbine Corporation and CoorsTek Sensors. The project examines the viability of using Solid-State Electrochemical Sensors for the continuous monitoring of Nitric Oxide (NO) emissions produced by Distributed Generation technology. Continuous Emissions Monitoring Systems or CEMS, the current technology that exists for monitoring emissions from the power generation sector, can exceed the cost of the distributed generation system itself, therefore a cost effective alternative is needed.

Using a 60 kW Gas Turbine (Capstone Turbine Corporation C-60) as a testbed, a primary task of this project is to monitor the NO emissions that the sensors report, and compare them to the data from the latest version of a HORIBA Portable Gas Analyzer (Model PG-350). Using the PG-350 as a referee instrument and as a representation of a CEMS, the UCICL plans to find a candidate sensor that closely matches the PG-350 and implement it in closed-loop emissions control within the Capstone C-60 Engine.

Sensor candidates being considered include NTK sensors from Ford and UniNOx® sensors from Continental. When used in the automotive industry,

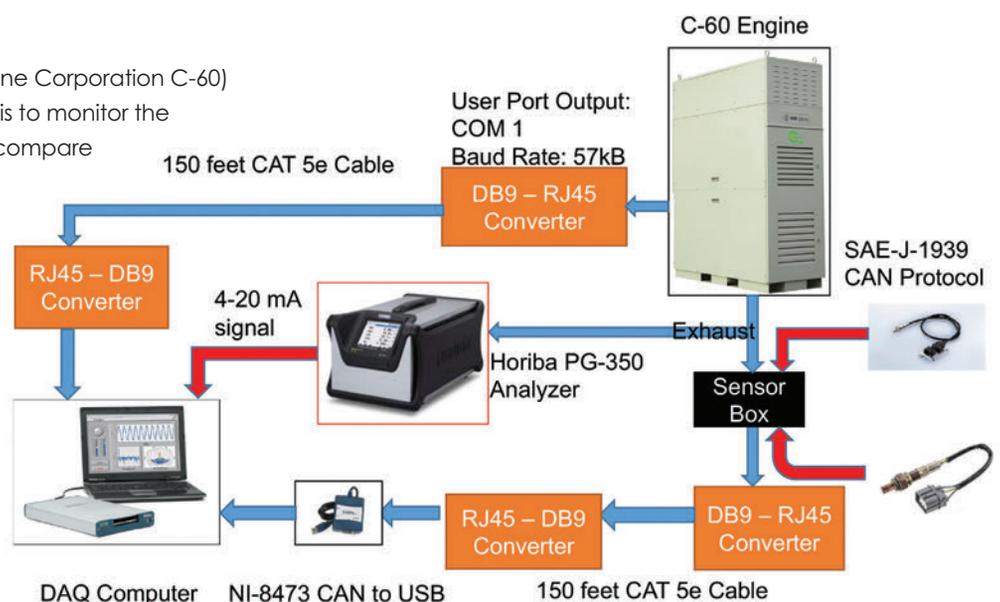
these NO sensors are found primarily in diesel passenger cars and in commercial trucks. A Selective Catalytic Reduction system (SCR) in diesel vehicles will typically have a NO sensor before and after Urea or Ammonia injection to control the amount injected into the system. These chemical compounds break down NO and form Nitrogen and Water.

Sensor characteristics that are being evaluated include:

- Linearity
- Lower detectable limit
- Lag time and rise time
- Precision

To date, the project has involved collecting months of data from candidate sensors and corresponding emissions data from the PG-350 Analyzer. Quantifying the linearity and accuracy characteristics using measured results for both sensors is showing promising results regarding trends in NO.

Because Distributed Generation emissions certification is done once, little is known about how these systems perform after installation. These sensors could prove vital to ensuring Distributed Generation system longevity and maintenance of their low emission performance.



**Figure 1: Flow Diagram of How Signals From Engine and Sensors are Sent to the DAQ Computer**

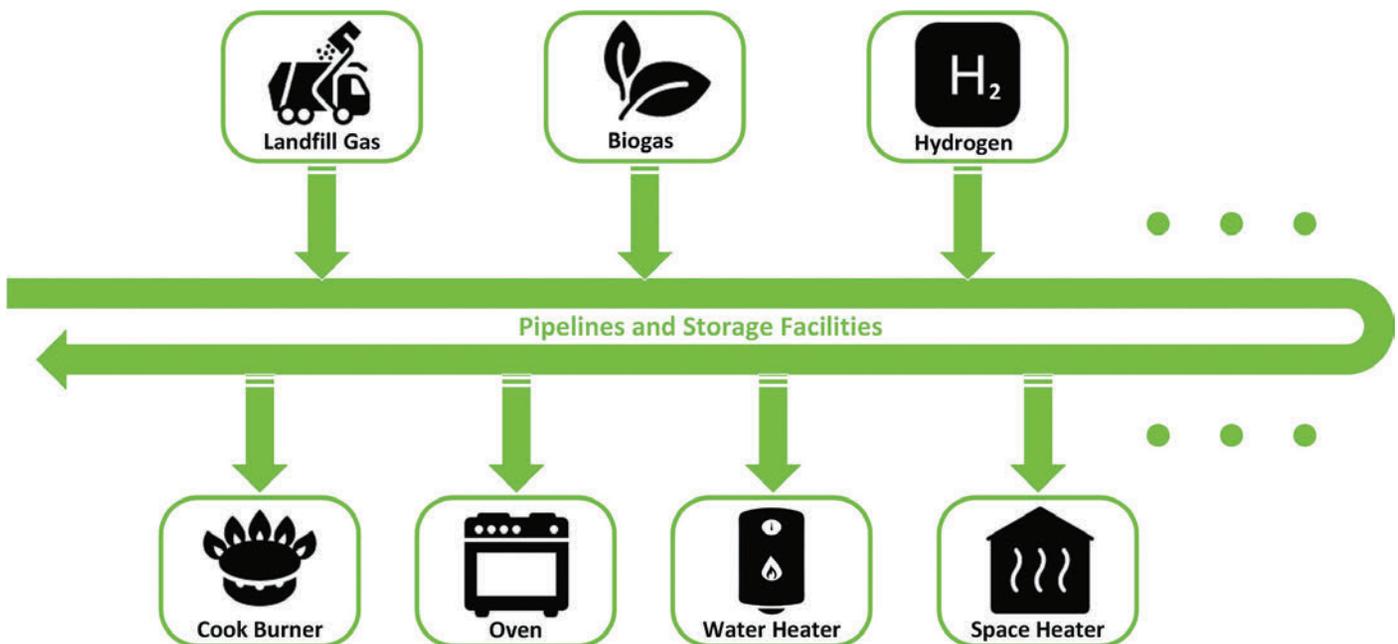
# UCI Combustion Laboratory Researches Increased Use of **Renewable Natural Gas** in Commercial and Residential Appliances

The University of California, Irvine Combustion Laboratory (UCICL) has received funding from the California Energy Commission to investigate the combustion performance of appliances when the percentage of renewable natural gas is increased in the fuel supply.

Currently, renewable sources represent a relatively small fraction of fossil derived natural gas that is used, however interest in renewable fuels is increasing. Two attractive strategies have emerged to increase renewable fuel utilization and the potential for significant displacement of fossil derived natural gas, and the associated reduction of the carbon intensity of gaseous fuels used for various applications. The first is the production of renewably generated hydrogen derived from electrolysis that is driven by using excess renewable electricity in a process known as Power to Gas (P2G). The second is renewable fuels created from landfills, biomass, and waste water treatment to generate methane rich gases. In either strategy, the resulting renewable fuel could be blended into the existing natural gas infrastructure.

As a result, questions arise as to how these blends might impact the performance of end use devices in terms of emissions, efficiency, and safety. This research effort will address these blending related questions.

The focus of this project is on how using these fuels might impact the performance of appliances such as stoves, ovens, water heaters, and space heaters. The past few decades have witnessed the plentiful and substantial achievements of advanced combustion techniques in industry with a resulting significant reduction of pollutants such as CO, SOX, and NOX. However, less research has been conducted to investigate the performance of commercial and residential appliances. For the critical task of evaluating the combustion performance of different appliances utilizing renewable natural gas, both experimental and simulation methods will be adopted to analyze the stability, fuel consumption, heating performance, and emissions of different types of appliances.



Schematic of the Introduction and Use of Renewable Natural Gas

# 2017 Graduates



**Kersey Manlicic (Ph.D.)**

Dissertation: A Suite of Methodologies to Systematically Site Distributed Generation Technologies, Such as Poly-Generation Fuel Cells, in Support of Alternative Transportation Infrastructure



**Robert J. Flores (Ph.D.)**

Dissertation: Costs and Operating Dynamics of Integrating Distributed Energy Resources in Commercial and Industrial Buildings with Electric Vehicle Charging



**Daniel Jaimes (M.S.)**

Thesis: Determination of Lower Flammability Limits of Mixtures of Air and Gaseous Renewable Fuels at Elevated Temperatures and Pressures



**Aria Etemadieh (M.S.)**

Thesis: Verification of a Solid Oxide Fuel Cell System for In-Rack Server Power Generation in Data Centers



**Matthew Clower (M.S.)**

Thesis: Analysis and Integration of an Intermediate-Temperature Solid Oxide Fuel Cell with Server Components for Distributed Power Generation in a Data Center

## Internships

- **Analy Munoz** – Paul Scherrer Institute, Switzerland (Fulbright Fellowship 2016-2017)
- **Ryan Ehlig** – Solar Turbines (Summer 2017)
- **Ali Kalantari** – Capstone Turbine (Summer 2017)
- **Scott Lee** – Southern California Edison (Summer 2017)
- **Jeremiah Blackburn** – Stone Edge Microgrid (Winter and Spring, 2017)
- **Derek McVay** – Stone Edge Microgrid (2016-2017)
- **Gabrielle Cobos** – Stone Edge Microgrid (Summer 2016)

## Awards

### Best Paper award

.....

#### **APPLICATION OF A TURBULENT JET FLAME FLASHBACK PROPENSITY MODEL TO A COMMERCIAL GAS TURBINE COMBUSTOR (2016).**

Paper GT2016-58059, Proceedings of ASME TurboExpo 2016, Seoul, South Korea, June 13-17. (A. Kalantari, E. Sullivan-Lewis, V.G. McDonell). (Subsequently published see page 12).

# HIGHLIGHTS of the 2016-2017 Academic Year

## Spring 2017

### Advanced Power and Energy Program Graduate Students Participate in GiGaTEC Event – May 19, 2017

- The Henry Samueli School of Engineering and the Paul Merage School of Business hosted the **Girls Gateway to Technology and Engineering Careers: GiGaTEC**. This 4 hour program provided High School Soccer athletes the opportunity to learn about engineering and technology careers in health, the environment, social networking, smart manufacturing, computing, mobility, information technology, and civil infrastructure, by interacting with UCI students, researchers, and employers.



### Pathways to 100% Renewables International Conference – May 11-12, 2017

- The conference hosted by the Renewables 100 Policy Institute with **Toward Electrification in All Sectors** as the theme, addressed the opportunities and challenges of transitioning to 100% renewable energy across sectors. The Advanced Power and Energy Program provided a tour of APEP's key energy research projects, a site visit to APEP's Power-to-Gas (P2G) project, and panel participation by APEP Associate Director Professor Jack Brouwer.

### Emerging Technologies Summit – April 19, 2017

- This one day Summit hosted by SoCalGas provided attendees the opportunity to learn about innovative approaches, trends, and improvement opportunities in cutting edge energy efficiency and demand response technologies. The Advanced Power and Energy Program provided tours of the APEP research laboratory and a site visit to APEP's first of its kind P2G demonstration project located on the UCI campus.

### ICEPAG 2017: Grid Evolution Global Summit – Hydrogen – March 28 – 29, 2017

- A two day Summit hosted by the Advanced Power and Energy Program that brought together global experts from Industry, Government, and Academia to examine issues and share critical, cutting edge information on the role of HYDROGEN in the grid of the future. Presentation topics focused on Generation, Transport, Storage, and End Use.

### Atomization and Sprays Short Course – March 24 – 25, 2017

- A two day Course provided by the UCI Combustion Laboratory focused on an introduction to the theory of atomization and evaporation, and how these concepts connect to practical devices used in various applications that include fuel injection, coatings, and pharmaceuticals. The classroom presentations by APEP Associate Director Professor Vince McDonell were complemented with 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 20-23, 2017

- Offered annually since 1993, this four-day Course provided by the UCI Combustion Laboratory provides detailed instruction on the emissions, design, performance, theory, and regulations associated with gas turbine combustion systems. Hosted by APEP Director Professor Scott Samuelsen and Associate Director Professor Vince McDonell, the primary areas of instruction covered combustor design, emissions, and the solution of practical problems that arise in the course of advanced combustor development.

### APEP Supports South Coast Air Quality Management District (SCAQMD) Board Meeting

- APEP Director Professor Samuelsen, graduate students and staff provided a presentation and laboratory tour highlighting key areas of APEP research for the March 9, 2017 SCAQMD board of directors winter meeting. The Anteatr Express Fuel Cell bus provided transportation between APEP and the UCI Student Center where the meeting was held.

### The NFCRC Welcomes the Toyota Mirai to its Fleet of Alternative Fuel Vehicles

- The dark blue 4-door sedan arrived on February 21, 2017 and joined 32 vehicles in the APEP Alternative Transportation fleet which consists of 12 Toyota IQ's, 10 Toyota Prius Plug-in's, and 10 Kia Soul Electric Vehicles. The Mirai is being used in APEP and NFCRC Outreach efforts to support awareness and adoption of Fuel Cell vehicles. In one of the largest events to date, the Mirai was showcased at ICEPAG 2017 which had 170 registrants.



### Best Paper Award Received

- Professor Vince McDonell, graduate student Alireza Kalantari, and Dr. Elliot Sullivan-Lewis (Associate Manager of the UCICL) won the Best Paper Award at the Turbine Technical Conference and Exposition, hosted by the American Society of Mechanical Engineers. Their paper, selected from 118 submissions, describes a design tool developed by the team that can predict boundary-layer “flashback” – a flame propagating upstream of the combustor – in gas turbine systems.

### Second Edition of Best Seller “Atomization and Sprays” Released

- Professor Vince McDonell authored the fully updated second edition of the seminal *Atomization and Sprays* by Arthur Lefebvre. The second edition of this long-time bestseller provides a framework for designing and understanding sprays for a wide array of engineering applications. In this second edition, McDonell provides a thorough update that retained the overarching theme of the content while retaining a practical focus and the readability of the original work by Lefebvre.

## Publications

### Journals

**A SPATIALLY AND TEMPORALLY RESOLVED MODEL OF THE ELECTRICITY GRID: ECONOMIC vs. ENVIRONMENTAL DISPATCH (2016).** *Applied Energy*, Vol. 178, pp. 540-556 (Ghazal Razeghi, Jack Brouwer, and Scott Samuelsen).

**ASSESSING THE NEED FOR HIGH IMPACT TECHNOLOGY RESEARCH, DEVELOPMENT AND DEPLOYMENT FOR MITIGATING CLIMATE CHANGE (2016).** *Collabra*, 2(1): 19, pp. 1–24, (D. Auston, S. Samuelsen, J. Brouwer, S. DenBaars, W. Glassley, B. Jenkins, P. Petersen, and V. Srinivasan).

**PREDICTING FLAMEHOLDING FOR HYDROGEN AND NATURAL GAS FLAMES AT GAS TURBINE PREMIXER CONDITIONS (2016).** *ASME Journal of Engineering for Gas Turbines and Power*, Vol. 138(12), pp. 121502-1 - 121502-9 (E. Sullivan-Lewis and V.G. McDonell).

**APPLICATION OF A TURBULENT JET FLAME FLASHBACK PROPENSITY MODEL TO A COMMERCIAL GAS TURBINE COMBUSTOR (2016).** *ASME Journal of Engineering for Gas Turbines and Power*, Vol. 139(4), pp. 041506-04156-8 (Alireza Kalantari, Elliot Sullivan-Lewis, and Vincent McDonell).

**AIR QUALITY IMPACTS OF FUEL CELL ELECTRIC HYDROGEN VEHICLES WITH HIGH LEVELS OF RENEWABLE POWER GENERATION (2016).** *International Journal of Hydrogen Energy*, Vol. 41, 38, pp. 16592-16603 (Michael A. Mac Kinnon, Brendan P. Shaffer, Marc Carreras-Sospedra, Donald Dabdub, G. Scott Samuelsen, and Jacob Brouwer).

**ANALYTICAL INVESTIGATION OF HIGH TEMPERATURE 1 KW SOLID OXIDE FUEL CELL SYSTEM FEASIBILITY IN METHANE HYDRATE RECOVERY AND DEEP OCEAN POWER GENERATION (2016).** *Applied Energy*, Vol. 179, pp. 909-928 (M. Ali Azizi, Jacob Brouwer, and Derek Dunn-Rankin).

**MASS-ACTION KINETICS APPROACH TO CONCURRENT H<sub>2</sub> AND CO ELECTROCHEMISTRY IN A PATTERNED SOFC ANODE (2016).** *Journal of the Electrochemical Society*, Vol. 163, pp. F1399-F1411 (Nicolas Valle-Marchante, and Jack Brouwer).

**AIR QUALITY IMPACTS OF FUEL CELL ELECTRIC HYDROGEN VEHICLES WITH HIGH LEVELS OF RENEWABLE POWER GENERATION (2016).** *International Journal of Hydrogen Energy*, Vol. 41, 38, pp. 16592-16603 (Michael Mac Kinnon, Brendan Shaffer, Marc Carreras-Sospedra, Donald Dabdub, and Jacob Brouwer).

### Hydrogen Fueling Station Workshops Delivered

- The Fuel Cell Technology Institute (FCTI), the educational outreach arm of the National Fuel Cell Research Center, held workshops in Sacramento and Irvine on October 17 and 20, 2016 for stakeholders involved in mobile fuel cells. The workshops entitled “*Insights Gained from Building and Operating the California Hydrogen Station Network: Perspectives from First Element Fuel*”, focused on lessons learned in design, permitting, construction, commissioning, and operations.

### Power to Gas Grand Opening Event

- On October 7, 2016 APEP held a Grand Opening event showcasing the first successful Power to Gas (P2G) proof of concept in the U.S. The event was attended by over 50 people including project partners Proton OnSite, Southern California Gas Company, and UCI Facilities Management. P2G is the featured article in this Bridging annual report.

**DYNAMIC PERFORMANCE OF AN IN-RACK PROTON EXCHANGE MEMBRANE FUEL CELL BATTERY SYSTEM TO POWER SERVERS (2017).** *International Journal of Hydrogen Energy*, Vol. 42, 15, pp. 10158-10174 (Li Zhao, Jacob Brouwer, Sean James, John Siegler, and Jie Liu).

**DYNAMIC MODEL OF A MICRO-TUBULAR SOLID OXIDE FUEL CELL STACK INCLUDING AN INTEGRATED COOLING SYSTEM (2017).** *Journal of Power Sources*, Vol. 342, pp. 504-514 (Martin Hering, Jacob Brouwer, Wolfgang Winkler).

**ELECTRICITY COSTS FOR A LEVEL 3 ELECTRIC VEHICLE FUELING STATION INTEGRATED WITH A BUILDING (2017).** *Applied Energy*, Vol. 191, pp. 367-384 (Robert J. Flores, Brendan P. Shaffer, and Jacob Brouwer).

**DIRECT EMISSIONS OF NITROUS OXIDE FROM COMBUSTION OF GASEOUS FUELS (2017).** *International Journal of Hydrogen Energy*, Vol 42, pp. 711-719. (A. Colorado, V. McDonell, and S. Samuelsen).

**BOUNDARY LAYER FLASHBACK OF NON-SWIRLING PREMIXED FLAMES: MECHANISMS, FUNDAMENTAL RESEARCH, AND RECENT ADVANCES (2017).** *Progress in Energy and Combustion Science*, Vol 61, pp. 249-292 (A. Kalantari and V.G. McDonell).

**COMMENTARY: CALIFORNIA DROUGHT INCREASES CO<sub>2</sub> FOOTPRINT OF ENERGY (2017).** *Sustainable Cities and Society*, Vol. 28, pp. 450-452, (E. Hardin, A. AghaKouchak, M.J.A. Qomi, K. Madani, B. Tarroja, Y. Zhou, T. Yang, S. Samuelsen).

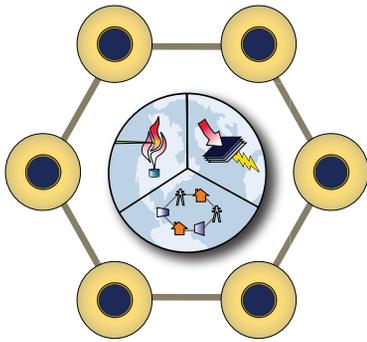
**IMPACT OF ELECTRICITY DEREGULATION IN THE STATE OF CALIFORNIA (2017).** *Energy Policy*, Volume 103, pp. 105–115 (Ghazal Razeghi, Brendan Shaffer, Scott Samuelsen).

### Book

**ATOMIZATION AND SPRAYS, 2nd Edition (2017).** CRC Press, Boca Raton, FL, April (A.H. Lefebvre and V.G. McDonell).

### Book Chapter

**LEAN COMBUSTION IN GAS TURBINES, 2nd Edition (2016).** In *Lean Combustion—Technology and Control*, edited by D. Dunn-Rankin, Academic Press, San Diego. (V.G. McDonell).



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The Advanced Power and Energy Program (AEP) 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 the Engineering Service Road.

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