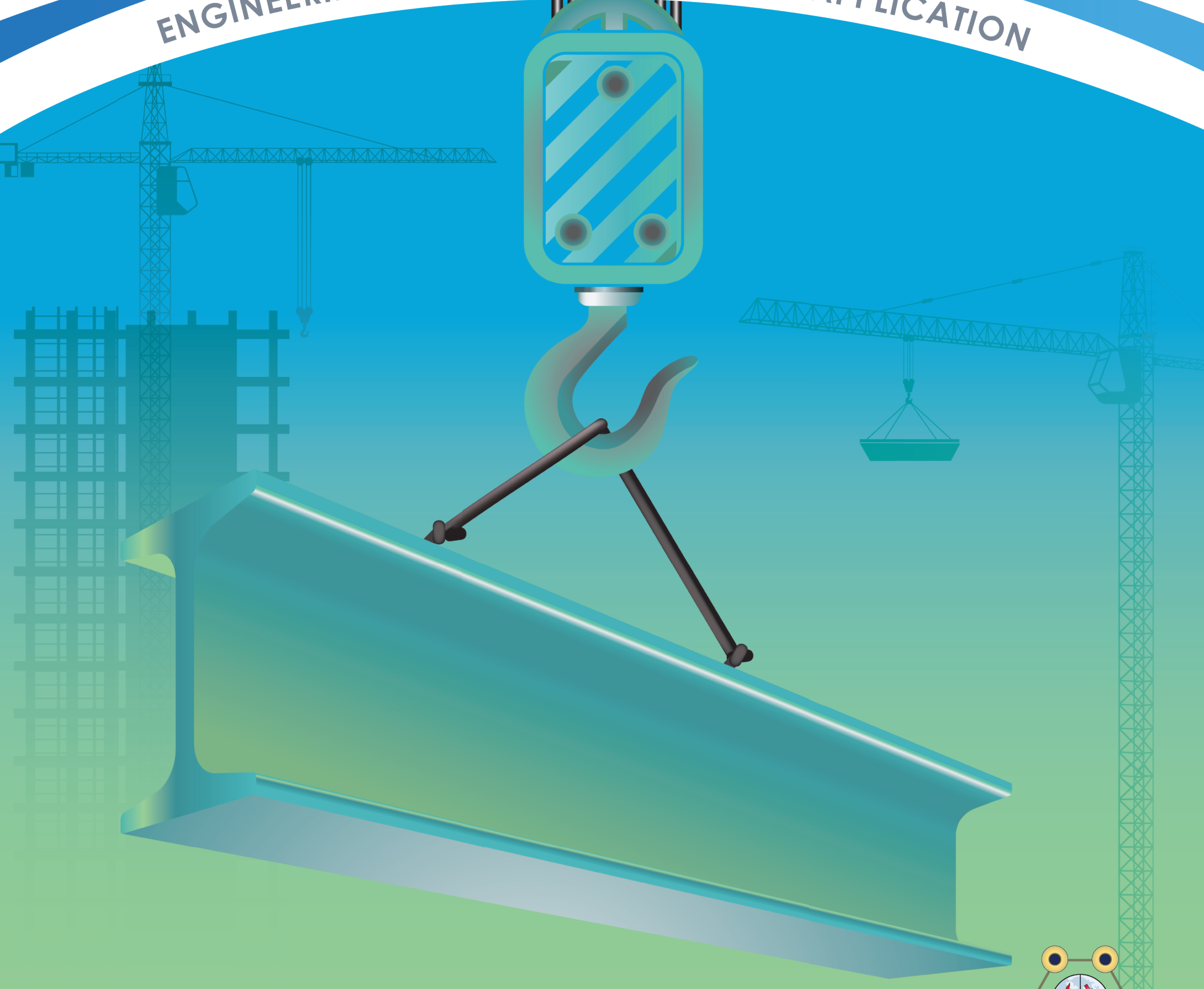
Annual Report | Volume 10 | 2022

ADVANCED POWER AND ENERGY PROGRAM

BRIDGING

ENGINEERING SCIENCE TO PRACTICAL APPLICATION



Hydrogen for Green Steel

DIRECTOR'S MESSAGE

PROFESSOR JACK BROUWER, PH.D.

DIRECTOR, ADVANCED POWER AND ENERGY PROGRAM (APEP)

While the 2021-22 academic year included the continued challenges of special precautions and procedures that were required to manage the COVID-19 pandemic, we are pleased to report that the Advanced Power and Energy Program has only continued to grow, expand, and succeed in accomplishing important and impactful research.

We are especially grateful to the UC Irvine (UCI) Administration, the Vice Chancellor for Research, Pramod Khargonekar, and Deans Magnus Egerstedt and James Bullock, in particular, for supporting the elevation and advancement of the Advanced Power and Energy Program (APEP) in becoming a University-level Institute, called the Clean Energy Institute! We are currently developing the strategic plan for the Clean Energy Institute and expect its formal launch and establishment in the 2022-23 academic year.

The Clean Energy Institute will be the umbrella organization within which all UCI clean energy research centers and organizations collaborate and work together. Of course, this includes the historical centers of APEP, i.e., the National Fuel Cell Research Center (NFCRC), UCI Combustion Laboratory (UCICL), and Horiba Institute for Mobility and Connectivity^2 (HIMaC^2), and future energy-related centers both within the Samueli School of Engineering, School of Physical Sciences, and other schools into the future.

We expect the Clean Energy Institute to build upon the outstanding reputation for broad and deep industry-academia and collaborative and interdisciplinary research that APEP is well-known for, including the bridging of fundamental science to practical application and even demonstration within the world-class UCI Microgrid.

The first draft motto for the Clean Energy Institute is "Clean energy for everything through electrochemistry and hydrogen!" We welcome and desire to work with all of you to firmly establish the Institute as an effective and impactful organization that serves UCI, Orange County, California, the U.S., and the world!

In addition, while the Horiba Institute for Mobility and Connectivity^2 (HIMaC^2) has been formally established at UCI with its founding director, Professor Vojislav Stamenkovic, and while we have had a virtual grand opening for HIMaC^2 last July, we look forward to the full in-person grand opening of HIMaC^2 on October 14, 2022.

This year, Chancellor's Professor Plamen Atanassov and I worked diligently to develop a framework for a California regional hydrogen hub entitled the Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES). With the incredible leadership and support of Angelina Galiteva, founder of the Renewables 100 Policy Institute and Chair of the California Independent System Operator (CalISO), we have been able to unify the entire University of California (the largest and most successful university in the world) to work together toward establishing ARCHES to lead the world into a completely zero-emissions future through use of electrochemistry and hydrogen.

We are incredibly grateful for the important and impactful work that APEPers are accomplishing around the world in academia, national labs, industry, entrepreneurism, advocacy, and consulting. The very most important thing that we do is mentor and educate all of you who actually change the world and make it a better and more sustainable world for us and our posterity for many generations to come.

In this 10th annual edition of "**Bridging**," we feature (1) a federal award for decarbonization of steel production, and (2) UCICL research pushing water heaters to 80-100% hydrogen . Notable accomplishments during the past year include:

- Telluride Innovative Workshop on Cement Decarbonization
- California-regional hydrogen hubs to support the U.S. Department of Energy's "Hydrogen Energy Earthshot"
- Research by APEP that is exploring the optimal role of decarbonized gaseous fuels in the future zero-carbon economy

We are very proud of our graduate student accomplishments during the 2021-2022 academic year, which includes 9 MS graduates, 5 Ph.D. graduates, and 7 internships with diverse entities such as:
Tesla, HydroPlane, Henkel, NREL, Northrup Grumman, Bosch, and Schweitzer Engineering Laboratories.

Finally, we encourage you to donate to the ***Samuelsen Energy Visionary Fellowship*** (envelope enclosed, or online at: www.apep.uci.edu/Support_APEP.html), of which funds will perpetually support a graduate student conducting visionary sustainable energy research in the mold of Professor Scott Samuelsen.

Jack Brouwer

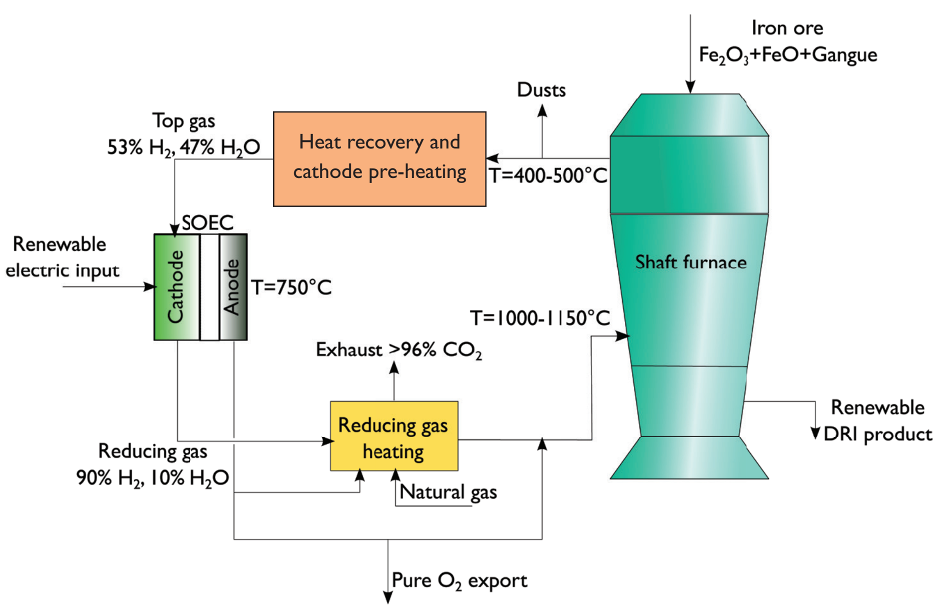
CONTENT

Solid Oxide Electrolysis Cells (SOEC) Integrated with Direct Reduced Iron (DRI) Plants for Producing Green Steel

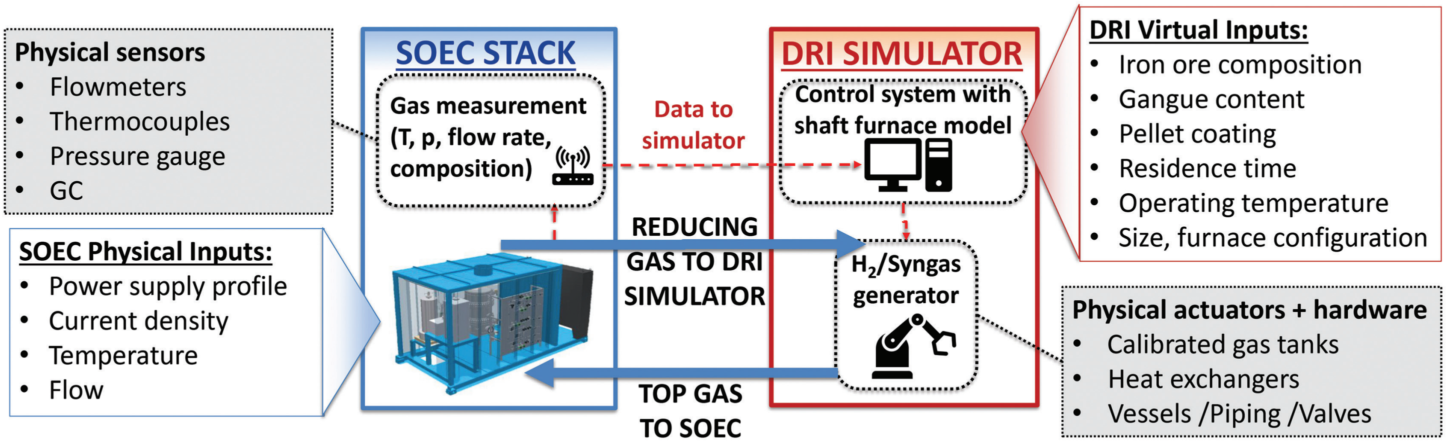
Steel production continues to be the most impactful industrial sector in our economy in terms of carbon emissions. The main difference compared to just a couple of years ago is that now, a plethora of new renewable hydrogen projects have been announced across the world by both private and public consortia. The industry interest towards novel decarbonization technologies and feasibility studies has skyrocketed and the low-carbon steel community is rapidly growing.

UC Irvine's Advanced Power and Energy Program is leading a Department of Energy (DOE) HySteel project to use an integrated high temperature Solid Oxide Electrolysis Cells (SOEC) system to produce renewable hydrogen that can be used to convert raw iron ore (Fe_2O_3) into iron (Fe) through a process called hydrogen direct reduced iron (HDR). This reaction only produces water as a by-product, allowing for the complete elimination of CO_2 emissions from the ironmaking process. The team expects that the SOEC thermal and electrochemical integration with the DRI system will reduce the primary energy consumption and CO_2 emissions by more than 30% and 40%, respectively.

The project is now at its first year mark and it has theoretically shown the possibility of producing hot iron at 0.8% carbon content and >97.5% metallization with a primary energy consumption of 8.0-8.8 GJ/t_{DRI} and with CO_2 emissions ranging from 15 to 97 kg_{CO2}/t_{DRI}. This contrasts with a typical natural gas-based DRI system and a blast furnace-basic oxygen furnace route performing 10.1 GJ/t_{DRI} and 19-20 $GJ/t_{crude\ steel}$, and 442 kg_{CO2}/t_{DRI} and 1.8-1.9 $t_{CO2}/t_{crude\ steel}$, respectively.



The team has also modelled the unique capability of SOEC to operate with mixtures of steam and CO_2 to produce a renewable carbon-based syngas, which can be used as a reducing gas in the shaft furnace instead of natural gas. This configuration allows for a shorter-term transition from a state-of-the-art natural gas-based



technology to a low-carbon renewable process. The SOEC can operate in so-called co-electrolysis mode, simultaneously converting H_2O and CO_2 into H_2, CO, and CH_4.

The project is now at the design phase for the laboratory-scale demonstration unit, which will integrate an SOEC module with a simulated HDR furnace using a "Hardware-In-the-Loop" concept. The 10 Nm^3/day hydrogen production capacity SOEC unit will be manufactured and installed at the FuelCell Energy site in Danbury, Connecticut, which will experimentally prove: i) hydrogen production efficiencies of pressurized and thermally integrated SOECs <35 kWh_{el}/kg; ii) system integration of SOEC and HDR units to measure primary energy consumptions <8 GJ/ton_{DRI} and CO_2 emissions <50 kg_{CO2}/t_{DRI}.

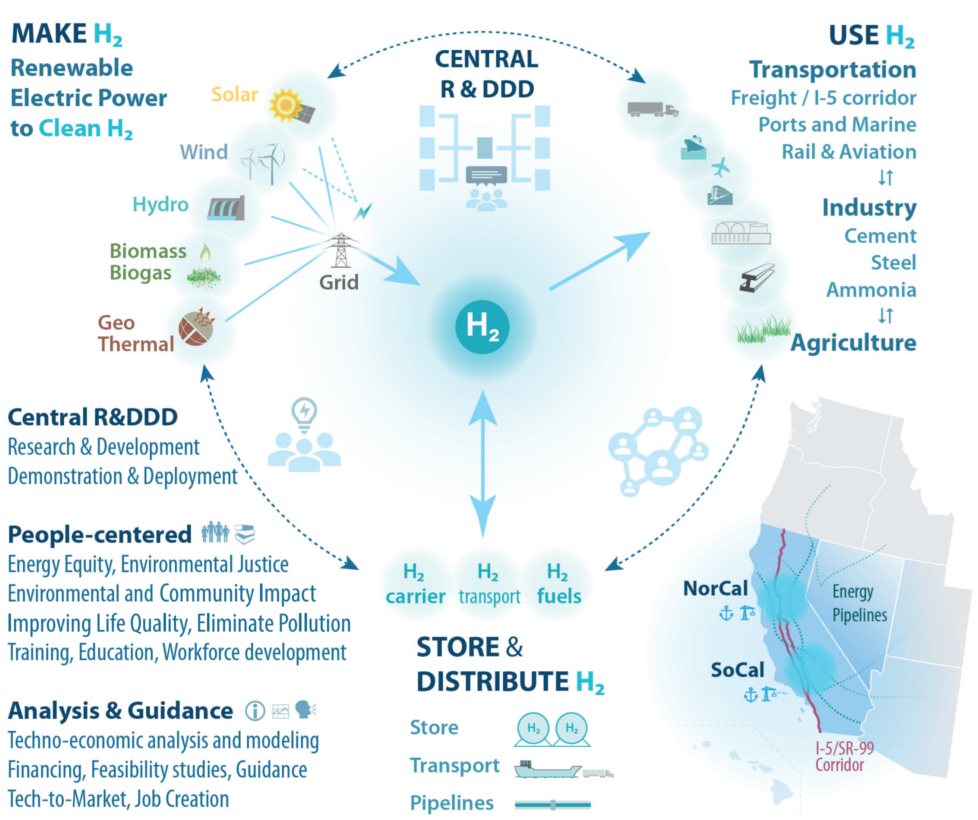
> *"This reaction only produces water as a by-product, allowing for the complete elimination of CO_2 emissions...*

The UCI APEP HySteel team – comprised of the largest U.S. manufacturer of Solid Oxide Electrolysis systems; FuelCell Energy; the engineering consulting firm, Hatch; the two international academic and tech-transfer institutions, Politecnico di Milano and LEAP; and Southern California Gas Company (SoCalGas) – continue working together with DOE support to ensure the industrial relevance of the demonstration proposed in the project. The team is in continuous communication with its Advisory Board members, now counting some of the major U.S.-based and international steel manufacturers, namely Arcelor Mittal, Nucor Corporation, Tenova, and Midrex, as well as the major European gas transmission operator Snam. Additional Advisors are welcome to join the project to broaden the relevance of the project's outcomes throughout the steel industry. Similarly, the team is looking for possible industrial partners interested in deploying a containerized SOEC module at a DRI plant during phase two of the project.

California-Regional Hydrogen Hub

> *"...eventually bring the cost of hydrogen production to less than \$1/kg...*

With the support of UC Irvine Vice Chancellor for Research (VCR), Pramod Khargonekar, and all of his VCR colleagues throughout the University of California system, Professors Plamen Atanassov and Jack Brouwer have been leading a team to develop a public-private partnership (PPP) that can develop and deploy a California-regional hydrogen hub. The team includes subject matter experts from all 10 UC campuses, and affiliated Lawrence Berkeley and Lawrence Livermore National Laboratories, working together with organized labor (National Electrical Contractors Association (NECA), International Brotherhood of Electrical Workers (IBEW), AFL-CIO, and others), AES, and the California Governor's Office of Business and Economic Development (GoBiz) to advance the platform for this PPP, entitled the "Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES)." ARCHES intends to rally businesses, ports, cities, and concerned communities to work together to garner \$2 billion in federal funding from the U.S. Department of Energy's "Hydrogen Energy Earthshot," which has established the new Office of Clean Energy Demonstrations to support regional hydrogen hubs. This funding will be matched by at least \$2 billion from the private sector and perhaps another \$2 billion from existing hydrogen-supporting programs and new state and local agency funding to produce the world-leading prototypical and extensible model for scaling up and innovating renewable and clean hydrogen technologies, including fuel cells and solar and wind electrolysis, to eventually bring the cost of hydrogen production to less than \$1/kg.



Credit: Visualization by Ahmet Kusoglu (Berkeley) for ARCHES

Pushing Water Heaters to 80-100% Hydrogen

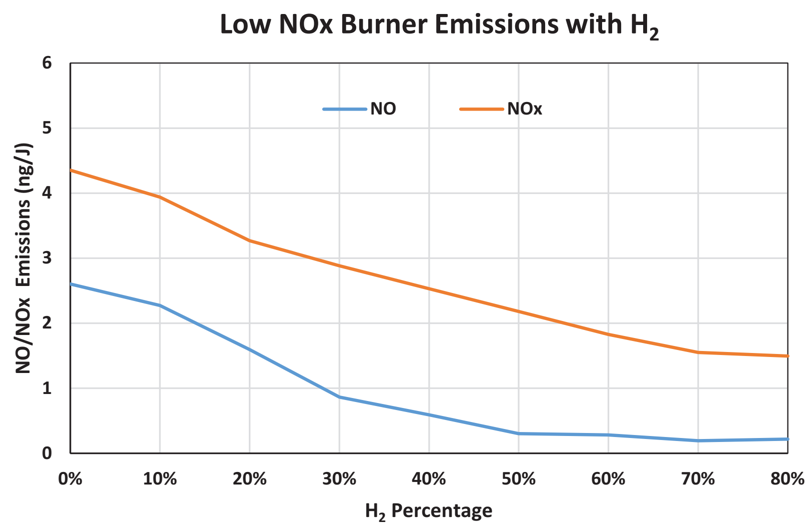
With the state of California seeking to reduce its greenhouse gas (GHG) emissions and achieve carbon-free electricity by 2045, one area to target has been the household consumption of natural gas. UCICL research in partnership with the Southern California Gas Company (SCG) has explored the possibility of mixing hydrogen into the natural gas supply to reduce the carbon emissions involved with residential usage, particularly in water heaters. Using the existing gas pipeline infrastructure to deliver clean hydrogen, or a mix of hydrogen and natural gas, could be an effective way to transition California homes toward carbon-neutral energy usage. Around 23% of California's natural gas usage is utilized in the residential sector, over half of which is used for water heating[1,2], so this is an ideal target area for reduction that could greatly impact the state's overall GHG emissions.

Flashback in conventional burner

> *"...NO and NOx emissions of each heater decreased as the share of hydrogen was increased...*

While the potential benefits are clear, there are challenges with this approach that need to be addressed. For water heater burners designed to run with natural gas, an increasing portion of hydrogen in the fuel corresponds to higher volumetric flowrates of fuel, which can lead to flashback. This is where flames travel upstream into the area of fuel mixing, causing burner failure. Another concern is the potential, under certain conditions, for hydrogen fuel to generate more Nitrogen Oxide (NOx) than burning natural gas.

In previous testing led by UCICL Director Professor Vince McDonell, it was determined that both the conventional and low-NOx water heater models operated safely with up to 10% hydrogen in natural gas (by volume). While carbon dioxide (CO_2) levels predictably dropped, it was also observed that the NO and NOx emissions of each heater decreased as the share of hydrogen was increased.[3]



To build off these initial findings, Professor McDonell and his team have been pushing to find the upper limits of hydrogen tolerance in existing models of water heaters. With commercial, low NOx water heaters, stable operation with up to 80% hydrogen fuel was achieved, and a notable concurrent reduction in emissions was observed. Preliminary data taken with one low NOx heater shows the levels of NO and NOx emissions decreasing by 90% and 75% respectively when compared to heating with pure natural gas. More conventional heater models, while showing a healthy tolerance to hydrogen blends up to 40-50%, didn't show as significant a drop in NO or NOx.

Using this baseline assessment, Professor McDonell's group will begin evaluating modifications to existing water heater burners, aiming to run safely and effectively at up to 100% hydrogen fuel.

[1] U.S. Census Bureau, California, B25040 House Heating Fuel, 2019 American Community Survey 1-Year Estimates.
[2] U.S. EIA, Natural Gas Consumption by End Use, California, Annual, 2016-21.
[3] McDonell, V., Zhao, Y., and Choudhury, S. (2020). Implications of Increased Renewable Natural Gas on Appliance Emissions and Stability, CEC Report CEC-500-2020-070

Telluride Innovative Workshop on Cement Decarbonization

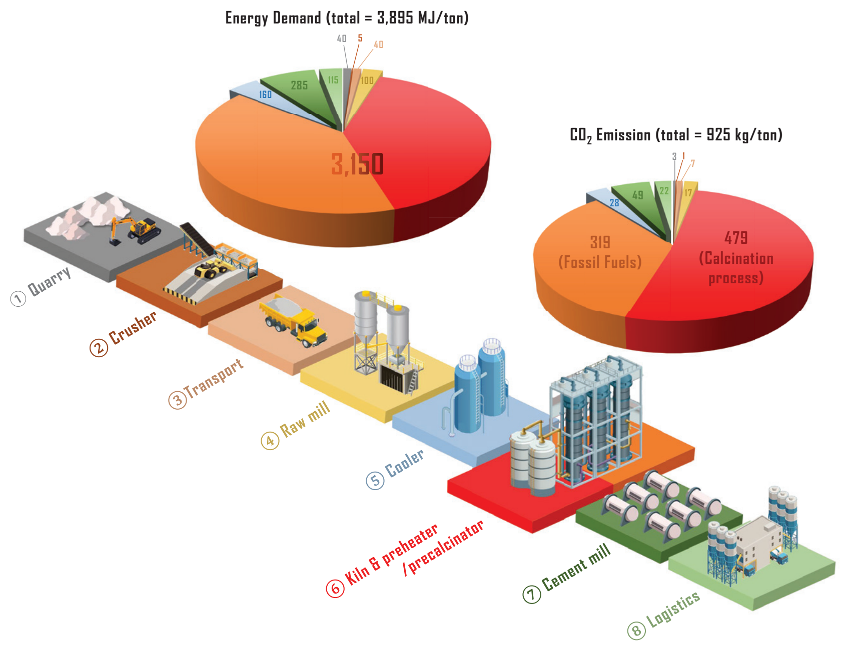


Figure 1. A schematic of the cement manufacturing process with energy intensity and CO_2 emissions reported for each production step. Adopted from McKinsey.

The Inaugural Telluride Innovative Workshop on Cement Decarbonization took place in Telluride, Colorado, USA on February 7 – 11th, 2022. The workshop was organized by NFCRC Associate Director Professor Iryna Zenyuk, and Professor Mo Li, Department of Civil and Environmental Engineering, UCI. This workshop was designed to bridge electrochemistry and encourage communities to brainstorm solutions on how to decarbonize the cement industry. Participants from industry, academia, and national laboratories took place in the workshop.

Portland cement concrete is the most widely used man-made material in the world. More than one tonne of concrete is produced annually per person on Earth. Cement production contributes to about 8% (2.8 Gtons/year) of carbon dioxide emissions and accounts for 5% of industrial energy consumption globally. After World War II, cement production has increased 30 fold since 1950 and 4 fold since 1990. This increase was overall more rapid than global fossil energy production. In the conventional manufacturing process of Portland cement, energy input from fossil fuels is used to calcine limestone ($CaCO_3$), where $CaCO_3$ is decomposed into CaO and CO_2. The CO_2 emission thus stems from: 1) fossil fuel combustion needed to heat the raw materials ultimately to ~1450 °C to calcine and sinter, and 2) decomposition of $CaCO_3$ in the kiln. About 1 ton of CO_2 is released for every ton of Portland cement produced in this manner. Basic research to reduce this ratio is urgently needed, as pointed out in a most recent Proceeding of National Academy of Sciences comment.

The electrochemistry community has a potential to play an important role in cement decarbonization. As the US has pledged to decarbonize its economy by 2050, the cement industry will be one of the most challenging to decarbonize. Currently, there are no plug-in replacement technologies available to decarbonize the cement industry. CO_2 emissions stem from $CaCO_3$ decomposition and from fossil-fuel burning (Figure 1). Electrolysis of $CaCO_3$ transformation to $Ca(OH)_2$ is a low-temperature process and has a potential to reduce CO_2 emissions by substituting the source of power from fossil fuel burning to renewably-generated electricity (solar and wind, for example). However, currently the process is still at low technology level (TRL) and requires significant innovation in terms of processes, materials, and system level designs. The Telluride Workshop on Cement Decarbonization brought cement and electrolysis communities together to address some of the challenges in cement decarbonization (Figure 2).

Figure 2. Some of the participants of the Telluride workshop. From left to right: Devashish Kulkarni (UCI), Hung-Ming Chang (UCI), Paul Kempler (University of Oregon), Ertan Agar (University of Massachusetts, Lowell), Iryna Zenyuk (UCI), Mo Li (UCI), Chris Arges (Penn State University), Chris Capuano (NEL Hydrogen).

Fuel Cells in Transportation

Over the past few decades, the demand for energy has increased across almost all sectors of society. The increase in demand is a global phenomenon and reflects an economic advancement in many developing countries. Yet, economic development is not without cost. The global carbon dioxide (CO_2) concentration, which has never exceeded 300 ppm over the past 800,000 years, breached 400 ppm earlier this century, causing the significant increase in global average temperatures. The transportation sector accounts for 21% of world energy consumption and relies heavily on carbon-based fuels that release CO_2 during combustion. To reduce global CO_2 emissions and maintain global average temperatures at a safe level, it is critical to find alternative clean and sustainable power sources for transportation whilst minimizing any adverse impacts to the environment, ultimately achieving a zero-carbon energy system.

Hydrogen (H_2) is a clean and attractive energy carrier, owing to its carbon-neutrality and high gravimetric energy density (120.21 MJ kg^{-1} vs. 46.0 MJ kg^{-1} for gasoline). Therefore, a significant effort has been devoted to developing energy conversion devices to utilize H_2 efficiently and replace fossil fuel-based energy systems.

Fuel cells have been the subject of substantial research as novel electrochemical energy conversion devices. Specifically, proton exchange membrane fuel cells (PEMFCs) can directly and efficiently convert the chemical energy of H_2 into electricity, which can be readily applied in combination with an electric motor to drive vehicles. Such vehicles are known as fuel cell electric vehicles (FCEVs) and have multiple advantages over their electric vehicle (EVs) counterparts in use as light-duty vehicles (LDVs) — charging times (< 5 min) and driving range (> 400 miles) — which are comparable to the prevailing internal combustion engine (ICE)-based LDVs. The energy efficiency of FCEVs is higher than that of conventional ICE (> 60%) with zero direct pollutants. A representative example of a commercially available light-duty FCEV is the Toyota Mirai. Recently, interest in the application of fuel cells to heavy-duty vehicles (HDVs) has also increased, driven by the distinctive scalability of energy storage and power density of hydrogen powertrains; this can be easily achieved through cell stacking and H_2 tank enlargement with relatively low cost and weight penalties. Considering the heavy-duty markets are responsible for a large portion of total CO_2 emissions in the transportation sector, the commercialization of the fuel cell HDVs could be an effective strategy for decarbonization. Anglo American, an international mining company, unveiled the first prototype of the hydrogen-powered ultra-class mine haul truck in May 2022. Nevertheless, limited availability of H_2-fuelling infrastructure, high cost of catalysts — typically Platinum — and system durability still limit the widespread adoption of FCEVs. Beyond road vehicles, fuel cell technology has been deployed in maritime, rail, and aviation sectors with notable success for Cummins, Alstom, and Ballard in commercialization.

> “ *...interest in the application of fuel cells to heavy-duty vehicles (HDVs) has also increased...*

Lithium-ion battery-based EVs introduced to the mass market by Tesla exhibit high power density and stability. EVs are, however, fundamentally limited by long-charging times, restricting suitability to commuting and light-duty applications. In contrast, FCEVs have comparable fuelling times and driving range — two critical metrics for industrial haulage and long-distance transport — to their ICE counterparts. EVs and FCEVs therefore form a complementary partnership rather than a competition. The latest trends in the industry sector are implying that fuel cell technology will first target the heavy-duty vehicles sector in transportation.

Chaewon Lim, Alasdair Fairhurst, Benjamin Ransom, Dominik G. Haering and Vojislav R. Stamenkovic*
Department of Chemical & Biomolecular Engineering, University of California, Irvine, CA 92697, USA

Commercial Catalytic Stove Project

Current commercial gas stoves utilize natural gas as their main source of energy and release carbon dioxide and nitrogen oxides (NO_x) into the atmosphere as a result of the combustion process. Switching to clean and renewable energy has become a global goal in the past years due to climate change. Introducing carbon-free fuels, such as renewable hydrogen, into the natural gas pipeline has the potential to decrease the amount of fossil fuel used and reduce greenhouse gas emissions; however, it can cause an increase in the amount of NO_x emissions depending on the application and the type of burner that is used. Reduction in NO_x emissions can be achieved by reducing the combustion temperature. Catalytic combustion provides the advantage of lowering the temperature of the fuel oxidation reaction, thus resulting in significantly lower NO_x emissions. Directors of the UC Irvine Combustion Laboratory (UCICL) Professor Bihter Padak and Professor Vince McDonell have partnered with the Southern California Gas Company to investigate the use of hydrogen in commercial stoves employing catalytic combustion. They will design an ultra-low NO_x catalytic burner to burn natural gas/hydrogen blends for commercial cooking applications.

Flow Test of the Catalytic Honeycomb in the Burner Prototype

This project will benefit the commercial food service industry and the communities where restaurants are located by decreasing emissions from the cooking process. Commercial cooking appliances are widely used throughout urban regions. As a result of the universal need for sustainment and the social interaction aspect of locations where meals are prepared and/or served, locations using commercial cooking appliances are located in highly diverse population centers. As a result, improvements in performance, either energy cost or emissions performance, stand to benefit a large sector of the population relative to inequity in the energy sector. Reducing the emissions resulting from the cooking process would benefit the society, especially disadvantaged communities, by improving the quality of their life.

Fire in Inner Tube of Catalytic Stove Inside View

Value of Gas Grid Transformation

Economies around the globe are exploring optimal pathways to achieve deep decarbonization. Conversion of many existing uses of liquid and gaseous fuel to technologies powered by renewable electricity is a dominant theme in decarbonization strategies. However, certain applications lack feasible and cost-effective all-electric solutions. In general, these are applications that require the storage and/or transport of large amounts of energy or the ability to transfer energy at a high rate such as vehicle fueling. So-called hard-to-decarbonize applications include high-payload transportation such as freight, marine, rail and aviation applications, high-temperature process heat, and firming of variable renewable energy sources. These applications must be decarbonized in other ways such as the use of low- and zero-carbon liquid and gaseous fuels. Recent and ongoing research by APEP is exploring the optimal role of decarbonized gaseous fuels in the future zero-carbon economy.

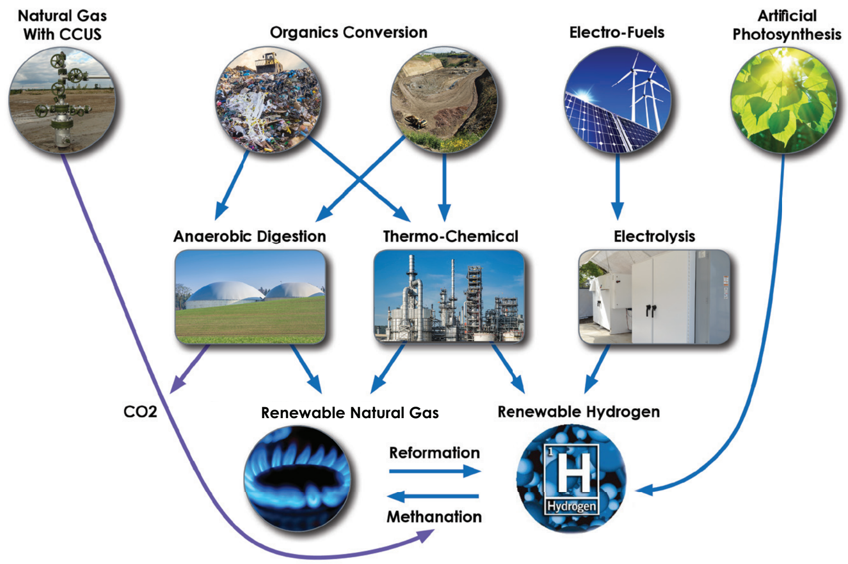


Figure 1. Renewable and Zero-Carbon Hydrogen and Methane Pathways

As seen in Figure 1, there are several ways to produce zero-carbon gaseous fuels using renewable feedstocks or capturing carbon from fossil resources. The cost of producing the various forms of zero-carbon fuels differs. Figure 2 shows long-term (2040-to-2050 timeframe) cost projections for the primary pathways. Carbon capture from power generators and large industrial processes projects to be a low-cost solution but requires the establishment of a CO_2 pipeline network and is only suitable for the largest industrial facilities and power generators. Among the renewable pathways, hydrogen projects to be lower cost than methane for both electrochemical and thermochemical pathways. However, hydrogen requires new or repurposed infrastructure and conversion devices as indicated in Table 1 for Southern California. All-in, the costs for converting to a pure hydrogen network in the future are estimated to be on the order of $29 billion for the region. In spite of the cost, initial analysis predicts that the lower cost of renewable hydrogen in comparison to renewable methane will make conversion to pure hydrogen the least-cost renewable gas solution.

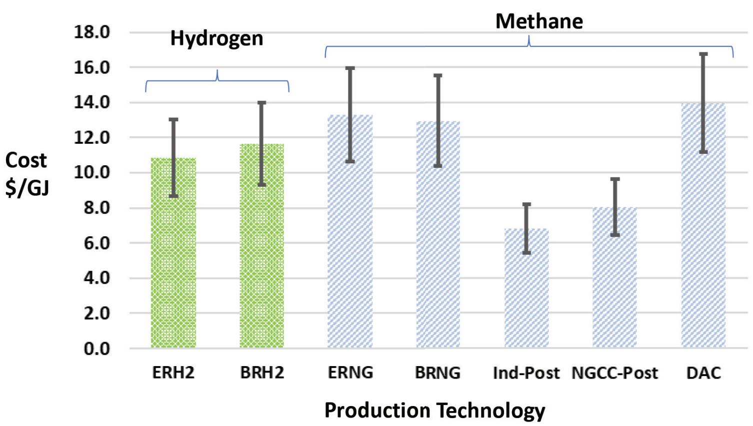


Figure 2. Cost of Alternative Zero-Carbon Gaseous Fuels in 2050 Timeframe

System Element	Costs (rounded)	
	Region (billion)	*Unit Cost*
Transmission	$3.2	$4 million/mile
Storage	$3.1	$8/kg H_2
Distribution	$0.93	$155/meter
Customer Side of Meter Residential Commercial & Industrial Power Generation	 $17 $2.1 $2	 $2,900/meter $125/kW$_{th}$ $170/kW$_{th}$
Total	29 billion	

Table 1. Elements of Conversion of the Gas System to Pure Hydrogen

Graduates & Internships

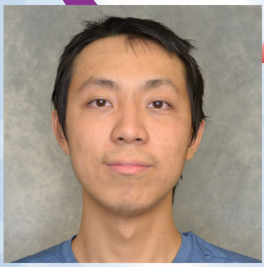
M.S. GRADUATES

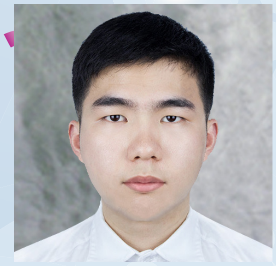

Khaled Alsamri


Candy Hernandez


Ramon Garcia


Joliette Li


Weixi Wang


Kai Wu

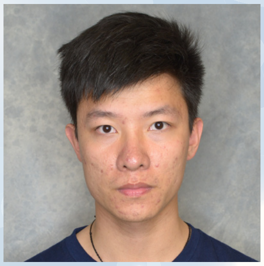
PH.D. GRADUATES


Maryam Asghari


Arezoo Avid


Alejandro Lavernia


Gi Jung Lee


Yongzhen Qi

INTERNSHIPS 2021-2022

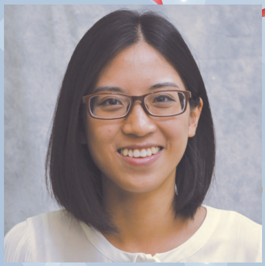

Arezoo Avid
Bosch (Sunnyvale, CA)


Candy Hernandez
Boeing


Alejandra Hormaza
HydroPlane


Jennifer Lee
Schweitzer
Engineering Laboratories


Pegah Mottaghizadeh
Tesla


Shan Tian
Tesla


Britney Tran
Northrup Grumman


Joseph Suratt
NREL

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1 July 2021-30 June 2022

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Featured Highlights

Scholars at Risk Program

NFCRC Associate Director Professor Iryna Zenyuk worked with the Scholars at Risk program to bring Ukrainian academics to the UC Irvine campus. Thus far, her program has raised $250k to support Ukrainian scholars and their families. Under this program, two academics are in the process of transitioning to UC Irvine.

Read more about Professor Zenyuk's efforts here: https://news.uci.edu/2022/03/16/helping-her-homeland

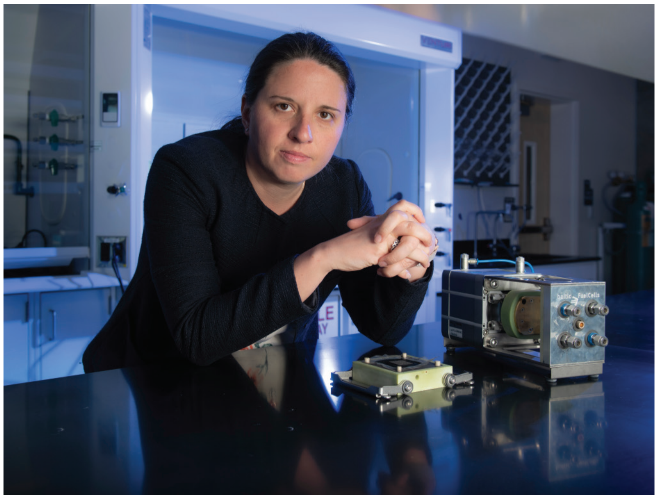

Photo by Steve Zylius, UCI Strategic Communications Photographer

Decarbonization REU Program

The National Science Foundation (NSF) has recently awarded UCI a new Research Experiences for Undergraduates (REU) Program on decarbonization. This REU site, directed by Professors Erdem Sasmaz (CBE) and Bihter Padak (APEP), offers a nine-week interdisciplinary summer program related to sustainable energy pathways in the Schools of Engineering and Physical Sciences at UCI. The program will support ten non-UCI undergraduate students each year for a three-year program (2022-2024). The REU students will be exposed to comprehensive decarbonization research topics and learn interdisciplinary approaches to tackle the science and engineering challenges of achieving net-zero carbon emissions. The students will address fundamental questions across a broad range of disciplines and applications related to decarbonization routes, including sustainable hydrogen production, energy storage, use of efficient fuel cells, electrochemical and thermochemical production of high-value chemicals, advanced nuclear fuel cycle, and waste management; novel functionalized nanomaterials and complex oxides for carbon dioxide and proton reduction, efficient radiofrequency heat delivery, advanced combustion technologies and use of renewable hydrogen in gas turbines and internal combustion engines. This REU site will provide a collaborative research platform for undergraduate students, graduate students, and faculty to address challenges associated with decarbonization. For more information: https://faculty.sites.uci.edu/decarbonizationreu

Highlights of the Academic 2021-2022 Year

Summer 2021

U.S. DOE's 2021 Solar District Cup—June 2021
APEP graduate students Yanchen Wu, Weixi Wang, and Shan Tian earned a second place finish in the U.S. Department of Energy's 2021 Solar District Cup, organized by the National Renewable Energy Laboratory (NREL).

Electrochemical Society Award—July 2021
NFCRC Associate Director Iryna Zenyuk received the Electrochemical Society's Energy Technology Division Supramaniam Srinivasan Young Investigator Award.

U.S. Secretary of Labor—July 2021
APEP Director Jack Brouwer discussed UCI's research contributions to decarbonizing transportation and the important role of H_2 with US Secretary of Labor Marty Walsh during his visit to UC Irvine.

Department of Energy Award—August 2021
HIMaC² was awarded a $6M grant from the Department of Energy to establish a "Public Road Network Platform" in collaboration with the City of Irvine, Argonne National Lab, and UCI Institute of Transportation Studies to evaluate connected and autonomous vehicle technologies.

Fall 2021

ACS Applied Energy Materials—September 2021
NFCRC Associate Director Iryna Zenyuk joined the ACS Applied Energy Materials as an Associate Editor.

AIChE Annual Meeting—November 2021
UCICL Associate Director Bihter Padak served as the chair of the Diversity & Inclusion Task Force of the AIChE's Catalysis and Reaction Engineering (CRE) division and organized several events at the AIChE Annual Meeting.

UCI Innovator Awards—November 2021
NFCRC Associate Director Iryna Zenyuk was the recipient of The Emerging Innovation/Early Career Innovator of the Year Award by the UCI Samueli School of Engineering.

Top 1% Rank by Citations—November 2021
HIMaC² Director Voya Stamenkovic was named a Highly Cited Researcher by Clarivate Web of Science for the second year in a row.

Winter 2021

Decarbonizing Steel Production with Green Hydrogen Seminar—December 2021
SoCalGas® and APEP hosted a seminar about the $5.7 million effort with the U.S. Department of Energy (DOE) to develop novel, renewable and more efficient manufacturing processes for producing green steel.

Spring 2022

UC Irvine Hydrogen Fuel Station Record—March 2022
The UC Irvine hydrogen refueling station had an uptime of 96% during March 2022, the highest among all high-production stations.

National Association of Regulatory Utility Commissioners Meeting (NARUC)—March 2022
APEP hosted NARUC members from GA, MA, CA, NY, CO, & NV for presentations on California's decarbonization strategy and a tour of APEP research labs.

Intergovernmental Panel on Climate Change (IPCC) Assessment Report—April 2022
4 APEP research papers were cited in the recently released IPCC 6th Assessment Report, which provides an updated global assessment of climate change mitigation progress.

Senator Josh Newman Visit—April 2022
APEP hosted California State Senator Josh Newman for an informative tour as well as to demonstrate ongoing research on hydrogenenergy and its contributions toward clean energy and transportation systems.

PBS NewsHour—April 2022
APEP Director Jack Brouwer was featured on a segment of PBS NewsHour, where he discussed the role of green hydrogen and the future of clean renewable energy.

PBS Special Broadcast—April 2022
NFCRC Associate Director Iryna Zenyuk was interviewed by David Nazar for the PBS special broadcast on Sustaining US regarding the Russian invasion in Ukraine and regional energy solutions that could save lives.

Recent Research on Front Page of the U.S. DOE Office of Science—May 2022
NFCRC research was spotlighted on the front page of the U.S. DOE Office of Science's webpage. Featured was Graduate Student Researcher Kaustubh Khedekar's paper, "Probing Heterogeneous Degradation of Catalyst in PEM Fuel Cells under Realistic Automotive Conditions with Multi-Modal Techniques."

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Advanced Power and Energy Program
University of California, Irvine
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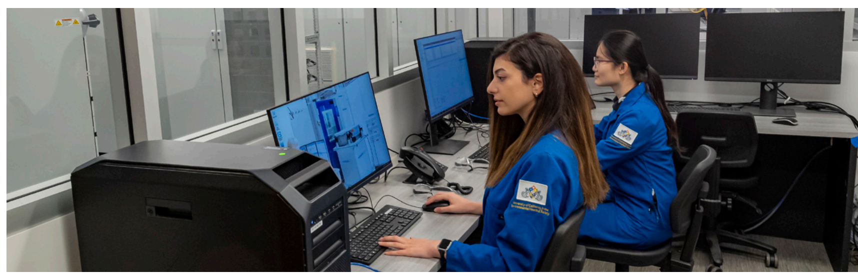
The UCI Advanced Power and Energy Program (APEP) encompasses three organizational elements: the National Fuel Cell Research Center, the UCI Combustion Laboratory, and the Horiba Institute for Mobility and Connectivity[2].

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.

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