Annual Report | Volume 3 | 2015

ADVANCED POWER & ENERGY PROGRAM

BRIDGING

Engineering Science to Practical Application

UCI Hydrogen Fuel Cell Bus Unveiled

WWW.APEP.UCI.EDU
UC IRVINE

DIRECTOR'S MESSAGE

Professor Scott Samuelsen

Director, Advanced Power and Energy Program

For the third edition of our annual "BRIDGING" report, we are pleased to highlight a year in which the practical application and deployment of APEP research has reached new heights. As the umbrella organization for the National Fuel Cell Research Center (NFCRC) and the University of California Irvine Combustion Lab (UCICL), not only has APEP been instrumental in bringing the Fuel Cell Future to the Fuel Cell Present, APEP has strengthened its leadership in the areas of Microgrids and Smart Grids, initiated a major initiative in Power to Gas (P2G) Energy Storage, and furthered its valued contributions in establishing the impact of alternative fuel properties on combustion performance. A cornerstone of APEP is "bridging" engineering science and practical application in close collaboration with industry, national and international agencies, and laboratories. Five significant examples are:

As the subject of our feature story on mobile fuel cells, we are grateful for the commitment and dedication provided by an alliance of **Ballard Systems, BAE Systems, El Dorado National, CALSTART, the Southern California Gas Company, and the California Energy Commission** to deliver the first Hydrogen Fuel Cell Bus to the popular UC Irvine Anteater Express bus fleet. This fuel cell bus will send a message to the new generation of students and the community as a whole that the Fuel Cell Future is here.

In stationary fuel cell deployment, the California Stationary Fuel Cell Collaborative, a strategic initiative developed by the NFCRC in 2001 in collaboration with the **California Air Resources Board** and industry, has facilitated the evolution of the market. This year, the deployment of stationary fuel cell product exceeds 100 megawatts over a wide spectrum of market applications including hotels, hospitals, grocery stores, and universities. A notable example is the deployment of a 1.4 MW integrated high-temperature fuel cell with 200 ton absorption chiller at the UCI Medical Center's Douglas Hospital, a collaborative effort with **FuelCell Energy, the Southern California Gas Company, Empowered Energy, and the California Energy Commission.**

In the rapidly evolving area of Microgrids and Smart Grids, APEP has been awarded a U.S. Department of Energy grant to develop and demonstrate a Generic Microgrid Controller (GMC). Partnering with APEP on this project is **Southern California Edison, ETAP, MelRok, CalSO, and UCI Facilities Management.** Using the Southern California Edison (SCE) OPAL-RT dynamic simulation platform, the team is designing and systematically and thoroughly testing the GMC using an ETAP model of the UCI Microgrid. In parallel, the UCI Microgrid is being upgraded with a 2 MW SCE battery and over 120 MelRok high-resolution meters to inform the GMC design and enable a demonstration of the GMC on the UCI Microgrid.

APEP in partnership with the **Southern California Gas Company,** and the **National Renewable Energy Laboratory** has launched the first U.S. research and development project to create and evaluate a carbon-free "Power to Gas" (P2G) system utilizing electricity from renewable sources, to produce carbon-free hydrogen gas.

The UCICL has collaborated with the **Ener-Core Corporation** to demonstrate at the APEP Beta Test Facility the ability to generate electricity with low-BTU fuels, and is now deploying the technology to a landfill operated by the **County of Orange**.

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 "bridging" from needed research in engineering science to the ultimate goal of deployment in practical application.

Scott Samuelsen

OUR APEP MEMBERS

TOYOTA

Southern California Gas Company
A Sempra Energy utility

HORIBA
Explore the future

U.S. DEPARTMENT OF ENERGY

FuelCell Energy

Capstone

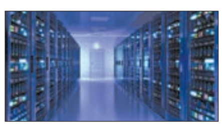
California Environmental Protection Agency
Air Resources Board

State of California Energy Commission

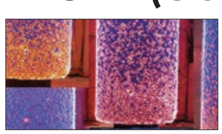
CONTENTS

ADVANCED POWER AND ENERGY PROGRAM (APEP)

NATIONAL FUEL CELL RESEARCH CENTER (NFCRC)



UCI COMBUSTION LABORATORY (UCICL)



Also in this issue:

First Hydrogen Fuel Cell Bus on a UC Campus

The recent addition of a Hydrogen Fuel Cell Electric Bus (FCEB) to the UC Irvine Anteater Express fleet is the first of its kind on a University of California campus. It will join a group of 29 biodiesel buses that reached a ridership of over two million passenger miles in fiscal year 2014, and is expected to log nearly four thousand miles per month on its assigned route. FCEB demonstrations have occurred over the past 10 years in more than 65 cities across the globe, this specific demonstration will allow students to experience today, the future of mass transportation.

Fuel Cell Buses as a Solution

Hydrogen Fuel Cell Electric Buses have proven to be a zero emission technology. When compared to diesel and natural gas buses, FCEB' s represent an opportunity to help achieve greenhouse gas (GHG) reductions with similar durability, availability, and road call frequency, while exceeding the average range and fuel economy. The similarities in the refueling procedure and fueling-time when compared to natural gas buses also contributes to making this technology a good fit for the transition to zero emission vehicles. Additional significant benefits of FCEB's include:

- Zero tailpipe pollutant emissions, with water and nitrogen (from the air) the only tailpipe emissions. It is notable that a similar amount of water is emitted from the tailpipes of gasoline and diesel engine vehicles.
- Low vibration reduces acoustic emissions providing a quiet and smooth riding experience.
- Hydrogen can be renewable-produced from several domestic sources such as biogas and renewable electricity.

A well-to-wheels analysis performed for a large transit agency in Southern California showed that when hydrogen is produced from steam methane reformation using natural gas and renewable electrolysis, a 78% reduction in greenhouse gases can be achieved when compared to compressed natural gas (CNG) buses, as illustrated in Figure 1 for three FCEB scenarios (SC).

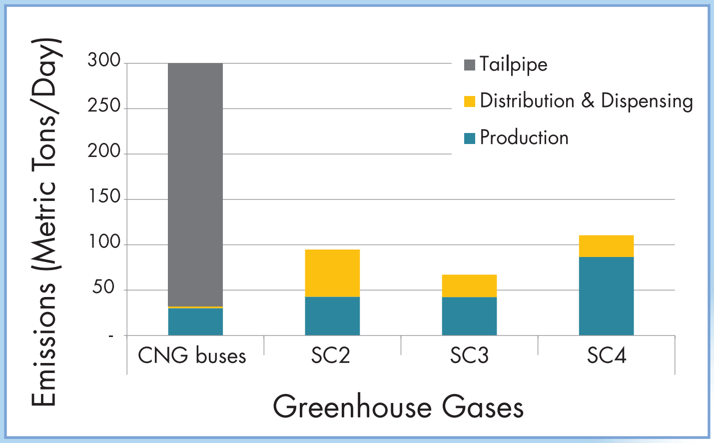


Figure 1. Well-to-wheel GHG Emissions for Different FCEB Scenarios

SC2: FCEB scenario with 100% of H2 produced from centralized steam methane reformation (SMR) using natural gas (NG) and biogas to produce 33% renewable hydrogen; delivered as liquid hydrogen.

SC3: FCEB scenario with 52% of H2 produced with SMR using NG and 38% produced from renewable electrolysis.

SC4: FCEB scenario with 52% of H2 produced with SMR using biogas and 38% from electrolysis powered by the grid.

Demonstration at UCI

The National Fuel Cell Research Center (NFCRC) in partnership with Anteater Express, Ballard Power Systems, El Dorado, and BAE Systems, was awarded a contract by the California Energy Commission under its Alternative and Renewable Fuel and Vehicle Technology Program to build and demonstrate the addition of a FCEB to the UC Irvine fleet. CALSTART, a member-supported organization dedicated to advancing clean transportation alternatives, was the project manager.

The 40 foot FCEB which complies with the Buy American Act requiring more than 60% domestically sourced content, was assembled at the El Dorado National bus manufacturing facility in Riverside, California, with the aesthetics of the bus custom designed by UCI's Anteater Express group. BAE Systems served as the system integrator and hybrid powertrain developer. Ballard provided the FCvelocity-HD6 150 kW power plant. The FCEB has 200 kW of electrical energy storage and 50 kg of hydrogen storage at 350bar, providing the bus with a range of 260 miles under a typical urban transit cycle, while transporting up to 37 seated and 19 standing passengers. Based on the route of the FCEB it will displace criteria pollutant and greenhouse gas emissions as depicted in Figure 2 below.

The NFCRC will collect and use data on the FCEB's operation in modeling tools developed for planning and assessing operational and environmental impacts of zero emission technology deployed in transit fleets. Additionally, the NFCRC will collect data from the refueling of the FCEB at the UCI hydrogen refueling station to determine the impact on this station that also serves light duty passenger vehicles.

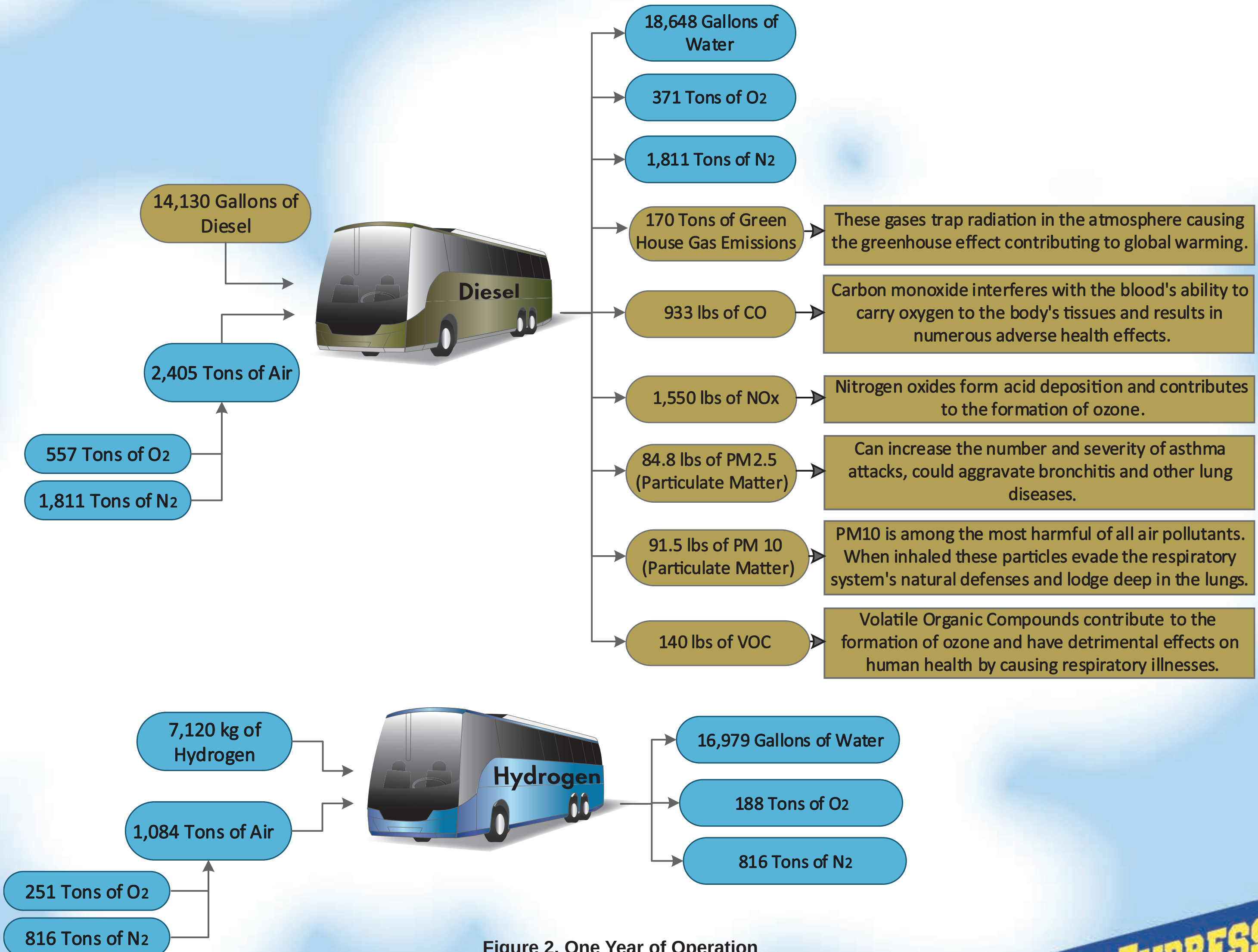
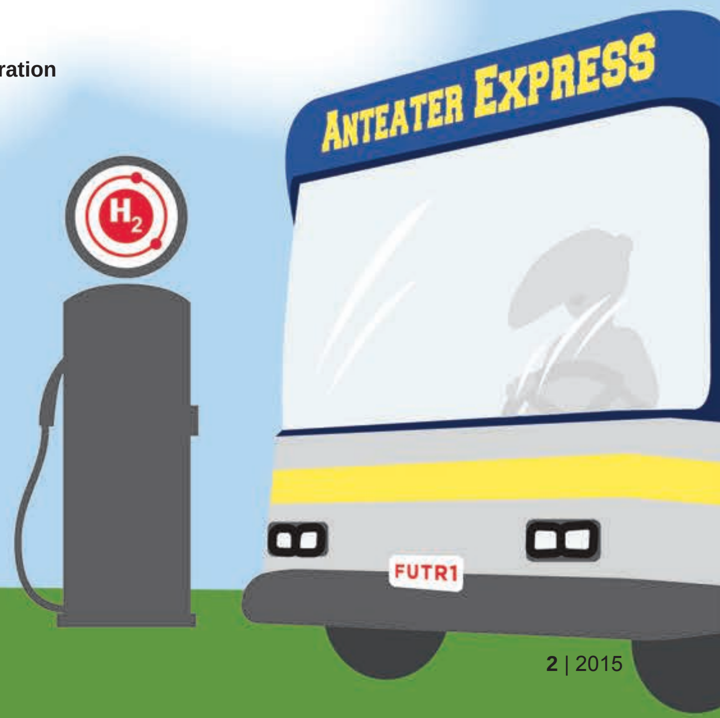


Figure 2. One Year of Operation

Hydrogen Fuel Cell Electric Buses have proven to be a zero emission technology



Enhancing the Value of Microgrids

Microgrids have the potential to increase grid reliability by being able to disconnect from and reconnect to the grid, and operate in islanded mode independent from the grid. They can also contribute to enhanced resiliency and safety of communities served by, and in the vicinity, of the Microgrid.

To achieve this potential, judiciously designed energy storage, high-resolution metering, and high-performance control must be integrated into Microgrids. These capabilities are required to manage and dispatch resources and provide ancillary services in an economic manner, seamlessly disconnect/reconnect from the grid in response to a grid outage or a fault on the grid, and operate the Microgrid in islanded mode serving critical loads without interruption.

The Advanced Power and Energy Program (APEP) has been awarded a $1.2 million U.S. Department of Energy grant to develop and test a Generic Microgrid Controller (GMC). Partnering with APEP in this project are Southern California Edison, ETAP, MelRok, CalSO, and UCI Facilities Management.

The GMC will provide:

- Seamless islanding and reconnection of the Microgrid.
- Efficient, reliable, and resilient operation of the Microgrid, with the required power quality, whether islanded or grid-connected.
- The ability to provide existing and future ancillary services to the larger grid.
- Capability for the Microgrid to serve the resiliency needs of participating communities.
- Communication with the electric grid utility as a single controllable entity.
- Increased reliability, efficiency and reduced emissions.

The Advanced Power and Energy Program (APEP) has been awarded a $1.2 million U.S. Department of Energy grant to develop and test a Generic Microgrid Controller (GMC)

The project will be conducted in two phases: (1) Research, Development, and Design, and (2) Testing, Evaluation, and Verification. During Phase 1 of the project, the GMC will be developed and is envisioned as a set of generic modules. During Phase 2, the GMC will be applied to the UCI Microgrid first on the OPAL-RT platform in collaboration with Southern California Edison, and then on the physical UCI Microgrid. The GMC generic modules and various modes of operation are shown in Figure 1.

A select set of Microgrids, operating a variety of Microgrid configurations, will serve as "collaborating microgrid partners" in the project and thereby assure that the GMC developed under this program can readily be applied to Microgrids of different sizes, and equipped with various resources, attributes, and equipment. Microgrid partners collaborating with APEP include the UCI Medical Center (UCIMC), the Port of Los Angeles, and the Irvine Ranch Water District.

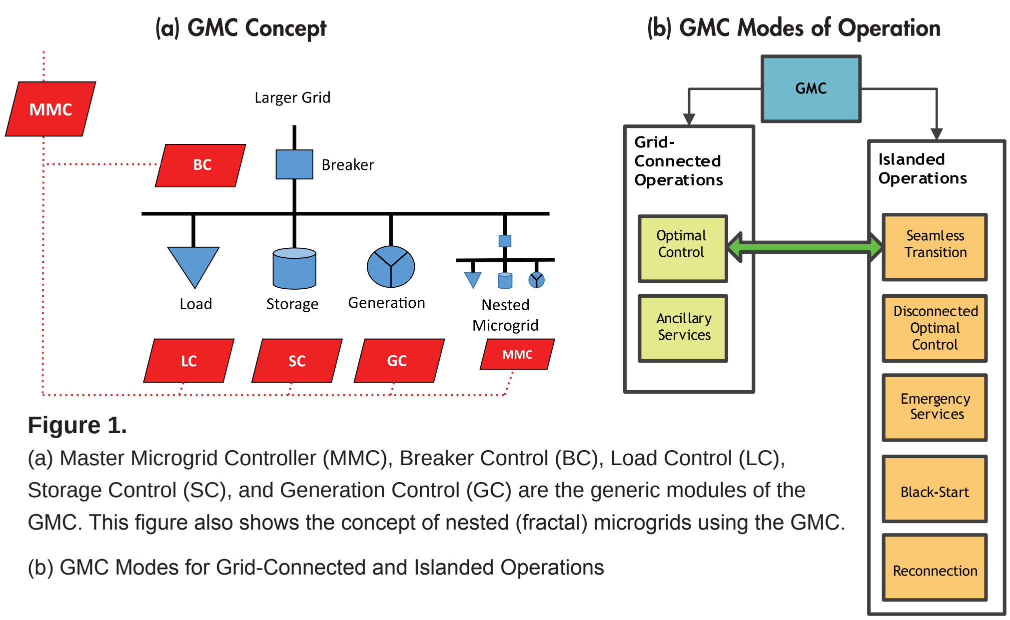


Figure 1.

(a) Master Microgrid Controller (MMC), Breaker Control (BC), Load Control (LC), Storage Control (SC), and Generation Control (GC) are the generic modules of the GMC. This figure also shows the concept of nested (fractal) microgrids using the GMC.

(b) GMC Modes for Grid-Connected and Islanded Operations

Pioneering "Power-to-Gas" (P2G) Research

Massive daily, weekly, and even seasonal amounts of energy storage will be required to utilize the high levels of renewable power use now being mandated. California for example, will require 50% renewable power utilization by 2030. The National Fuel Cell Research Center (NFCRC) with support from the Southern California Gas Company has launched the first U.S. research and development project to create and evaluate a carbon-free "Power-to-Gas" (P2G) system.

Using electrolyzer-based methods, the P2G concept uses the highly dynamic and intermittent electricity from renewable sources such as solar and wind, to make carbon-free hydrogen gas by breaking down water into hydrogen and oxygen. The hydrogen can be directly and safely introduced into existing natural gas pipelines at low levels, or it can be converted to methane — synthetic, renewable natural gas. The 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 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.

The renewable gaseous fuels that are produced and delivered by P2G can be used to dynamically dispatch gas-fired power plants with net zero carbon emissions, and can also be used to fuel zero emission transportation applications such as fuel cell electric vehicles. FCEV's offer long-range, rapid fueling, and large vehicle capabilities that are unmatched by any other zero emission transportation option.

In this pioneering project the NFCRC will conduct research with SoCalGas and the National Renewable Energy Laboratory to:

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

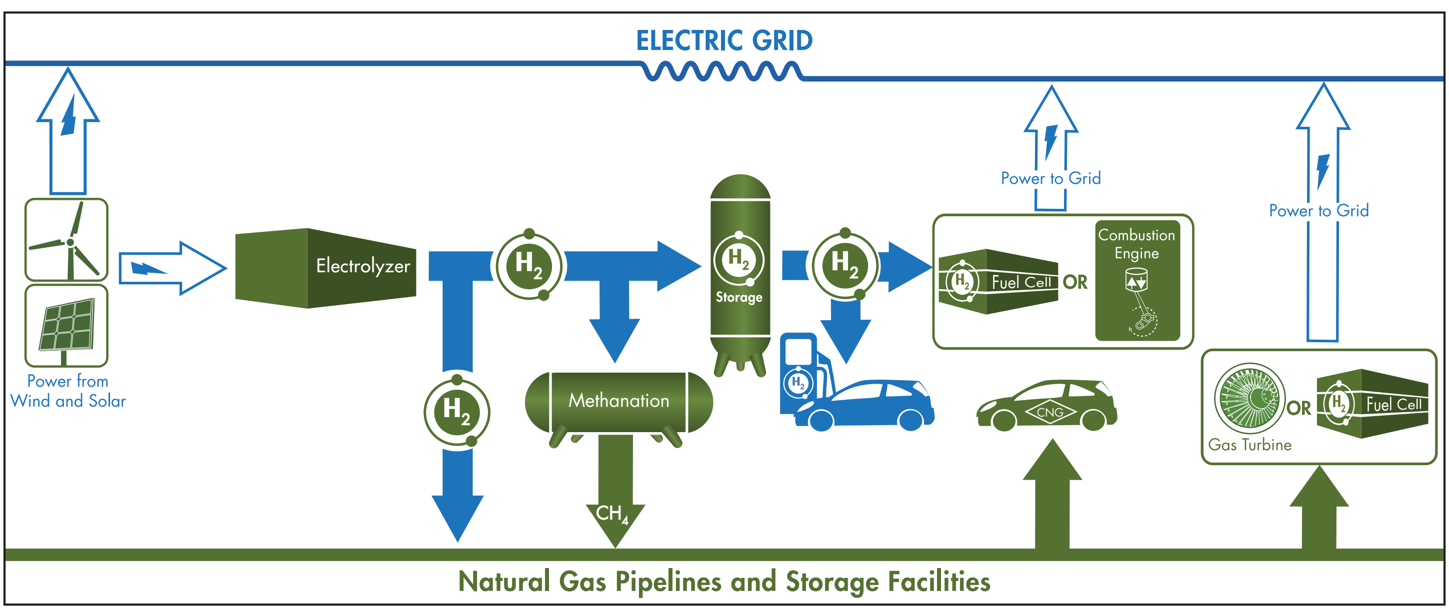


Figure 1. Power-to-Gas Concept

The Energy Water

The development of sustainable energy and water supplies are strongly co-dependent. Water resources however are dependent on inherently variable weather and climate patterns. Although the water supply infrastructure has been developed to adapt to this variability as much as possible, areas which experience extreme drought such as California in recent years, or other permanently arid regions of the world, still may not be able to meet water demands. With looming potential impacts of climate change, water resources in these areas will be subject to increased stress. Therefore, to develop sustainable water supplies in these regions, reliance on alternative supply methods such as reclamation, desalination, storm capture, and reduction of demand through efficiency and conservation will be required.

The Advanced Power and Energy Program (APEP) is engaged in a number of research activities to investigate key questions regarding the nexus of water resources and energy sustainability. The California Energy Commission recently awarded a research grant to APEP in collaboration with Water UCI for their proposal entitled *"Building a Climate-Change Resilient Electricity System for Meeting California's Energy and Environmental Goals".* The focus is on determining the climate change related hydrological and atmospheric impacts on the resiliency and sustainability of the electrical system.

Additional research involves investigating the impact of shifting precipitation patterns and drought on hydropower generation and grid reliability. Implementing alternative water supply measures has a diverse range of impacts on the energy infrastructure including but not limited to, direct energy usage, the introduction of large electric loads of varying profiles, and changes in the amount of energy utilized for conveyance, treatment, distribution, and wastewater post-treatment. These impacts have implications for greenhouse gas emissions from the combined energy-water system, therefore the energy infrastructure to support these methods needs to be understood. Due to the intensity of energy usage and spatial location within the topology of the infrastructure, each measure impacts the water supply infrastructure differently, however, on a large scale there can be synergies between developing sustainable water and energy supplies:

- Urban conservation reduces greenhouse gases and the stress on water resources.
- Water reclamation produces emissions, but for some regions the offset in conveyance related emissions allows its implementation to cause a net reduction in greenhouse gas emissions.
- Desalination causes a net emissions increase, but benefits from conveyance offset.

Nexus

In California with a 50.3% share of renewable resources on the electric grid, Figure 1 presents the change in greenhouse gas intensity per unit of water produced when implementing different alternative water supply methods on different aspects of the water supply infrastructure [1].

Overall, implementing a measure may reduce emissions from one component, but increase it for another, highlighting the importance of capturing these impacts for an accurate greenhouse gas assessment for any given region.

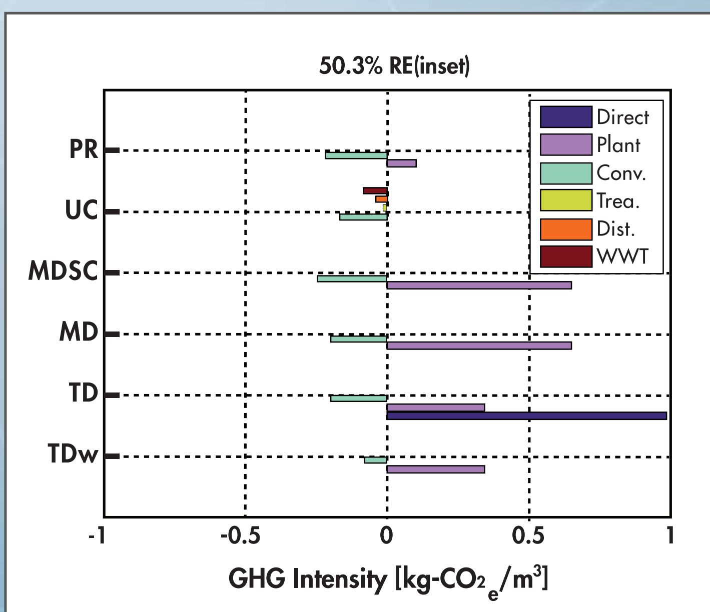


Figure 1. Greenhouse Gas Intensity Change for Water Supply Infrastructure Components of Different Alternative Water Supply Methods at 50.3% Renewable Electricity.

- PR = Water Purification and Reuse
- UC = Urban Water Conservation
- MD = Membrane Desalination distributed by urban population
- MDSC = Membrane Desalination emphasized in higher population areas
- TD = Thermal Desalination using natural gas
- TDw = Thermal Desalination using waste heat

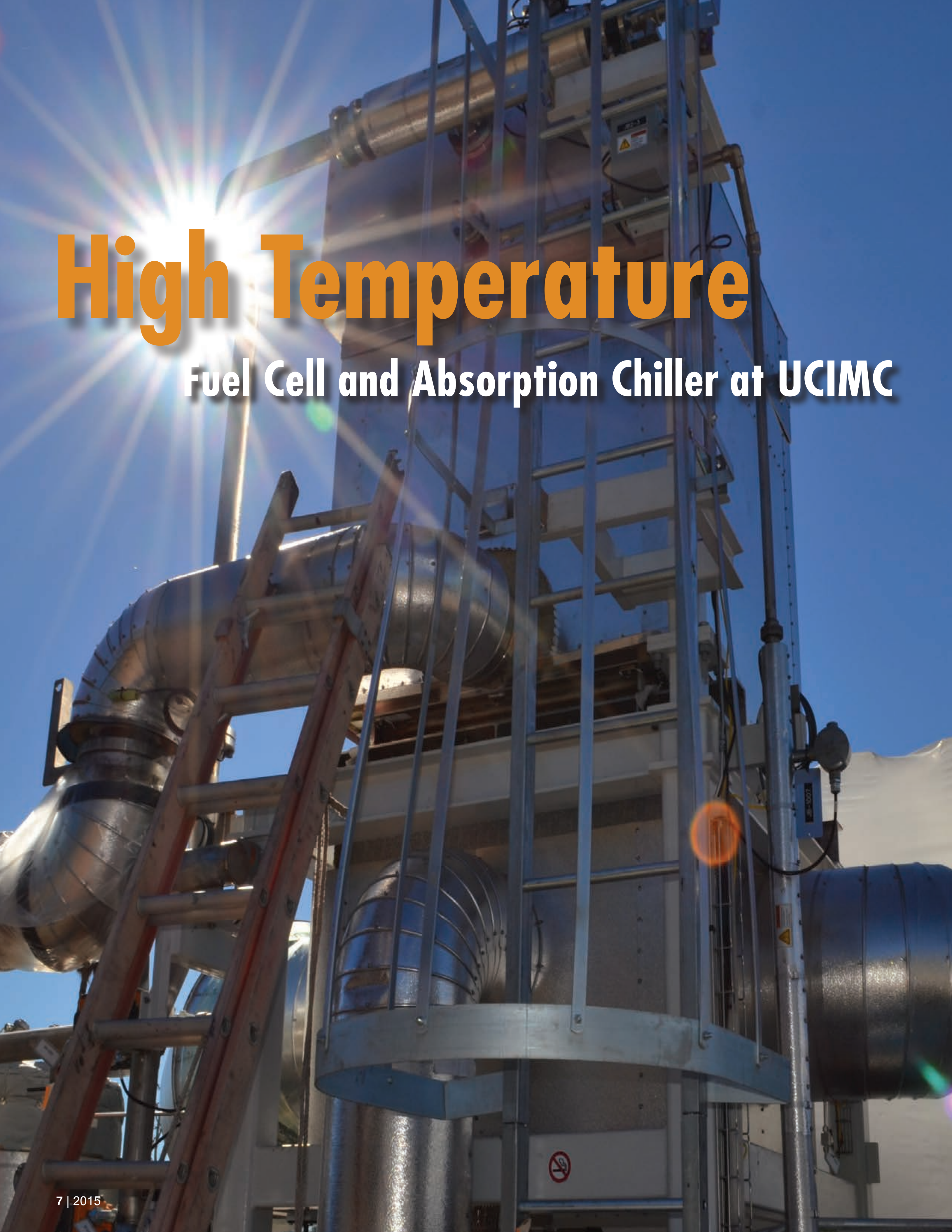
The different colors represent the change in greenhouse gas emissions intensity for different components of the water supply infrastructure.

- “Direct” - Greenhouse gas emissions sourced directly from the facility implementing this measure
- “Plant” - Emissions due to the electric load produced by the facility
- “Conv.” - Emissions due to energy use for water conveyance
- “Trea.” - Emissions due to energy use in water treatment
- “Dist.” - Emissions due to energy use in water distribution
- “WWT” - Emissions due to energy use in wastewater treatment plants

1. Tarroja, B., AghaKouchak, A., Sobhani, R., Feldman, D., Jiang, S., Samuelsen, S., *Evaluating options for balancing the water–electricity nexus in California: Part 2—Greenhouse gas and renewable energy utilization impacts.* Science of The Total Environment, 2014. 497–498(0): p. 711-724.

High Temperature

Fuel Cell and Absorption Chiller at UCIMC



High-Temperature Fuel Cell and Absorption Chiller System Installed at the UC Irvine Medical Center's Douglas Hospital

A significant challenge facing the electricity sector today is de-carbonization while also ensuring reduced criteria air pollutant (CAP) emissions. Fuel cells offer a near zero CAP emission power plant that can be sited near and within load centers with much greater ease than fossil fuel power plants. This site flexibility also indicates a huge potential for waste heat recovery to supply not only heating loads, but also cooling loads using an absorption chiller to further offset both CAP and greenhouse gas emissions.

With funding from the California Energy Commission, the National Fuel Cell Research Center (NFCRC), in conjunction with the University of California, Irvine Medical Center (UCIMC) is deploying an integrated high-temperature fuel cell and absorption chiller (HTFC/AC) system at the UCIMC's Douglas Hospital. The HTFC/AC system will provide the hospital with 1.4 MW of electricity and over 200 refrigeration tons of cooling (800 kW) while serving as a technology transfer showcase for the Distributed Generation market.

The fuel cell chosen for this application is FuelCell Energy's DFC1500. This molten carbonate fuel cell is designed to operate as a base load electricity provider and has the benefit of producing high quality waste heat. An absorption chiller is used in this application to capture the waste heat and convert its energy into cooling for the Douglas Hospital hydronic air conditioning system.

Figure 1. Workers Put Final Touches on the HTFC/AC at UCIMC

The project is scheduled for completion in the summer of 2015. As a showcase of HTFC/AC technology, it will incorporate an onsite technology transfer room dedicated to informing the public, students, industry leaders, and government officials of the benefits of clean HTFC/AC technology

Phase 2

Fuel Cell Powered Data Centers

Power Generation Inches from the Servers...*Continues*

2014: In-Rack PEM Fuel Cell Generation Demonstration (Phase 1)

In 2014, the National Fuel Cell Research Center (NFCRC) successfully collaborated with Microsoft to demonstrate a direct power generation method that places fuel cells in the server rack. In this project, the NFCRC successfully powered a rack of servers with direct current (DC) output from a fuel cell. The demonstration validated the design and the use of a 10kW Proton Exchange Membrane Fuel Cell (PEMFC) stack and system that eliminated the use of the power distribution system in the data center and use of the grid outside the data center.

Figure 1. NFCRC Laboratory Data Center Fuel Cell Testing Equipment

2015: Solid Oxide Fuel Cells for Data Centers and Residential Applications (Phase 2)

In 2015, the collaboration has been continued and expanded with Microsoft and NRG Energy to evaluate the implementation of a Solid Oxide Fuel Cell (SOFC) not only for data center server racks, but also for residential applications. SOFC's provide advantages over PEM fuel cells that include:

- Fuel flexibility.
- Use of a non-precious metal catalyst.
- Completely solid-state cell components.
- The production of high quality waste heat for co-generation applications.

These advantages will enable the direct utilization of natural gas as a fuel, and the synergistic integration of power and cooling to benefit the data center.

Standardized testing procedures are being applied for assessing the Solid Oxide Fuel Cell systems and their suitability to meet either Microsoft data center requirements or residential application requirements. Two 2.5 kW SOFC systems from SolidPower are being tested and evaluated, with Unit 1 being primarily subjected to Microsoft data center operation conditions, and Unit 2 being primarily subjected to residential application conditions.

The NFCRC will also conduct additional tests that will be used to help determine the suitability and degradation of the system in the intended environment, as well as establish engineering parameters, and provide engineering information to the system designer.

Beyond Today

The NFCRC, Microsoft and NRG Energy collaboration will continue as the partnership moves to actual deployment of the Solid Oxide Fuel Cell (SOFC) into data centers and residential applications.

MAZDA ENGINES

for Low Cost Micro DG/CHP Use in Laundry Facilities

With 3,000 MW of energy removed from the Southern California grid due to the closure of the San Onofre Nuclear Generation Station (SONGS) new, low cost, reliable distributed generation with combined heat recovery (DG/CHP) is needed.

The California Energy Commission Public Interest Energy Research (PIER) program awarded the Advanced Power and Energy Program (APEP) and its partner, Mazda North American Operations funding to install and test a low-cost, small-scale micro-DG/CHP. The system that is being tested for laundry facility applications has electric output less than 35 kW and utilizes a Mazda rotary engine.

This new DG/CHP design is targeted to meet CARB 2013 certification by reducing criteria pollutants and greehouse gas emissions. Based on the use of this system's compact rotary engine and unique application of waste heat recovery to address both hot water needs for washing, and hot air needs for drying, it is expected that the system will be a valuable and welcome addition at the estimated 3,700 or more laundry facilities in the SONGS service territory targeted by the CEC program. In addition, the system should find application at the more than 8,000 laundry facilities throughout California.

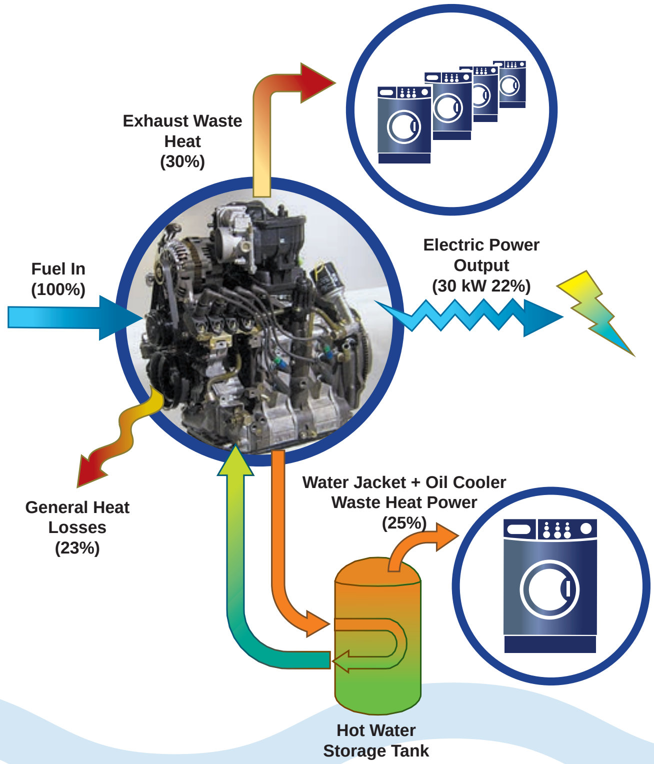


Figure 1. The Micro DG/CHP System

The final configuration utilizes a MoTeC engine management system controlling a multipoint, low pressure fuel injection scheme. While originally utilizing a stock Mazda 3-way catalytic converter, emissions performance was enhanced through the use of a natural gas specific catalytic converter. The engine has completed multi-week testing and tuning on a dynamometer at rotary engine specialists Racing Beat in Anaheim, California. Benchmark performance numbers for the engine at the conclusion of the testing are:

- 22% net fuel to shaft power thermal efficiency.
- Criteria emissions of NOx <2 ppmvd (@15% O_2) and CO<12 ppmvd (@15% O_2).
- Heat energy balances measured suggest overall system thermal efficiency (electric power + waste heat / fuel power input) of >75% based upon HHV.

This program also provides a demonstration of the applicability of the Mazda rotary engine for micro-DG/CHP applications beyond laundry facilities. Wide spread application of the micro-DG/CHP system has the potential to reduce congestion on electric grid transmission and distribution lines within the SONGS service territory and beyond.

Alternative Fuel Research

The Colors of Combustion. A wide range of visible spectrum colors observed during fuel flexibility experiments at the UCI Combustion Laboratory. The photo shows the structure of premixed flames with multiple fuel compositions and lean regime air to fuel ratios. Fuel compositions included blends of hydrogen, natural gas, and biogas. The ceramic Duratherm™ burner by ALZETA Corporation uses a porous material to stabilize the reactions.

During the past year, using numerous experimental diagnostics and numerical methods, the UCI Combustion Lab has continued exploring how adaptation of various alternative fuels impact combustion system operability and emissions. In a project sponsored by the California Energy Commission to study the behavior of gaseous fuels, efforts have continued in exploring how different types of fuels and fuel composition impact the behavior of various burner configurations.

Alternative Fuel Research at the UCI Combustion Lab

Recent work has focused on the behavior of a surface stabilized burner provided by Alzeta Corporation. The burner which is shown in Figure 1 is installed in the 117 kW boiler at the UCI Combustion Lab simulator facility. Using a combination of experimental exhaust stack measurements from Horiba PG-250 and Horiba MEXA 1400QL-NX instruments, the pollutant emissions behavior of this burner are being studied when operated on biogas (CO_2 /methane), hydrogen enriched natural gas, and natural gas with higher hydrocarbons. These measurements are used in combination with simulations as shown in Figure 2 to predict how emissions change with fuel type and concentration.

A summary of the simulation results, as validated by measurements, is shown in Table 1 for fuels that would be acceptable for use in the California Natural Gas Pipeline based on requirements for Wobbe Index, yellow-tipping behavior, and liftoff. As shown in Table 1, when compared to pure natural gas, some fuels provide benefits for both NOx and CO (e.g., hydrogen enriched natural gas), whereas others (e.g., higher hydrocarbons within natural gas) lead to increases in emissions. Using analysis of the simulations, burner configuration behavior when using different fuels can be determined (e.g., flame thickness, flowfield gradients, contributions of different formation mechanisms, etc.) This ongoing work is being applied to eight other burner configurations that represent a significant portion of natural gas used in California. These results can be looked to for insight into how adopting future fuels may impact pollutant emissions and operability of different burners.

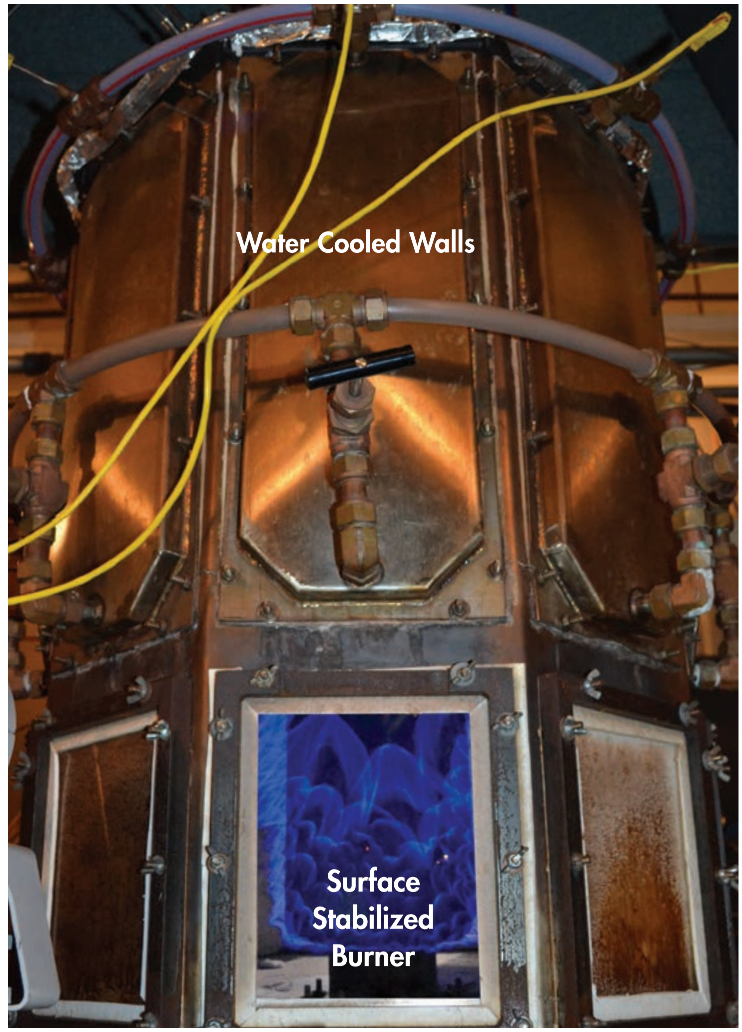


Figure 1.
Stack-Dry Emissions to Gas Analyzer (CO_2, CO, NO_x, O_2)

Fuel Mixture	Equivalence Ratio at 3% O_2	NO_x [ppmdv]	CO [ppmdv]
76% CH_4 - 24% H_2	0.87	↓ 250%	↓ 40%
94% CH_4 - 6% C_2H_6	0.87	↑ 3%	↑ 6%
95% CH_4 - 5% C_3H8	0.87	↑ 4%	↑ 3%
98% CH_4 - 2% CO_2	0.87	↓ 3%	↑ 3%

Table 1.
Summary of Emissions for Interchangeable Fuel Mixtures Based on AGA Standards for Wobbe Index, Lifting, and Yellow Tipping.

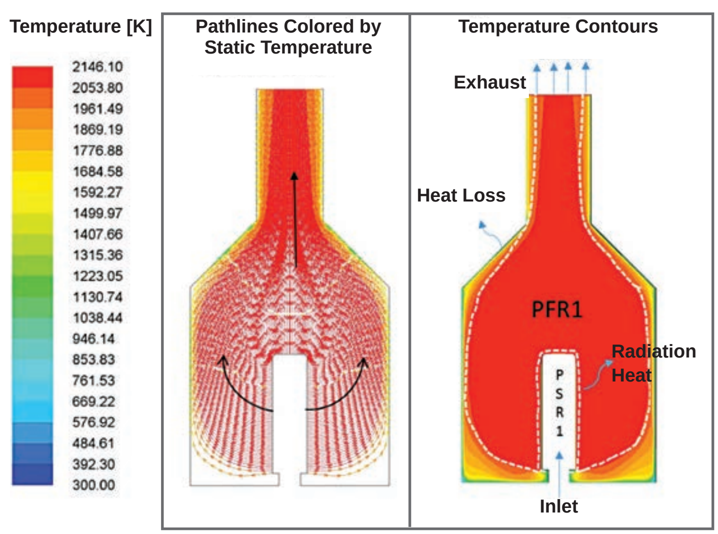


Figure 2.
Associated CFD Simulation

APEP Collaborates with TDA Research Inc.

Existing coal fired power plants are expected to continue providing a significant portion of global power generation for the foreseeable future. A majority of these plants are subcritical pulverized coal (PC) units which, on a MWe basis, have high CO_2 emissions due to their high heat rates. With CO_2 emissions an increasing concern and global pressure to limit greenhouse gas accumulation in the atmosphere, novel solid sorbent based CO_2 capture technologies are under development to capture the CO_2 via physical adsorption and desorption. Sorbent technologies consume far less energy for the sorbent regeneration process than current state-of-the-art CO_2 capture technology from flue gas.

The Advanced Power and Energy Program (APEP) is working with TDA Research Inc. to integrate TDA adsorption technology in both post- and pre-combustion applications. The novel TDA sorbent under development removes CO_2 via physical adsorption from flue gas ("post-combustion capture") and can be retrofitted into existing PC power plants. The technology can also be incorporated into the design of integrated gasification combined cycle (IGCC) plants to capture the CO_2 from synthesis gas (or syngas) derived by the gasification of coal, before the syngas is combusted in a gas turbine ("pre-combustion capture").

APEP's collaboration with TDA Research extends in two other areas:

- The design of a reactor that combines both the water gas shift reaction and the CO_2 sorption for IGCC applications, a combination that has the potential to further enhance plant performance and economics.
- The development of an advanced air separation process for use in IGCC as well as in oxy-combustion in place of the conventional cryogenic air separation which requires a large amount of energy and capital investment.

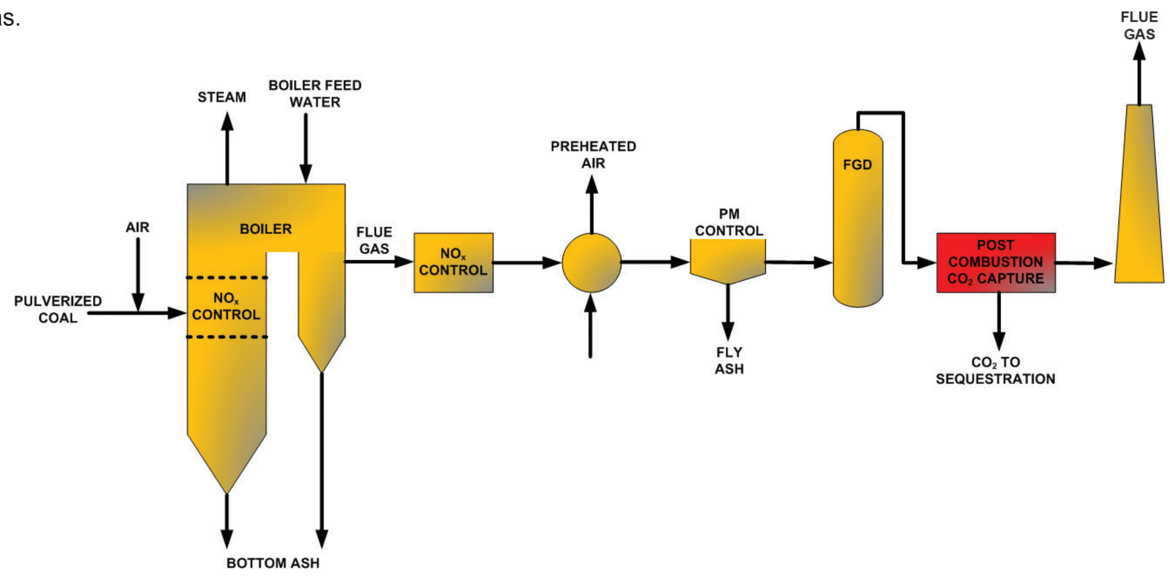
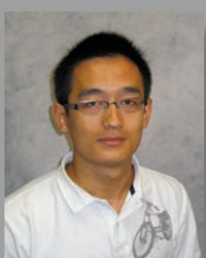


Figure 1. Schematic of PC Boiler Power Plant

Graduates 2014 - 2015

Doctor of Philosophy (Ph.D.)
in Mechanical and Aerospace Engineering



Qin Chen

"Advanced Clean Coal Technologies for Central Power Generation"

Robert Flores

"Integrating Combined Cooling Heat and Power Systems in Commercial and Industrial Buildings with Electric Vehicle Charging"

Michael Mac Kinnon

"Assessment of Emerging Regional Air Quality (AQ) and Greenhouse Gas (GHG) Impacts and Potential Mitigation Strategies in U.S. Energy Sectors"

Elliot Sullivan-Lewis

"Criteria Development for Gas Turbine Premixer Flameholding Tendencies of Natural Gas and High Hydrogen Content Fuels"

Master of Science (M.S.)
in Mechanical and Aerospace Engineering

Analy Castillo-Munoz

"Deployment of Fuel Cell Electric Buses in Transit Agencies: Hydrogen Demand Allocation and Preferable Hydrogen Infrastructure Rollout Scenario"

Ashley DiMola

"Enabling the Distributed Generation Market of High Temperature Fuel Cell and Absorption Chiller Systems to Support Critical and Commercial Loads"

Adam Silver

"Investigation of Atomization and Combustion Performance of Renewable Biofuels and the Effects of Ethanol Blending in Biodiesel"

PUBLICATIONS

Photo by Amy Johansson / Shutterstock

Journals

A HYBRID PHYSICS-BASED AND DATA DRIVEN APPROACH TO OPTIMAL CONTROL OF BUILDING COOLING/HEATING SYSTEMS (2014). IEEE Transactions on Automation Science and Engineering, Volume PP, Issue 99 pp. 1-11 (Seyed Vaghefi, Mohsen Jafari, J. Zhu, Jack Brouwer, and Yau Lu).

A POLY-GENERATING CLOSED CATHODE FUEL CELL WITH CARBON CAPTURE (2014). Applied Energy, Volume 131, pp.108-113 (Dustin McLarty and Jack Brouwer).

AIR QUALITY IMPACTS OF LIQUEFIED NATURAL GAS IN THE SOUTH COAST AIR BASIN OF CALIFORNIA (2014). Journal of Natural Gas Science and Engineering, Volume 21, pp. 680-690 (Marc Carreras-Sospedra, Brett Singer, Melissa Lunden, Jack Brouwer, and Donald Dabdub).

ECONOMIC AND SENSITIVITY ANALYSES OF DYNAMIC DISTRIBUTED GENERATION DISPATCH TO REDUCE BUILDING ENERGY COST (2014). Energy and Buildings, Volume 85, pp. 293–304 (Robert Flores, Brendan Shaffer, and Jack Brouwer).

ENHANCED PERFORMANCE OF COUNTER FLOW SOFC WITH PARTIAL INTERNAL REFORMATION (2014). International Journal of Hydrogen Energy, Volume 39, pp.19753-19766 (Mahshid Fardadi, Dustin McLarty, Jack Brouwer, and Faryar Jabbari).

EVALUATING OPTIONS FOR BALANCING THE WATER-ELECTRICITY NEXUS IN CALIFORNIA: PART 1 – SECURING WATER AVAILABILITY (2014). Science of the Total Environment, Volumes 497–498, pp. 697–710 (Brian Tarroja, Amir AghaKouchak, Reza Sobhani, David Feldman, Sunny Jiang, and Scott Samuelsen).

EVALUATING OPTIONS FOR BALANCING THE WATER-ELECTRICITY NEXUS IN CALIFORNIA: PART 2 – GREENHOUSE GAS AND RENEWABLE ENERGY UTILIZATION IMPACTS (2014). Science of the Total Environment, Volumes 497–498, pp. 711–724 (Brian Tarroja, Amir Agha Kouchak, Reza Sobhani, David Feldman, Sunny Jiang, and Scott Samuelsen).

EVALUATION OF THE CONSTANT VOLUME SAMPLER ON PLUG-IN HYBRID ELECTRIC VEHICLE COLD START EMISSION TESTING (2014). International Journal of Engine Research, Volume 15, No. 6, pp. 706-718, (Li Zhang, Tim Brown, and Scott Samuelsen).

MODEL PREDICTIVE CONTROL OF CENTRAL CHILLER PLANT WITH THERMAL ENERGY STORAGE VIA DYNAMIC PROGRAMMING AND MIXED INTEGER LINEAR PROGRAMMING (2014). IEEE Transactions on Automation Science and Engineering, Volume 12 Issue 2 pp. 565-579 (Kun Deng, Yu Sun, Sisi Li, Amit Chakraborty, Yan Lu, Jack Brouwer, Prashant Mehta, and Mengchu Zhou).

MODELING AND FORECASTING OF COOLING AND ELECTRICITY LOAD DEMAND (2014). Applied Energy, Volume 136, pp.186–196 (Seyed Vaghefi, Mohsen Jafari, Emmanuel Bisse, Yan Lu, and Jack Brouwer).

COMPARATIVE ANALYSIS OF SOFC–GT FREIGHT LOCOMOTIVE FUELED BY NATURAL GAS AND DIESEL WITH ONBOARD REFORMATION (2015). Applied Energy, Volume 148, pp. 412-438 (Andrew Martinez, Jack Brouwer, and Scott Samuelsen).

COPRODUCTION OF TRANSPORTATION FUELS IN ADVANCED IGCCS VIA COAL AND BIOMASS MIXTURES (2015). Applied Energy, (Qin Chen, Ashok Rao, and Scott Samuelsen).

DISPATCH OF FUEL CELLS AS TRANSMISSION INTEGRATED GRID ENERGY RESOURCES TO SUPPORT RENEWABLES AND REDUCE EMISSIONS (2015). Applied Energy, Volume 148, pp.178-186 (Brendan Shaffer, Brian Tarroja, and Scott Samuelsen).

FLAMEHOLDING TENDENCIES OF NATURAL GAS AND HYDROGEN FLAMES AT GAS TURBINE PREMIXER CONDITIONS (2015). ASME Journal of Engineering for Gas Turbines and Power, Volume 137(1): 011504-011504-9 (Elliot Sullivan-Lewis and Vince McDonell).

MICRO-GRID ENERGY DISPATCH OPTIMIZATION AND PREDICTIVE CONTROL ALGORITHMS; A UC IRVINE CASE STUDY (2015). International Journal of Electrical Power and Energy Systems, Volume 65, pp.179-190 (Dustin McLarty and Jack Brouwer).

STUDY OF CO2 RECOVERY IN A CARBONATE FUEL CELL TRI-GENERATION PLANT (2015). Journal of Power Sources, Volume 284, pp.16-26 (Giorgio Rinaldi, Dustin McLarty, Jack Brouwer, Andrea Lanzini, and Santarelli Massimo).

Books

SUSTAINABLE ENERGY CONVERSION FOR ELECTRICITY AND COPRODUCTS: PRINCIPLES, TECHNOLOGIES, AND EQUIPMENT (2015). John Wiley and Sons (Ashok Rao).

Winter/Spring 2014/2015

UCI Hydrogen Fueling Station Upgrade

UC Irvine's Hydrogen Fueling Station is slated for a major upgrade. Plans call for installation of the latest technology dispensing equipment, reconfiguration of the fuel storage and delivery systems, preparation of the station for future expansion to accommodate more cars fueling simultaneously, as well as the fueling of hydrogen buses.

Irvine Smart Grid Demonstration (ISGD) Project Nears Completion

Led by Southern California Edison and funded by the U.S. Department of Energy, APEP is conducting critical research, smart grid design simulation and modeling, management of the deployment of the project's electric vehicles, and providing overall coordination of the various UCI groups that are involved in the project. The primary goal of the project is to demonstrate how regional energy providers, local utility companies, and consumers can successfully work together to deploy various smart grid technologies in an integrated framework that is expected to be more reliable, secure, economic, efficient, safe, and environmentally friendly than the grids in use today.

STREET Receives Continued Support from CEC

The California Energy Commission (CEC) has approved a second amendment to the "Spatially and Temporally Resolved Energy and Environment Tool" (STREET) enhancement project. The amendment will continue APEP's support of the Alternative and Renewable Fuel and Vehicle Technology Program (ARFVTP) planning activities at the CEC.

EV Chargers Deployed for Research on Pricing and Distributed Energy Resources

Three dual-port chargers have been installed at the Multi-Purpose Science and Technology Building (MSTB) at UC Irvine. In addition to providing Electric Vehicle charging, they will be used to help investigate how pricing for EV charging can best utilize energy from Distributed Energy Resources (DER's), such as the photovoltaic array and batteries that are located at the building.

The NFCRC Participates in the Toyota Mirai Media Event

In November 2014, Toyota held a major media event for a group of 60 international journalists to announce the fall 2015 California availability of its highly anticipated Mirai fuel cell electric vehicle (FCEV). NFCRC Director, Scott Samuelsen, moderated a panel discussion by representatives from the DOE's Office of Energy Efficiency and Renewables, the California Air Resources Board, and Air Liquide Advanced Technologies U.S., LLC.

UCICL Gas Turbine Research Well Represented at U.S. Department of Energy's Annual University Turbine Systems Research Workshop

Elliot Sullivan-Lewis and Professor Vincent McDonell attended the annual U.S. Department of Energy University Turbine Systems Research program review held at Purdue University. Elliot presented work on his project Flameholding Tendencies of Natural Gas and Hydrogen Fuel at Gas Turbine Premixer Conditions. Professor McDonell presented a second UC Irvine project, Development of Flashback Criteria for Jet Flames. In addition Professor McDonell participated in an opening panel session on observations regarding modeling and measurements of ignition delay times for high hydrogen content fuels.

APEP and Ener-Core Team Up to Reduce Industrial Waste Emissions

APEP and Ener-Core Inc., an Irvine California based company, are working on gas pollution solutions and greenhouse gas emissions reduction by converting unusable industrial waste gases into clean power.

Fall 2014

UCICL Attends the 35th International Symposium on Combustion

Posters were presented by Ph.D. students Elliot Sullivan-Lewis, Andres Colorado, Howard Lee, and M.S. students Adam Silver and Nathan Kirksey on their research in the behavior of alternative fuels in combustion systems.

UCICL Graduate Student Presents Paper at 59th ASME International Gas Institute Expo

The UC Irvine Combustion Laboratory's Professor Vince McDonell and graduate student Elliot Sullivan-Lewis attended the 59th ASME International Gas Turbine Institute (IGTI) Expo. Elliot presented a paper on his research entitled Flameholding Tendencies of Natural Gas and Hydrogen Flames at Gas Turbine Premixer Conditions. Professor McDonell presented a paper on behalf of Ph.D. student Andres Colorado entitled Reactor Network Analysis to Assess Fuel Composition Effects on NOx Emissions from a Recuperated Gas Turbine.

Smart Burner System Under Development for Improved Performance and Fuel Flexibility

Together with Lawrence Berkeley National Laboratory, the UCICL will be working to develop and install a "smart" burner that can tune itself to maximize performance and minimize emissions. While development work is to be done in laboratories at the UCICL, the system will eventually be installed and operated at the Chiquita Water Reclamation Facility in the Santa Margarita Water District.

Summer 2014

Fulbright Scholarship Received by UCI Mechanical Engineering Postdoc

Ph.D. postdoctoral researcher, Dustin McLarty from the NFCRC has been awarded a Fulbright scholarship to continue his research at the University of Genoa, Italy. Dustin's research at the NFCRC is focused on the UC Irvine Microgrid and leveling out the intermittencies involved with a grid that relies on renewable sources of energy.

www.apep.uci.edu

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

Photos 1, 2 and 3 by Paul Kennedy

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**.

Major goals include Education, Research and Development, Beta Testing, Demonstration, and Deployment of new technology into the marketplace.

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.

For additional information, please contact:

Will Decker
Director of Outreach
Advanced Power and Energy Program
Tel: +1 (949) 824-7302 x11130 Fax: +1 (949) 824-7423
Email: wd@apep.uci.edu