Annual Report | Volume 9 | 2021

ADVANCED POWER AND ENERGY PROGRAM

BRIDGING

ENGINEERING SCIENCE TO PRACTICAL APPLICATION

HORIBA Institute for Mobility and Connectivity[2]

DIRECTOR'S MESSAGE

PROFESSOR JACK BROUWER, PH.D.

DIRECTOR, ADVANCED POWER AND ENERGY PROGRAM (APEP)

While conditions for research and instruction have been significantly impacted by the need to respond to the COVID-19 pandemic throughout this year, we are grateful and fortunate to have been extremely productive. We have been able to forge new relationships, accomplish significant experimental and theoretical research, complete the construction and equipping of the Horiba Institute for Mobility and Connectivity^2 (HIMaC^2), and garnered significant corporate, local, state, and federal support for our program and our outstanding students, our professional and research staff, and our faculty.

While APEP graduates, students, staff and faculty have recognized the important roles of hydrogen, fuel cells, renewable fuels, energy storage of all types, and zero emissions technology and systems for energy and environmental sustainability for a very long time, only this year have jurisdictions around the world begun to recognize these important roles, adopt supportive policies, and demonstrate these technologies.

This year has involved a coalescence and increased collaborative effort amongst teams of researchers led by Professor Iryna Zenyuk, Associate Director of the National Fuel Cell Research Center (NFCRC), Professor Bihter Padak, Associate Director of the UCI Combustion Laboratory (UCICL), Professor Vojislav Stamenkovic, Director of HIMaC^2, Chancellor's Professor Plamen Atanassov, Professor Vince McDonell, Director of UCICL and Associate Director of APEP, and Professor Scott Samuelsen, Founding Director of APEP. This world-class set of faculty leaders is increasingly recognized for its capabilities to advance zero emissions and sustainable energy technologies from science to practical application.

In fact, because of outstanding faculty leadership and collaboration, outstanding leadership of Chief Scientists Dr. Jeff Reed and Dr. Ashok Rao, and outstanding contributions from research team leaders Dr. Brian Tarroja, Dr. Ghazal Razeghi, Dr. Luca Mastropasqua, Dr. Michael Mac Kinnon, Dr. Robert Flores, Dr. Andrea Perego, Dr. Pongsarun Satjaritanun, Dr. Mohammed Mojdehi, Dr. Blake Lane, and Dr. Kate Forest, APEP is poised to become the most recognized place in the U.S. for advancing the science and technology of hydrogen and zero-emissions electrochemical and chemical conversion technologies from fundamental science, to application in technologies, to integration in systems and within energy systems.

With support from so many partners, graduates, agencies and other organizations, APEP will indeed become the most impactful place in the U.S. for enabling a completely zero-emissions world (both greenhouse gas and criteria pollutant emissions-free) by advancing hydrogen, fuel cells, electrolyzers, combustion, and capture technologies that complement solar, wind and other renewable resources, enable long duration and seasonal storage, and engender zero emissions in difficult sectors including industrial processes (e.g., cement, steel, ammonia, pharmaceuticals, computer chips, glass), and fuels for rapid fueling, long range and heavy payload (e.g., shipping, aviation, trains, long-haul trucks).

This vision for APEP is apparent in our ninth annual edition of "**Bridging**," in which we feature (1) the historic establishment of HIMaC^2 at APEP, and (2) two new federal awards for decarbonization of both cement and steel production. Notable accomplishments during the past year include:

- APEP research with support from **Southern California Gas Company** to transform the gas system to a renewable gas system,
- A **National Science Foundation** award to the NFCRC for electrochemical decarbonization of cement manufacturing,
- A $5.7 million collaborative award to NFCRC, **Hatch, FuelCell Energy, and Politécnico di Milano**, for manufacturing green steel using solid oxide electrolysis with funding support from the **U.S. Department of Energy**,
- A U.S. Department of Energy award to the UCICL for engendering renewable hydrogen production and conversion in UCI's **Solar Turbines** combined cycle power plant, and
- The completion of **HIMaC^2** construction and equipment installation and training in preparation of the virtual opening on 6 July 2021.

We are very proud of our graduate student accomplishments during the 2020-2021 academic year, which includes 5 MS graduates, 9 Ph.D. graduates, and 3 internships with diverse entities such as: **Tri-Alpha Energy Inc., the Environmental Defense Fund, and Robert Bosch LLC**.

We are indebted to our alumni of more than 250 graduate students, scores of undergraduate student researchers, and long-standing relationships that contribute in so many ways to our research programs and our "*Bridging* from engineering science to practical application."

Finally, we are thankful to the South Coast Air Quality Management District, Dr. Roger Brum (APEP alumnus), and other donors who have generously given almost $700,000 to establish a new endowment for the ***Samuelsen Energy Visionary Fellowship***. I ask that all of you please consider donating to this wonderful cause (envelope enclosed). If we can raise $1 million with your support, we will be able to perpetually support a graduate student conducting visionary sustainable energy research in the mold of Professor Scott Samuelsen.

Jack Brouwer

CONTENT

The HIMaC^2

HIMaC^2 is positioned at the entrance of UCI Engineering Plaza

The Horiba Institute for Mobility and Connectivity (HIMaC^2) emerged from a long-standing relationship between the Horiba Group, a global provider of analytical and measurement systems, and the University of California, Irvine (UCI). This decades-long partnership culminated in the summer of 2018 with the announcement of remarkable monetary commitment by the Horiba Group on behalf of UCI, dedicated to founding a new institute within the Advanced Power and Energy Program at the Henry Samueli School of Engineering. The new entity with state-of-the-art facilities is envisioned to pursue efforts on the future transition and integration of energy and transportation sectors. Despite pandemic constraints, HIMaC^2 has gone through a transformation from blueprints to commissioning in less than three years.

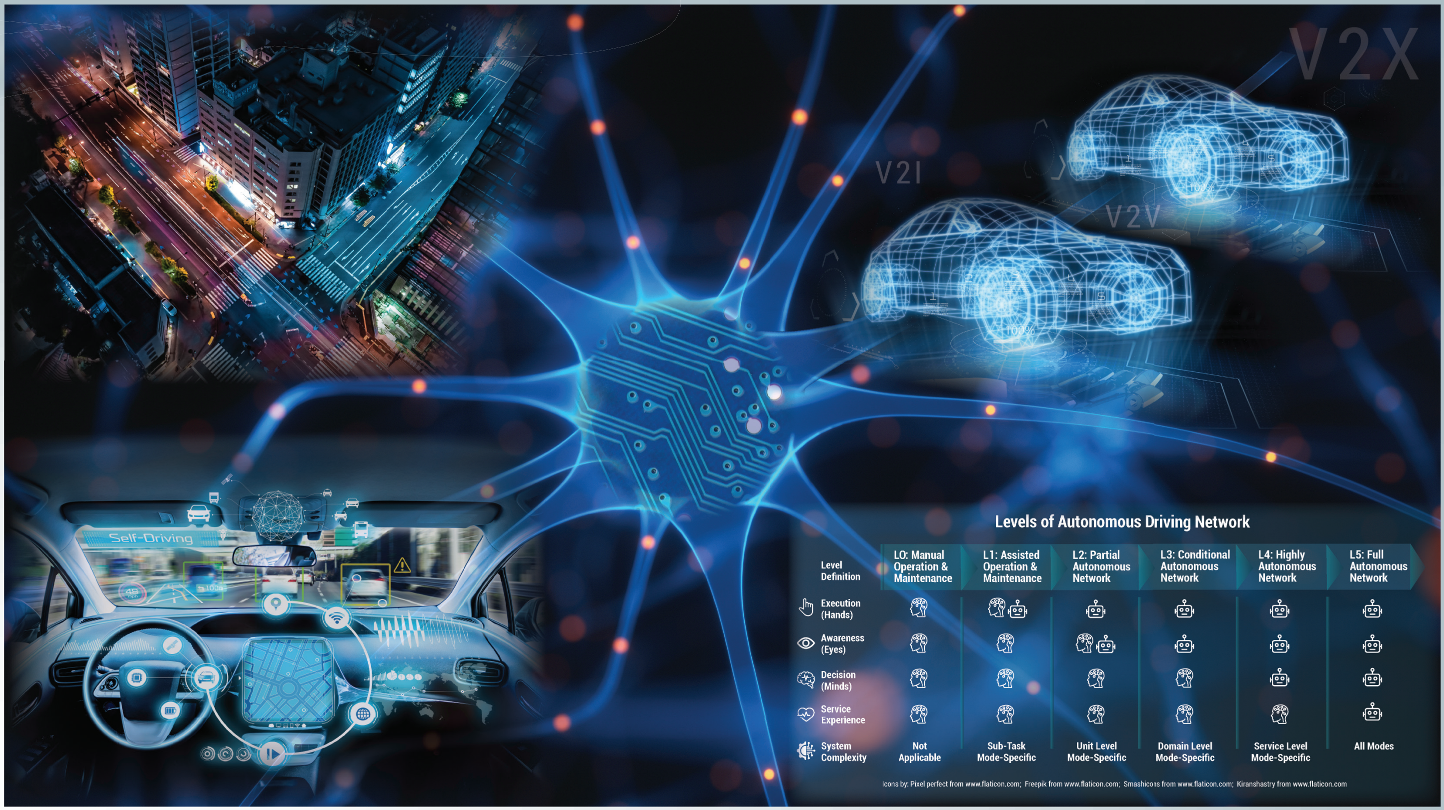
HIMaC^2 construction was completed in February 2021 and is located within UCI's Engineering Gateway near the entrance of Engineering Plaza, symbolizing its multidisciplinary research mission. A small virtual opening ceremony, which resembled a family reunion between UCI and the Horiba Group, was held on July 6th, 2021, when HIMaC^2 formally opened its door for operation. This marked the beginning of a new chapter at UCI, with the expectation of bringing together numerous experts in the quest to formulate a historic transition of the transportation and energy sectors. At the same time, the first U.S. Department of Energy's (DOE's) Energy Earthshot Initiative, focused on ***clean hydrogen production*** that would enable net-zero carbon emissions by 2050, was launched on July 7th, 2021. ***Hydrogen*** is a fuel that has potential to decarbonize energy systems, industrial processes, as well as the transportation sector through the wide deployment of hydrogen fuel cells that produce electricity onboard to power vehicles. The transition of transportation is underway in California, as the State announced in 2020 that only zero-emission electric vehicles will be sold after 2035 (currently accounts for about 8% of total new car sales). The executive order was preceded by setting a number of ambitious milestones, such as placement of 200 hydrogen fueling stations and 250,000 electric vehicle charging stations, to support the electric zero-emission vehicles powered by ***hydrogen fuel cells*** and ***batteries*** on California roads by 2025. In addition to the full ***electrification*** of drivetrains, the transportation sector is making progress towards an additional transition: ***autonomous driving***. The two evolutionary changes in transportation are the defining core activities of HIMaC^2, both of which are captured in its name: ***Mobility*** signifies a focus on sustainable transport based on zero-emission vehicles, and ***Connectivity^2*** encompasses the emerging synergy between vehicles and the grid through both electricity and hydrogen as well as networking platforms that support autonomous driving, whereas squared implies its multidimensional character. The evolution of transportation will have a profound environmental and socio-economic impact as well as large implications in many research disciplines. Moreover, the technologies that are replacing conventional internal combustion engine vehicles, including existing electric grid and wireless network infrastructure, still need to address a number of existing technical barriers to accommodate the transition of transportation at global scale. In order to facilitate the evolution of transportation and energy sectors, HIMaC^2 will rely on engaging with experts in engineering, physical sciences, information and computer sciences, social sciences, and business and economics. In essence, HIMaC^2 is at a crossroad for academia, industry, and the regulatory sector to identify, resolve and develop technology enablers towards sustainable zero-emission autonomous transportation.

"The transition of transportation is underway in California, as the State announced in 2020 that only zero-emission electric vehicles will be sold after 2035..."

HIMaC^2 provides research and educational programs through four integrative units based on the initial spectrum of research activities, which is anticipated to increase over time. The four units are comprised of state-of-the-art laboratories outfitted with selected equipment that enable a synergistic approach in tackling the most challenging research topics:

Vehicle Evolution Laboratory addresses the performance of zero-emission electric vehicle drivetrain components, including electric motors, batteries, and hydrogen fuel cell stacks. This lab hosts a two-wheel dynamometer and two environmental test chambers for in-situ evaluation of electrochemical power sources, hydrogen fuel cell, and battery stacks. These capabilities provide a wide range for the evaluation of vehicle powertrain, simulation of different driving cycles and environmental conditions that reflect on the drivetrain's energy efficiency, durability, charging demands, etc.

Grid Evolution Laboratory enables the study and evaluation of future electric grid demands due to the incremental increase of electric plug-in vehicles that are powered by battery stacks. Proper optimization of future power management is critical to assess in both modes of grid-to-vehicle (G2V) and vehicle-to-grid (V2G) during which the electric vehicle recharges from the grid or discharges power back into the electric grid. These efforts are complemented with approximately 200 charging stations



Autonomous driving networks - powered by artificial intelligence, will rely on connectivity platforms between vehicles and infrastructure

"The U.S. Department of Energy's Vehicle Technology Office has selected HIMaC² with its first federal grant aimed at the optimization of energy efficiency of zero-emission vehicles by artificial intelligence."

for electric vehicles and a hydrogen fueling station that is open to the public and the electric microgrid at UC Irvine, which makes HIMaC² fully equipped to address, evaluate, and optimize the electric grid in conjunction with the electrification of transportation sector.

Connectivity and Autonomous Mobility Laboratory considers both aspects of connectivity, including vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V). Communication between vehicles and infrastructure will be powered by artificial intelligence, which will aim to improve safety, energy efficiency, and travel time. In addition, sensor technology that relies on lidar, radar, and cameras will be evaluated as introduced with each level of autonomous driving. Communication ports, sensors, autonomous steering and breaking will put additional demand on electrochemical power source and hence, these components will be optimized for the most effective energy consumption.

These activities will be executed at three levels: driving *simulations*, *controlled* laboratory conditions through a testbed and the VEL, and a *field laboratory* that involves the UCI campus and the City of Irvine.

Analytical Laboratory is strategically equipped with scientific instrumentation that will be used in research and development of electrochemical devices, novel materials, and chemistries. The instrumentation for characterization of materials and interfaces is customized for the high-precision electrochemical evaluations that are critical in utilization of electrochemical systems in future transportation and stationary energy storage systems. Both batteries and fuel cells need substantial improvements in order to address demands in reliability, driving range, and recharging/refueling time while powering electric drivetrain of zero-emission vehicles.

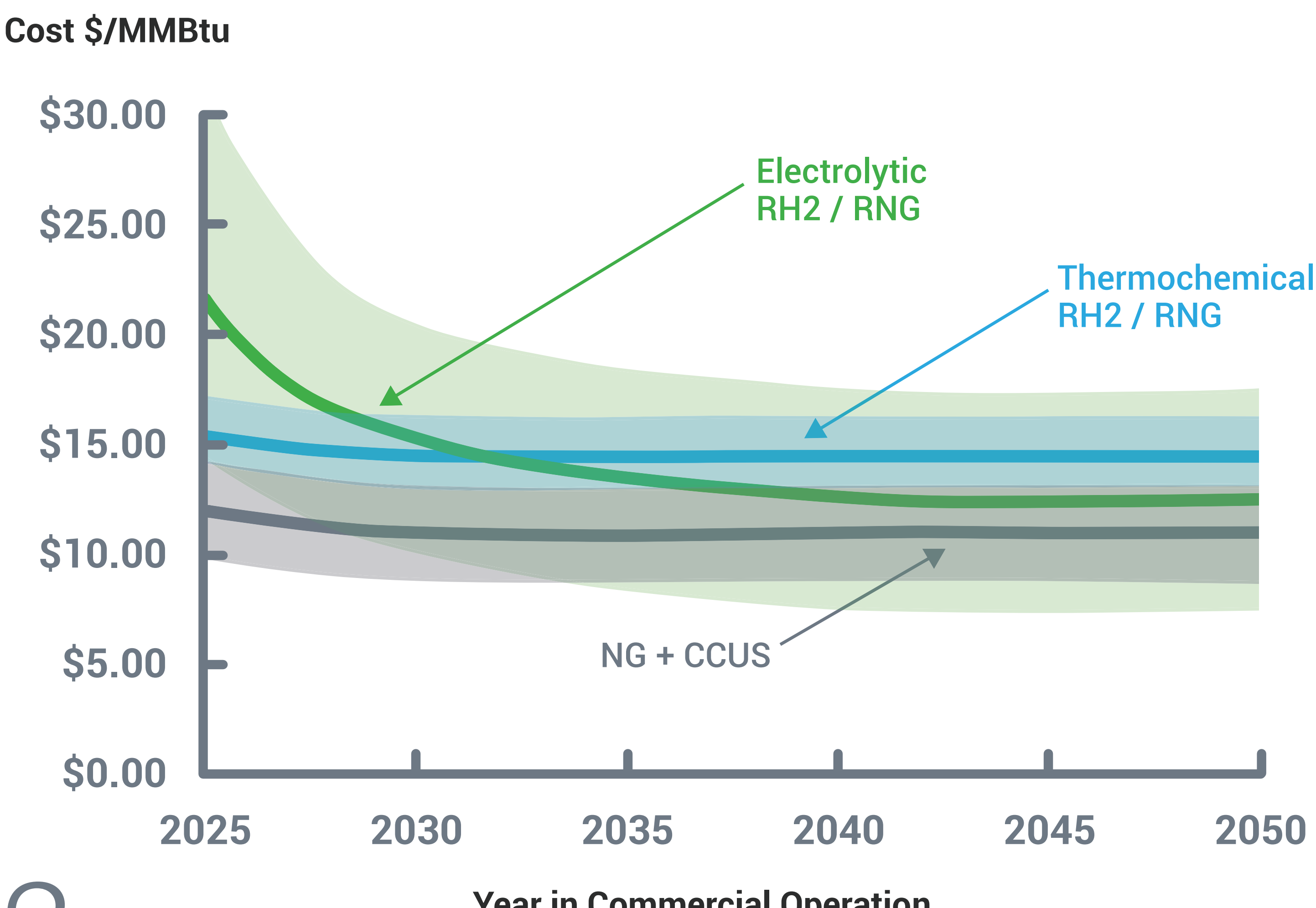
In the three years following the announcement by the Horiba Group, HIMaC² has evolved and is now operational with the capability to engage in complex tasks related to all aspects of future mobility and connectivity. The U.S. Department of Energy's Vehicle Technology Office has selected HIMaC² with its first federal grant aimed at the optimization of energy efficiency of zero-emission vehicles by artificial intelligence.

Vojislav (Voya) Stamenkovic
The Founding Director of HIMaC²
Professor of Chemical and Biomolecular Engineering and Chemistry
University of California, Irvine

Transforming the Gas System

To achieve deep reductions in economy-wide greenhouse gas (GHG) emissions, the fuel delivered over the natural gas pipeline system must be replaced by zero- or near-zero-carbon substitutes. Electrification of many end uses will reduce the need for gaseous fuel over time. However, the least-cost approach to economy-wide decarbonization will likely include expanded use of hydrogen and continued use of decarbonized forms of methane for a range of applications. Many national and regional decarbonization strategies envision the use of low- and zero-carbon hydrogen or methane to serve 20 percent or more of primary energy demand. Low-carbon gaseous fuels are well suited to replace current uses of natural gas, those of conventional hydrogen (predominantly refining and ammonia production), and applications served by liquid fuels. Hydrogen and methane can be decarbonized through production pathways that use renewable energy sources and feedstocks, or through carbon capture and sequestration in geological formations or solid products. The figure below shows the mid-point estimates for the future cost of a variety of zero-carbon gaseous fuel pathways developed from a recent Advanced Power and Energy Program (APEP) study. The study will compare the long-term costs of alternative strategies for decarbonizing the gas grid. Beyond the cost of fuel, optimal transition strategies must include the cost of adapting natural gas infrastructure to accept higher hydrogen fractions or its replacement with a new, dedicated hydrogen infrastructure system. The cost of appliances and other consumers of renewable fuel must also be considered. Recent work in the United Kingdom projects that a transition to renewable hydrogen is the least-cost transition approach. The association of European gas networks believes that both decarbonized hydrogen and decarbonized methane will co-exist in the European gas system by 2050. APEP is currently conducting research to determine the least-cost solution for the state of California.

> *"...the least-cost approach to economy-wide decarbonization will likely include expanded use of hydrogen..."*



Source: UCI APEP

Steps Toward a Hydrogen Ecosystem for **UC Irvine**

Support from the U.S. Department of Energy is allowing the Advanced Power and Energy Program (APEP) to carry out the evaluation of possible future pathways for UC Irvine (UCI) to add energy storage in the form of hydrogen to its overall portfolio of green energy options. APEP will augment a simulation program, Distributed Energy Resource Optimization (DEROpt), previously developed at APEP to predict and optimize deployment and use of the resources available for providing the campus with its overall energy needs. These needs include electricity as well as heating and cooling. The UCI campus requires, on average, 12.7 MW of electricity, 14.2 MW of cooling, and 8.7 MW of heating. How the University produces this depends on many complex factors including time of day, the price of fuel, the ability to store energy, and overall demand management through increased energy efficiency measures. As a microgrid, the UCI campus relies on its resources for providing the energy needs of the various buildings which house extensive research and development activities as well as critical services and student housing.

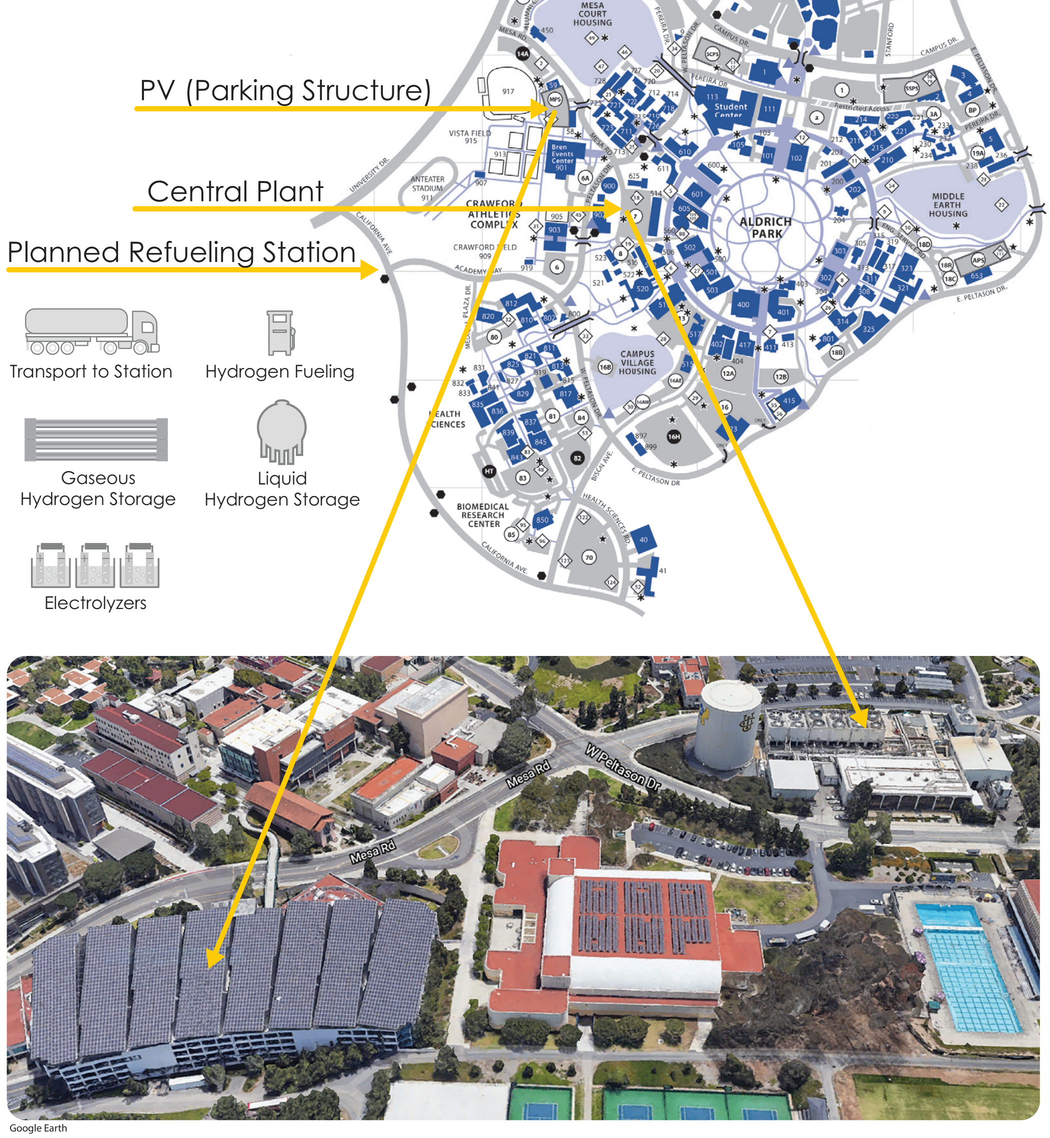
In the new project, APEP will enhance DEROpt to incorporate hydrogen vehicle refueling as well as the use of hydrogen as an energy storage mechanism.

> *"The project will identify an optimized combination of resources to minimize operating costs to the UCI campus and reduce carbon signature."*

By creating hydrogen from electrolysis, the campus can store energy for use at a time that is more economically and environmentally favorable. A key strategy is to modify the existing gas turbine fueled by natural gas to operate on up to 30% by volume mixed with natural gas. By enabling more hydrogen to be used, the gas turbine can use a mixture of hydrogen and natural gas, which will help decarbonize the overall fuel mix used by the campus. In addition, when existing photovoltaic (PV) resources are producing large amounts of electricity, the campus needs to ramp down the gas turbine, which has consequences relative to wear and tear, efficiency, and air pollutant emissions. By producing and storing green hydrogen with electricity otherwise curtailed by lack of campus demand, the gas turbine can continue to operate near full load, which helps maintain low pollutant emissions and high efficiency and also reduces wear and tear associated with ramping. The stored hydrogen can then be blended into natural gas when campus demand is high, which displaces carbon otherwise generated by the gas turbine when operated on natural gas.

By storing and using hydrogen on site, the campus may also be able to serve a critical role in maintaining grid stability during any potential planned safety power shutdowns.

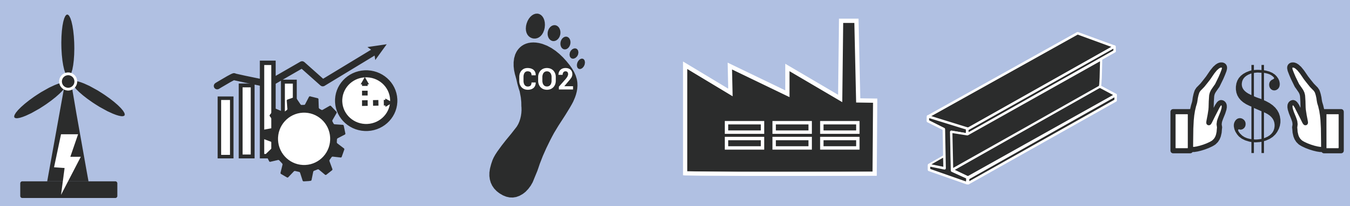
The project will identify an optimized combination of resources to minimize operating costs to the UCI campus and reduce carbon signature.



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

> *"The APEP team will prove that renewable hydrogen, produced from wind and solar resources, can be integrated with steel production, providing an economic pathway to completely decarbonize the steel production sector"*

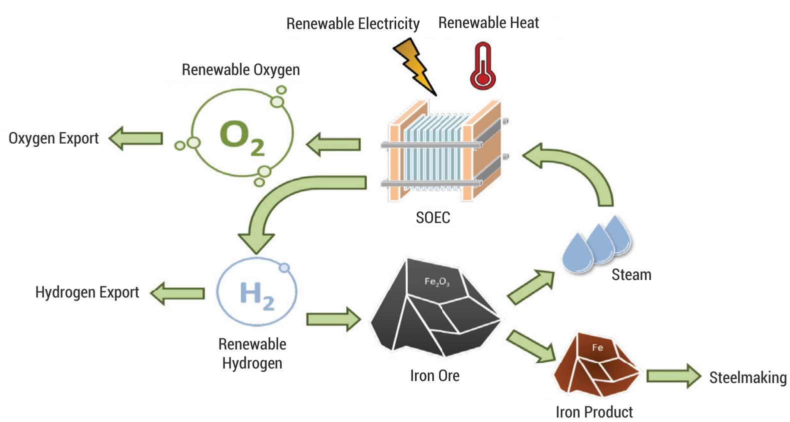
In 2016, the direct carbon dioxide (CO_2) emissions from industrial sector activities reached approximately 24% of global CO_2 emissions (8.3 $GtCO_2$). Steel production is a major CO_2 emitter (6.7% of global anthropogenic CO_2 emissions) in the industrial sector and its contribution is expected to rise due to growing steel production capacity (approximately 20% increase predicted until 2040). The APEP team will prove that renewable hydrogen, produced from wind and solar resources, can be integrated with steel production, providing an economic pathway to completely decarbonize the steel production sector. The concept involves the use of high temperature Solid Oxide Electrolysis Cells (SOEC) to produce hydrogen that can be used to convert raw iron ore (Fe_2O_3) into iron (Fe) in a process called hydrogen direct reduced iron (DRI). This



Specific primary energy consumption <8 Gj/t$_{DRI}$	Electric-to-hydrogen efficiency for an SOEC stack of <35 kWh/kg of H_2 produced	Specific CO_2 emissions rate < 90 kg CO_2 /ton DRI product w/o oxyfuel	Pilot system at production capacity of 1 ton/week and TRL 4	Scale-up design for a 2 Mton/year DRI product capacity	Total capital specific cost < $200/ton equivalent pig-iron per year

UCI APEP

reaction would only produce water as a by-product, allowing for the complete elimination of CO_2 emissions from the ironmaking process. The use of high temperature SOEC systems unlocks the potential of not only using renewable electricity to produce



hydrogen, but to recover high temperature heat from the DRI process and recycle it into the SOEC unit. The team expects that this 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 a three-year effort that relies on modelling and demonstration of the integrated SOEC and DRI process to achieve a substantial improvement of primary energy savings and CO_2 emissions reduction. It will also explore the synergistic integration between the SOEC-DRI system with other industrial activities that could be partly decarbonized by using the renewable hydrogen and oxygen produced by the SOEC plant. The demonstration of the integrated concept will be performed by using a "Hardware-In-the-Loop" configuration, where the SOEC prototype will be installed and connected to a virtual DRI system that will reproduce the real operation of a realistic DRI plant.

Funding is provided by the H2@Scale program of the U.S. Department of Energy, Hydrogen and Fuel Cells Technologies Office, with a total amount of $5.7M. This project boasts the collaboration of UC Irvine with the largest U.S. manufacturer of Solid Oxide Electrolysis systems: FuelCell Energy. The engineering consulting firm, Hatch, will contribute by performing techno-economic and scale-up analyses to evaluate the feasibility of the proposed concept at an industrially relevant scale. The team is partnered with two international institutions recognized for their work on industrial decarbonization using electrochemical systems: Politecnico di Milano and LEAP, both based in Italy. The Southern California Gas Company (SoCalGas) will contribute with the technology transfer to market.

The APEP team is working to secure the collaboration of new stakeholders in the steel and iron producing industries. The advisory board includes major steel companies around the world, including Arcelor Mittal, Nucor Corporation, and Tenova.

Decarbonizing Cement Production:

A Green Solution Derived from Electrochemistry

As of today, the three main sources of anthropogenic emissions of carbon dioxide (CO_2) are the oxidation of fuels, deforestation and other land-use changes, and carbonate decomposition. In the race against climate change, great effort is placed on solving the first two sources of emissions, while the third source of emissions is less explored but extremely necessary to reduce the carbon footprint of human society. Finding alternative green routes for the synthesis of chemicals may lead to a relevant cut in global emissions. Cement production emits up to 8% of total world CO_2 emissions, consumes 5% of the total energy using fossil fuels, and is the largest source of industrial CO_2 emissions worldwide[1,2]. Carbon dioxide emissions from the cement industry are linked to two distinct sources. The first source is the chemical reaction involved in the synthesis of the main component of the cement, alite, which is formed by calcium oxide (CaO) reaction with silica (SiO_2). CaO is formed in the following reaction: $\mathbf{CaCO_3 = CaO + CO_2}$

This reaction, which already produces a mole of CO_2 per mole of limestone ($CaCO_3$), is highly endothermic and requires temperatures as high as 900°C to occur; this is typically performed in a kiln operated by burning fossil fuels such as coal. Given that the CO_2 is already in the raw material, finding a CO_2-free alternative is not an easy endeavor. Alternative routes to target the decarbonization of this process cannot just follow a carbon-free path, at least from the heating part, but must provide a useful output of the CO_2. Recently, a group from MIT demonstrated a proof-of-concept electrochemical calcination where water and limestone react in a low temperature H-cell based on a bipolar membrane[3] (where the two electrodes are respectively at acidic and alkaline pH). In this reaction, limestone is converted to calcium hydroxide ($Ca(OH)_2$), which requires less energy to convert to CaO to produce the alite. At the same time hydrogen, oxygen, and CO_2 are also produced. The oxygen and CO_2 can be recycled in fuel cell technology, while the stream of CO_2 can be converted to a useful product through electrolytic processes. This work is relevant to demonstrate the feasibility of the reaction, however, the approach of the H-cell is limited to very low voltage efficiencies and, since it is a batch reaction, to low production volumes.

> *"Cement production emits up to 8% of total world CO_2 emissions, consumes 5% of the total energy using fossil fuels, and is the largest source of industrial CO_2 emissions worldwide[1,2]"*

NFCRC Associate Director Prof. Iryna Zenyuk and Prof. Mo Li received a $500,000 National Science Foundation (NSF) award from the Future of Manufacturing program to enable electrochemically-produced cement at scale. The team has filed a provisional patent on their innovation of using a bipolar electrolyzer to produce calcium hydroxide and co-produce value-added chemicals, such as hydrogen or to convert CO_2. The experimental team led by Dr. Andrea Perego designed a reactor based on a bipolar electrolyzer build with the goal of enabling batch production of cement. From a traditional bipolar electrolyzer design (Figure 1a): calcium carbonate is dispersed in acid and fed to the anode side and the reactions that occur are the following:

$$H_2O = {}^1/_2O_2 + 2H^+ + 2e^-$$

$$CaCO_3 \leftrightarrow CO_3^{2-} + Ca^{2+}$$

while at the cathode, hydrogen evolution in alkaline medium will occur:

$$2H_2O + 2e = 2H_2 + {}^1/_2O_2$$

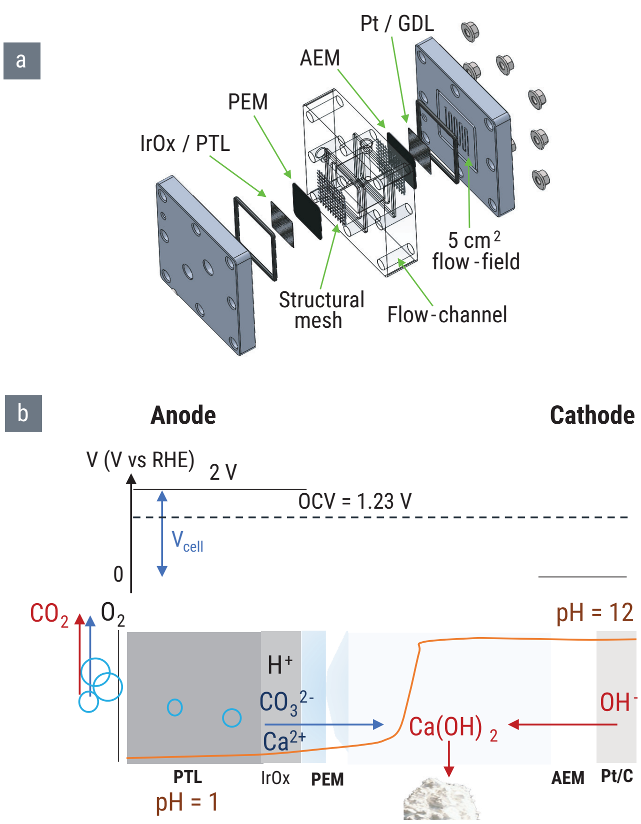


Figure 1

a) Drawing of the first iteration of the cement electrolyzer

b) Schematic of the reaction and pH gradient through the cell

Figure 1 shows a schematic of the reactor and photographs of various components, as well as the overall reaction schematic. The project has a goal of achieving high efficiency of calcium hydroxide generation at scale. The process is similar to the industrially scaled process of caustic soda generation with chlor-alkali. Prof. Zenyuk's team is responsible for $Ca(OH)_2$ generation, whereas Prof. Li will use a high temperature process to further synthesize cement from $Ca(OH)_2$.

This project will reduce CO_2 emissions from the cement production industry because the reaction occurs at a low temperature and does not include fossil fuels to heat the reactor. Furthermore, the emitted CO_2 can be easily collected as it will be concentrated down the stream. Lastly, the electrolyzer reactor can be adopted to convert CO_2 into value-added products.

References

1. Andrew, R. M. Global CO_2; emissions from cement production. *Earth Syst. Sci. Data Discuss.* 1–52 (2017) doi:10.5194/essd-2017-77.
2. Schneider, J. Decarbonizing construction through carbonation. *Proc. Natl. Acad. Sci.* 201913867 (2019) doi:10.1073/pnas.1913867116.
3. Ellis, L. D., Badel, A. F., Chiang, M. L., Park, R. J.-Y. & Chiang, Y.-M. Toward electrochemical synthesis of cement—An electrolyzer-based process for decarbonating $CaCO_3$ while producing useful gas streams. *Proc. Natl. Acad. Sci.* 201821673 (2019) doi:10.1073/pnas.1821673116.

Emissions from Stationary Power Applications Using Hydrogen

It has been well established that fossil fuels are the primary contributor when it comes to greenhouse gas (GHG) pollutant emissions or, more specifically, carbon dioxide emissions. For this reason, research into renewable energy sources, such as biomass and wind, have gained significant momentum. However, even with the current push for ongoing research and development for sole reliance on renewables to combat the effects of GHG emissions and ultimately climate change, current projections still show 78% fossil fuel usage globally in 2040[1]. Between the future fossil fuel usage predictions and the ambitious goal of achieving emissions 80% below 1990 levels by 2050 in the state of California, the demand to retrofit current fossil fuel combustion processes is essential[2].

"Introducing renewable hydrogen into the pipeline would decrease the amount of fossil fuel use and provide a massive resource for storage of renewable electricity."

One such method looks at the blending of a carbon-free fuel, in this case hydrogen, with natural gas. Traditionally, hydrogen is generated from fossil fuels, via gasification of solid fuels or reforming of methane. In the recent years, hydrogen generation from renewable resources, such as solar energy, biomass, wind power and splitting water by electrolysis, has gained interest. Introducing renewable hydrogen into the pipeline would decrease the amount of fossil fuel use and provide a massive resource for storage of renewable electricity. There have been studies which look at the flame behavior when using hydrogen/natural gas blends; however, there is a gap in research related to how the pollution control units downstream of the combustion unit would be impacted by fuel blending. UC Irvine Combustion Laboratory (UCICL) Associate Director, Professor Bihter Padak, has partnered with the Southern California Gas Company to work on selective catalytic reduction (SCR) of nitrogen oxides (NO_x) for stationary power applications.

Selective catalytic reduction of NO_x is used in several applications such as gas-fired utility boilers, coal-fired boilers, oil-fired boilers, process heaters, gas turbines and stationary engines. The SCR process aims to convert nitrogen oxides (NO and NO_2) to nitrogen and water on the surface of a catalyst by reacting with ammonia. In this project, performance of SCR catalysts will be tested to simulate different stationary power applications, such as gas-fired utility boilers, gas turbines, gas-fired reciprocating engines and process heaters, using hydrogen/natural gas blends. The results from this project will provide power plants further insight into optimal SCR parameters to further progress the transition into emissions-conscientious processes.

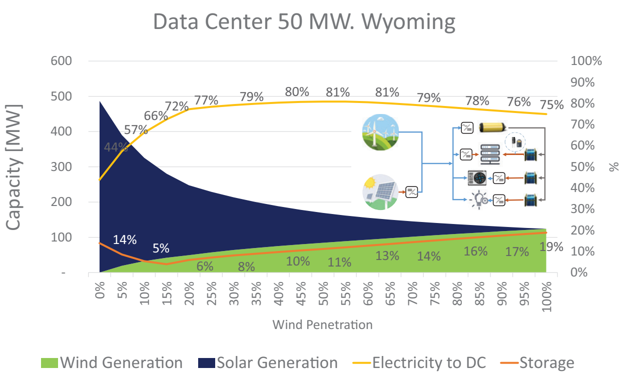
References

1. J. Conti, P. Holtberg, J. Diefenderfer, A. LaRose, J. T. Turnure and L. Westfall, "International Energy Outlook 2016 With Projections to 2040", Report DOE/EIA-0484(2016), United States, 2016.

2. California Legislative Information. Assembly bill No. 32 air pollution: greenhouse gases: California global warming solutions act of 2006. https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=200520060AB32.

100% Renewable Data Centers

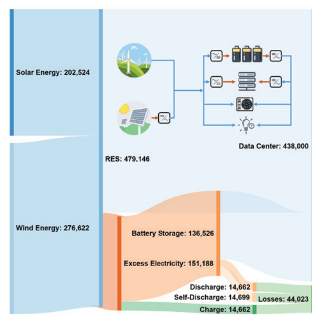
Electricity demand is increasing around the world and is directly linked to the growth of the information and communication technology sector. This sector already accounts for more than 2.3% of global greenhouse gas (GHG) emissions, 28.8% of which come from data centers. Energy use forecasts indicate that by 2030, data centers could account for 3–13% of global electricity demand. Efforts to decrease energy conversion in data centers have focused upon facility and cooling energy efficiency, equipment efficiency improvements, and shifting to low GHG emitting energy sources.



Today, the most common use of renewable and low GHG emissions energy sources for data center applications is accomplished by grid delivered and purchased renewable electricity or credits. Some data centers have installed fuel cell systems to lower emissions of both GHG and criteria air pollutants. Some data centers have installed local renewable energy generators complemented by the utility grid network. Importantly, all of these designs still rely on the use of diesel backup generator systems.

Microsoft Corporation is supporting NFCRC research to explore the design and operation of a completely zero-emissions data center powered directly and exclusively with renewable energy while achieving the reliability that is required. The current collaboration investigates data center locations' impact on energy consumption, with the generation system sizing based upon the renewable sources selected, measured renewable solar and wind power dynamics, the electricity supply chain architecture, and different energy conversion and storage technologies.

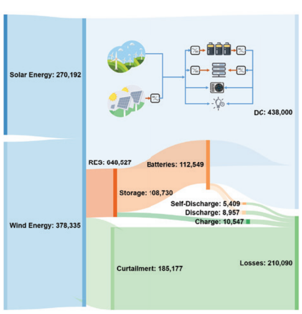
> *"Each of the data center's designs are simulated to operate in different regions of the United States and optimized for different objectives, such as...minimum land and capital, and levelized costs."*



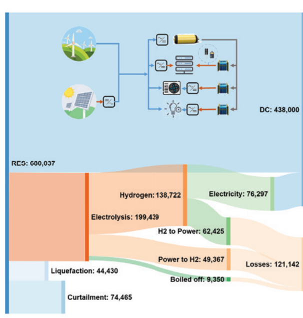
Battery Storage System
No curtailment. Energy Flows.

The NFCRC team has developed and applied optimization tools and software for dynamic mass and energy balance calculations to design data center power systems using annual hourly resolved solar and wind dynamics, together with technological capabilities, features, and constraints of various energy storage system technologies (batteries and hydrogen). Seven designs are developed and simulated to meet data center dynamic demand for 100% renewable data centers in 5 climatic regions of the United States.

Each of the 100% renewable data center designs are optimized for different objectives, such as minimum size of storage, minimum renewable generation capacity installed, maximum amount of direct use of electricity (generation to data center), minimum land and capital, and minimum levelized cost. The data center designs also explore the effects of electricity curtailment, impacts regarding the selection of wind and solar ratios, and impacts on generation systems and costs given different technologies and constraints of the storage systems.



Battery Storage System
No curtailment. Energy Flows.



Hydrogen Storage System
Excess Power to Gas Energy Flows

Preliminary results provide the important insight that wind and solar ratios can be tuned to decrease the size of the storage and/or increase the direct use of electricity. Also, seasonal storage is necessary to supply the data center with 100% of the electricity it requires throughout a year, leading to the fact that hydrogen energy storage systems always produce lower levelized cost of electricity to 100% renewable data centers.

Hydrogen is Important for Equity!

Concerns over the environmental, health, and social effects of continued fossil fuel use require a transition to a zero-carbon and zero-pollutant emissions energy system. From a technology standpoint, this will entail changing the energy resources and associated transmission, distribution, and conversion infrastructure that we use to provide the energy services that we depend upon. There are many possible technological pathways for building a zero-emission energy system. These pathways, however, are not equivalent in terms of how they distribute the environmental, social, and economic benefits of the energy system transformation. The transition to a zero-emission energy system also provides the opportunity to mitigate historical harms of fossil fuel infrastructure and technology to increase access to high quality energy services and decrease environmental and health impacts in historically disadvantaged communities. In choosing the methods by which we build a zero-carbon energy system, it is not enough to reduce greenhouse gas and pollutant emissions; we must strive to maximize the societal co-benefits of this transition. As an example, a key energy service that is critically important to disadvantaged communities is the provision of backup power services during extreme weather events or other contingencies. Electrochemical technologies such as batteries, electrolyzers, fuel cells, and hydrogen storage can serve as critical buffers for communities during times of outage. Underground delivery of renewable fuel will increase energy resiliency and reliability in all neighborhoods, especially those vulnerable to extreme weather events. Finally, the heavy duty (e.g., trucking, trains, ships, aviation) and industrial sectors, which emit pollutants that affect primarily disadvantaged communities, can best be decarbonized and made zero emissions using renewable hydrogen and its derivatives. Hydrogen is important for equity!

“Underground delivery of renewable fuel will increase energy resiliency and reliability in all neighborhoods, especially those vulnerable to extreme weather events”

Photo courtesy of the Port of Los Angeles, www.portoflosangeles.org/about/news-and-media/photo-gallery

Graduates and Internships

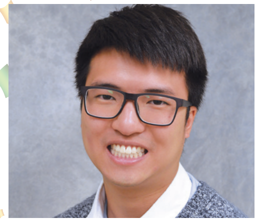
2020-2021 Master of Science Graduates

Amber Fong
Renewable Hydrogen Production Pathways from Biomass via Anaerobic Digestion for California

Emily Dailey
A Temporal and Spatial Evolution of the California Renewable Hydrogen Production Network Based on a Least-Cost Planning Framework

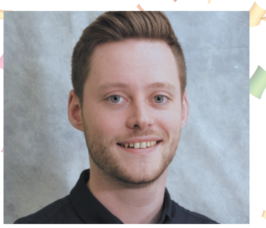
Breyah Matthews
Self-Healing Microgrids

Jae Hwan Yi
Minimizing the Cost of Charging Plug-In Vehicles through Smart Charging



Chun Yin Chan
Development and Techno-Economic Analysis of SOFC-GT Hybrid Systems Employing Renewable Hydrogen for Stationary Applications and LNG for Mobile Applications

2020-2021 Ph.D. Graduates



Scott Leask
Dynamical Feature Extraction of Atomization Phenomena Using Deep Koopman Analysis

Prantik Saha
Electric Double Layer at Metal-Electrolyte Interface: A Combined Electrokinetic-Electrochemical Method of Study

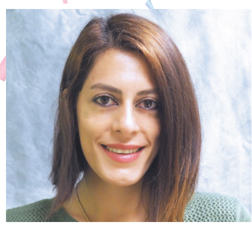
Fabian Rosner
Design and Thermo-Economic Analyses of Solid Oxide Fuel Cell-Gas Turbine Hybrid Systems with Water Recovery

Sarah Wang
Use of Excess Renewable Electricity Generation to meet Future California Stated System Goals

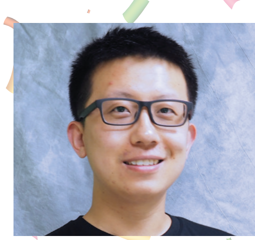
Daniel Jaimes
Novel Combustion Challenges Associated with High Pressure and High Temperature Solid Oxide Fuel Cell/Gas Turbine Hybrid Systems

Philipp Ahrend
Solid Oxide Fuel Cell Hybrid Systems for Dynamic Rail Applications

Alireza Saeedmanesh
Advanced Solid Oxide Electrolysis Cell (SOEC) and Systems Technology for Widespread Use with Renewable Energies



Zahra Heydarzadeh
Pressure and Flow Dynamics of the Natural Gas System for Hydrogen Gas Use



Yan Zhao
Impact of Increased Renewable Gases in Natural Gas on Combustion Performance of Self-aspirating Flames

2020-2021 Internships

Alejandro Lavernia
Tri-Alpha Energy (TAE) Incorporated
(Summer 2021)

Maryam Asghari
Environmental Defense Fund (EDF) Climate Corps Fellow
(Summer 2021)

Prantik Saha
Robert Bosch LLC
Sunnyvale, CA
(6 Months)

2020

FLOW BATTERY PRODUCTION: MATERIALS SELECTION AND ENVIRONMENTAL IMPACT (2020). Journal of Cleaner Production, 269, 121740 (H. He, S. Tian, B. Tarroja, O.A. Ogunseitan, S. Samuelsen, J.M. Schoenung).

ELECTROKINETIC STREAMING CURRENT METHOD TO PROBE POLYCRYSTALLINE GOLD ELECTROLYTE INTERFACE UNDER APPLIED POTENTIALS (2020). Journal of Electrochemical Society, 168, 046511 (P. Saha & I.V. Zenyuk).

GRAPHITE INTERCALATION COMPOUNDS DERIVED BY GREEN CHEMISTRY AS OXYGEN REDUCTION REACTION CATALYSTS (2020). ACS Applied Materials & Interfaces, 12, 42678-42685 (J. Zhao, J.H. Dumont, J. Maccossay, K. Artyushkova, U. Martinez, P. Atanassov, G. Gupta).

PERFORMANCE OF A HYDROGEN REFUELING STATION IN THE EARLY YEARS OF COMMERCIAL FUEL CELL VEHICLE DEPLOYMENT (2020). International Journal of Hydrogen Energy, 45(56), 31341-31352 (S. Samuelsen, B. Shaffer, J. Grigg, B. Lane, J. Reed).

NEURAL-NETWORK-BASED OPTIMIZATION FOR ECONOMIC DISPATCH OF COMBINED HEAT AND POWER SYSTEMS (2020). Applied Energy, 265, 114785 (M.J. Kim, T.S. Kim, R.J. Flores, J. Brouwer).

(PGM)-FREE Fe-N-C CATALYSTS FOR PEM FUEL CELLS (2020). Energy & Environmental Science, 13, 2480-2500 (M. Primbs, Y. Sun, A. Roy, D. Malko, A. Mehmood, M.T. Sougrati, P.Y. Blanchard, G. Granozzi, T. Kosmala, G. Daniel, P. Atanassov, J. Sharman, C. Durante, A. Kucernak, D. Jones, F. Jaouen, P. Strasser).

ENERGY AND ECONOMIC ASSESSMENT OF DISTRIBUTED RENEWABLE GAS AND ELECTRICITY GENERATION IN A SMALL DISADVANTAGED URBAN COMMUNITY (2020). Applied Energy, 280, 115974 (R.E. Silverman, R.J. Flores, J. Brouwer).

ELECTROCHEMICAL TOP-DOWN SYNTHESIS OF C-SUPPORTED Pt NANOPARTICLES WITH CONTROLLABLE SHAPE AND SIZE: MECHANISTIC INSIGHTS AND APPLICATION (2020). Nano Research, 1-8 (B. Garlyyev, S. Watzele, J. Fichtner, J. Michalicka, A. Schokel, A. Senyshyn, A. Perego, D. Pan, H.A. El-Sayed, J.M. Macak, P. Atanassov, I.V. Zenyuk, A.S. Bandarenka).

FACILE ALL-OPTICAL METHOD FOR IN SITU DETECTION OF ULTRALOW AMOUNTS OF AMMONIA (2020). iScience (Y. Liu, T. Asset, Y. Chen, E. Murphy, E.O. Potma, I. Matanovic, D.A. Fishman, P. Atanassov).

ESTIMATING THE TECHNICAL FEASIBILITY OF FUEL CELL AND BATTERY ELECTRIC VEHICLES FOR THE MEDIUM AND HEAVY DUTY SECTORS IN CALIFORNIA (2020). Applied Energy, 276, 115439 (K. Forrest, M. Mac Kinnon, B. Tarroja, S. Samuelsen).

EFFECT OF ACTIVE SITES POISONING ON Fe-N-C ORR PLATINUM GROUP METAL-FREE CATALYSTS OPERATING IN NEUTRAL MEDIA: A ROTATING DISK ELECTRODE STUDY (2020). ChemElectroChem, 7, 3044-3055 (V.C.A. Ficca, C. Santoro, A. D'Epifanio, S. Licoccia, A. Serov, P. Atanassov, B. Mecheri).

DATA AND ANALYSIS TOOLBOX FOR MODELING THE NEXUS OF FOOD, ENERGY, AND WATER (2020). Sustainable Cities and Society, 61, 102281 (M. Sadegh, A. AghaKouchak, I. Mallakpour, L.S. Huning, O. Mazdiyasni, M. Niknejad, E. Foufoula-Georgiou, F.C. Moore, J. Brouwer, A. Farid, M.R. Alizadeh, A. Martinez, N.D. Mueller, S.J. Davis).

WATER MANAGEMENT STRATEGIES FOR PGM-FREE CATALYST LAYERS FOR POLYMER ELECTROLYTE FUEL CELLS (2020). In Press, Current Opinion in Electrochemistry (P. Satjaritanun & I.V. Zenyuk).

IDENTIFICATION OF DURABLE AND NON-DURABLE FeNx SITES IN Fe-N-C MATERIALS FOR PROTON EXCHANGE MEMBRANE FUEL CELLS (2020). Nature Catalysis, 4(1), 10-19 (J. Li, M.T. Sougrati, A. Zitolo, J.M. Ablett, I.C. Oguz, T. Mineva, I. Matanovic, P. Atanassov, Y. Huang, I.V. Zenyuk, A. Di Cicco, K. Kumar, L. Dubai, F. Maillard, F. Jaouen).

DEVELOPMENT OF LOW TEMPERATURE FUEL CELL HOLDERS FOR OPERANDO X-RAY MICRO AND NANO COMPUTED TOMOGRAPHY TO VISUALIZE WATER DISTRIBUTION (2020). Journal of Physics Energy, 2(4), 044005 (D. Kulkarni, S.J. Normile, Y. Huang, L.G. Connolly, I.V. Zenyuk).

TOWARDS DEFECT ENGINEERING IN HEXAGONAL MoS_2 NANOSHEETS FOR TUNING HYDROGEN EVOLUTION AND NITROGEN REDUCTION REACTIONS (2020). Applied Materials Today, 21, 10081 (I. Matanovic, K. Leung, S. Percival, J.E. Park, P. Lu, P. Atanassov, S.S. Chou).

MAPPING OF HETEROGENEOUS CATALYST DEGRADATION IN POLYMER ELECTROLYTE FUEL CELLS (2020). Advanced Energy Materials, 10(28), 2000623 (L. Cheng, K. Khedekar, M. Rezaei Talarposhti, A. Perego, M. Metzger, S. Saravanan, S. Stewart, P. Atanassov, N. Tamura, N. Craig, I.V. Zenyuk, C. Johnston).

CHARACTERIZING COMPLEX GAS-SOLID INTERFACES WITH IN SITU SPECTROSCOPY: OXYGEN ADSORPTION BEHAVIOR ON Fe-N-C CATALYSTS (2020). Journal of Physical Chemistry C, 124, 16529-16543 (M.J. Dzara, K. Artyushkova, M.T. Sougrati, C. Ngo, M.A. Fitzgerald, A. Serov, B. Zulevi, P. Atanassov, F. Jaouen, S. Pylypenko).

ASSESSING CONCURRENT EFFECTS OF CLIMATE CHANGE ON HYDROPOWER SUPPLY, ELECTRICITY DEMAND, AND GREENHOUSE GAS EMISSIONS IN THE UPPER YANGTZE RIVER BASIN OF CHINA (2020). Applied Energy, 279, 115694 (P. Qin, H. Xu, M. Liu, C. Xiao, K. Forrest, S. Samuelsen, B. Tarroja).

PLATINUM GROUP METAL-FREE OXYGEN REDUCTION ELECTROCATALYSTS EMPLOYED IN NEURAL ELECTROLYTES FOR BIO-ELECTROCHEMICAL REACTORS APPLICATIONS (2020). Current Opinion in Electrochemistry, 23, 106-113 (C. Santoro, A. Serov, K. Artyushkova, P. Atanassov).

OBSERVATION OF PREFERENTIAL PATHWAYS FOR OXYGEN REMOVAL THROUGH POROUS TRANSPORT LAYERS OF POLYMER ELECTROLYTE WATER ELECTROLYZERS (2020). iScience, 23(12), 101783 (P. Satjaritanun, M. O'Brien, D. Kulkarni, S. Shimpalee, C. Capuano, K.E. Ayers, N. Danilovic, D.Y. Parkinson, I.V. Zenyuk).

INVESTIGATING LIQUID WATER TRANSPORT IN DIFFERENT PORE STRUCTURE OF GAS DIFFUSION LAYERS FOR PEMFC USING LATTICE BOLTZMANN METHOD (2020). In press, Journal of Electrochemical Society, 167(10) (M. Sepe, P. Satjaritanun, S. Hirano, I.V. Zenyuk, N. Teppayawong, S. Shimpalee).

THERMO-ECONOMIC ANALYSES OF ISOTHERMAL WATER GAS SHIFT REACTOR INTEGRATIONS INTO IGCC POWER PLANT (2020). Applied Energy, 227, 115500 (F. Rosner, Q. Chen, A. Rao, S. Samuelsen).

CATHODE CATALYSTS BASED ON COBALT AND NITROGEN-DOPED NANOCARBON COMPOSITES FOR ANION EXCHANGE MEMBRANE FUEL CELLS (2020). ACS Applied Energy Materials, 3, 5375-5384 (J. Lilloja, E. Kibena-Põldsepp, A. Sarapuu, M. Kodali, Y. Chen, T. Asset, M. Käärik, M. Merisalu, P. Paiste, J. Aruväli, A. Treshchalov, J. Leis, V. Sammelselg, St. Holdcroft, P. Atanassov, K. Tammeveski).

FUEL CELL TRANSMISSION INTEGRATED GRID ENERGY RESOURCES TO SUPPORT GENERATION-CONSTRAINED POWER SYSTEMS (2020). Applied Energy, 276, 115485 (L. Novoa, R. Neal, S. Samuelsen, J. Brouwer).

PATHWAY TO COMPLETE ENERGY SECTOR DECARBONIZATION WITH AVAILABLE IRIDIUM RESOURCES USING ULTRA-LOW LOADED WATER ELECTROLYZERS (2020). ACS Applied Materials Interfaces, 12(47), 52701-52712 (Z. Taie, X. Peng, D. Kulkarni, I.V. Zenyuk, A.Z. Weber, C. Hagen, N. Danilovic).

IRON (II) PHTHALOCYANINE (FePc) OVER CARBON SUPPORT FOR OXYGEN REDUCTION REACTION ELECTROCATALYSTS OPERATING IN ALKALINE ELECTROLYTE (2020). Journal of Solid-State Electrochemistry (M.A. Costa de Oliveira, R. Gokhale, C. Santoro, B. Mecheri, A. D'Epifanio, S. Licoccia, P. Atanassov).

MARGINAL METHANE EMISSION ESTIMATION FROM THE NATURAL GAS SYSTEM (2020). Applied Energy, 277, 115572 (Z. Heydarzadeh, M. Mac Kinnon, C. Thai, J. Reed, J. Brouwer).

IRON-NITROGENCARBON CATALYSTS FOR PROTON EXCHANGE MEMBRANE FUEL CELLS (2020). Joule, 4, 33-44 (T. Asset & P. Atanassov).

CONFINEMENT EFFECTS FOR NANO-ELECTROCATALYSTS FOR OXYGEN REDUCTION REACTION (2020). Current Opinion in Electrochemistry, 25, 100634 (A. Avid & I.V. Zenyuk).

HIDDEN IN PLAIN SIGHT: UNLOCKING THE FULL POTENTIAL OF CYCLIC VOLTAMMETRY WITH THE THIN-FILM ROTATING (RING) DISK ELECTRODE STUDIES FOR THE INVESTIGATION OF OXYGEN REDUCTION REACTION ELECTROCATALYSTS (2020). Current Opinion in Electrochemistry, 25, 100626 (V. Di Noto, E. Negro, A. Nale, G. Pagot, K. Vezzù, P. Atanassov).

USING OPERANDO TECHNIQUES TO UNDERSTAND AND DESIGN ALKALINE MEMBRANE FUEL CELLS WITH EXCELLENT PERFORMANCE AND LONG OPERATIONAL STABILITY (2020). Nature Communications, 11(1), 1-10 (X. Peng, D. Kulkarni, Y. Huang, T.J. Omasta, B. Ng, L. Wang, J.M. LaManna, D.S. Hussey, J. Varcoe, I.V. Zenyuk, W.E. Mustain).

INTEGRATING NANOSTRUCTURED Pt-BASED ELECTROCATALYSTS IN PROTON EXCHANGE MEMBRANE FUEL CELLS (2020). Journal of Power Sources, 478, 228516 (A. Ly, T. Asset, P. Atanassov).

2021

EVALUATION OF A TURBULENT JET FLAME FLASHBACK CORRELATION APPLIED TO ANNULAR FLOW CONFIGURATIONS WITH AND WITHOUT SWIRL (2021). Paper GTP-20-1566, to appear, Journal of Engineering for Gas Turbines and Power (E. Sullivan Lewis, V.G. McDonell, A. Kalantari, P. Saxena).

SELF-ANCHORED PLATINUM DECORATED ON ANTIMONY-DOPED-TIN OXIDE IS A DURABLE OXYGEN REDUCTION ELECTROCATALYST (2021). ACS Catalysis (C. He, A. Ells, S. Sankarasubramanian, J. Parrondo, C. Gumeci, M. Kodali, I. Matanovic, A.K. Yadav, K. Bhattacharyya, N. Dale, P. Atanassov, V.K. Ramani).

DYNAMICS OF HIGH PENETRATION PHOTOVOLTAIC SYSTEMS IN DISTRIBUTION CIRCUITS WITH LEGACY VOLTAGE REGULATION DEVICES (2021). International Journal of Electrical Power and Energy Systems, 124, 106388 (G. Razeghi, J. Payne, F. Gu, J. Brouwer, S. Samuelsen).

MAPPING TRANSITION METAL-MN4 MACROCYCLIC COMPLEX CATALYSTS PERFORMANCE FOR THE CRITICAL REACTIVITY DESCRIPTORS (2021). Current Opinion in Electrochemistry, 27, 1000683 (J. Zagal, S. Specchia, P. Atanassov).

HYBRID LATTICE BOLTZMANN AGGLOMERATION METHOD FOR MODELING TRANSPORT PHENOMENA IN POLYMER ELECTROLYTE MEMBRANE FUEL CELLS (2021). Journal of Electrochemical Society, 168, 044508 (P. Satjaritanun, F.C. Cetinbas, S.Hirano, I.V. Zenyuk, R.K. Ahluwalia, S. Shimpalee).

AN EPISODIC ASSESSMENT OF VEHICLE EMISSION REGULATIONS ON SAVING LIVES IN CALIFORNIA (2021). Environmental Science and Technology, 55, 547-552 (S. Samuelsen, S. Zhu, M. Mac Kinnon, O.K. Yang, J. Brouwer, D. Dabdub).

CATALYSTS BY PYROLYSIS: DIRECT OBSERVATION OF CHEMICAL AND MORPHOLOGICAL TRANSFORMATIONS LEADING TO TRANSITION METAL-NITROGEN-CARBON MATERIALS (2021). In Press, Materials Today (Y. Huang, Y. Chen, M. Xu, T. Asset, P. Tieu, A. Gili, D. Kulkarni, V. De Andrade, F. De Carlo, H. Barnard, A. Doran, D.Y. Parkinson, X. Pan, P. Atanassov, I.V. Zenyuk).

MODAL EXTRACTION OF SPATIO-TEMPORAL ATOMIZATION DATA USING A DEEP CONVOLUTIONAL KOOPMAN NETWORK (2021). Physics of Fluids, 33(3), 033323 (S.B. Leask, V.G. McDonell, S. Samuelsen).

CATALYTIC HYBRID ELECTROCATALYTIC/BIOCATALYTIC CASCADES FOR CARBON DIOXIDE REDUCTION AND VALORIZATION (2021). ACS Catalysis, 11, 5172-5188 (S. Guo, T. Asset, P. Atanassov).

CHALLENGES ESTIMATING DISTRIBUTED SOLAR POTENTIAL WITH UTILIZATION FACTORS (2021). Applied Energy, 282, 116209 (C. Thai & J. Brouwer).

$Ni(OH)_2$-FREE NiCu AS A HYDROGEN EVOLUTION AND OXIDATION ELECTROCATALYST (2021). Electrochemistry Communications, 125, 106999 (M.R. Talarposhti, T. Asset, A. Roy, K. Artyushkova, L.-K. Tsui, F.H. Garzon, A. Serov, P. Atanassov).

NEURAL NETWORK PREDICTION OF BOUNDARY LAYER FLASHBACK (2021). Journal of Engineering for Gas Turbines and Power, 143(5), 054501 (S.B. Leask, V.G. McDonell, S. Samuelsen).

INTERPRETING IONIC CONDUCTIVITY FOR POLYMER ELECTROLYTE FUEL CELL CATALYST LAYERS WITH ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY AND TRANSMISSION LINE MODELING (2021). Journal of Electrochemical Society, 168(5), 054502 (Y. Qi, J. Liu, D. Sabarirajan, Y. Huang, A. Perego, A.T. Haug, I.V. Zenyuk).

OPTIMAL DER ALLOCATION IN MESHED MICROGRIDS WITH GRID CONSTRAINTS (2021). International Journal of Electrical Power and Energy Systems, 128, 106789 (L. Novoa, R. Flores, J. Brouwer).

MAPPING TRANSITION METAL-NITROGEN-CARBON CATALYSTS PERFORMANCE ON THE CRITICAL DESCRIPTORS DIAGRAM (2021). Current Opinion in Electrochemistry, 27, 1000687 (S. Specchia, P. Atanassov, J. Zagal).

CORRIGENDUM TO INFLUENCE OF HYDROGEN ADDITION TO PIPELINE NATURAL GAS ON THE COMBUSTION [INT J HYDROGEN ENERGY 44 (2019) 12239-12253] & AN INTRODUCTION TO COMBUSTION: CONCEPTS AND APPLICATIONS (3RD EDITION) MCGRAW HILL (2012)] (2021). International Journal of Hydrogen Energy, 46(17), 10586-10588 (Y. Zhao, V. McDonell, S. Samuelsen)

FABRICATION OF PGM-FREE CATALYST LAYER WITH ENHANCED MASS TRANSPORT CHARACTERISTICS VIA ELECTRO-SPRAYING TECHNIQUE (2021). Materials Today Energy, 20, 100641 (Y. Kim, T. Asset, F. Wei, P. Atanassov, M. Secanell, J. Barralet, J.T. Gostick).

Fe-N-C ELECTROCATALYSTS' DURABILITY: EFFECT OF SINGLE ATOMS' MOBILITY AND CLUSTERING (2021). ACS Catalysis, 11, 484-494 (K. Kumar, T. Asset, X. Li, Y. Liu, X. Yan, Y. Chen, M. Mermoux, X. Pan, P. Atanassov, F. Maillard, L. Dubau).

STUDY ON THE IMPACT OF CATHODE CATALYST LAYER LOADING ON THE OPEN CIRCUIT VOLTAGE IN A PROTON EXCHANGE MEMBRANE FUEL CELL (2021). Journal of Electrochemical Society, 168, 044519 (M. Moore, S. Shukla, S. Voss, K. Karan, A.Z. Weber, I.V. Zenyuk, M. Secanell).

NEW GENERATION OF ALUMINUM-AIR BATTERIES: CRITICAL ADVANCES IN ALLOYS, ELECTROLYTES AND DESIGN (2021). Journal of Power Sources (R. Buckingham, T. Asset, P. Atanassov).

THE ROLE OF FUEL CELLS IN PORT MICROGRIDS TO SUPPORT SUSTAINABLE GOODS MOVEMENT (2021). Renewable and Sustainable Energy Reviews, 147, 111226 (M.A. Mac Kinnon, G. Razeghi, S. Samuelsen).

PRACTICAL DEMONSTRATION OF APPLICABILITY AND EFFICIENCY OF PLATINUM GROUP METAL-FREE BASED CATALYSTS IN MICROBIAL FUEL CELLS FOR WASTEWATER TREATMENT (2021). Journal of Power Sources, 491, 22958 (S. Babanova, C. Santoro, J. Jones, T. Phan, A. Serov, P. Atanassov, O. Bretschger).

MEASUREMENT OF CONTACT ANGELS AT CARBON FIBER-WATER-AIR TRIPLE-PHASE BOUNDARIES INSIDE GAS DIFFUSION LAYERS USING X-RAY COMPUTED TOMOGRAPHY (2021). ACS Applied Materials and Interfaces, 13(17), 20002-20013 (C.P. Liu, P. Saha, Y. Huang, S. Shimpalee, P. Satjaritanun, I.V. Zenyuk).

TRANSITION METAL CHALCOGENIDES AS VERSATILE AND TUNABLE PLATFORM FOR CATALYTIC CO_2 AND N_2 ELECTRO-REDUCTION (2021). ACS Materials Au (G. Giuffredi, T. Asset, Y. Liu, P. Atanassov, F. Di Fonzo).

HOW COMPARABLE ARE MICROBIAL ELECTROCHEMICAL SYSTEMS AROUND THE GLOBE? AN ELECTROCHEMICAL AND MICROBIOLOGICAL CROSS-LABORATORY STUDY (2021). ChemSuschem (Santoro, S. Babanova, P. Cristiani, K. Artyushkova, P. Atanassov, A. Bergel, O. Bretschger, R. Brown, K. Carpenter, A. Colombo, R. Cortese, B. Erable, F. Harnisch, M. Kodali, S. Phadke, S. Riedl, L.F.M. Rosa, U. Schröder).

IMPACT OF CATALYST LAYER MORPHOLOGY ON THE OPERATION OF HIGH-TEMPERATURE PEM FUEL CELLS (2021). Journal of Power Sources Advances, 7, 1000042 (N. Bevilacqua, T. Asset, M. A. Schmid, H. Markötter, I. Manke, P. Atanassov, R. Zeis).

Highlights of the 2020-2021 Academic Year

100% Renewable Future Video—June 2020
Informational video sponsored by the NFCRC that explains the path to a 100% renewable future by utilizing curtailed renewable energy sources to make hydrogen and also discusses the critical role of fuel cells in the future grid. www.nfcrc.uci.edu/RoadmapVid

Renewable Hydrogen Production Roadmap—June 2020
APEP completed a roadmap for the scaling and build-out of the renewable hydrogen production sector in California to serve a broad range of applications in the energy and transportation sectors.

ICEPAG Hydrogen: A Platform for Sustainability—September 2020
A three-day virtual summit hosted by APEP that brought together global experts from Industry, Government, and Academia to examine and share cutting edge information on real-world, on-the-ground hydrogen technology developments. Major topics included mobility, transportation electrification and storage.

Vojislav Stamenkovic, Ph.D. joins APEP as Inaugural HIMaC^2 Director—October 2020
Dr. Vojislav Stamenkovic, an expert in electrochemical systems for energy conversion and storage, joined APEP on October 1, 2020, and will serve as the inaugural director of UC Irvine's Horiba Institute for Mobility and Connectivity^2 (HIMaC^2).

Tomorrow's World Today—February 2021
APEP Director Jack Brouwer was featured on a segment for Discovery Channel's "Tomorrow's World Today," where he discussed APEP's clean energy research and how renewable hydrogen and fuel cells are powering a clean and zero-emissions future.

2020-2021 Media Outreach Coverage

The 2020-2021 academic year involved several outreach engagements with the media ranging from a feature article on Hydrogen with the New York Times, interviews with: Bloomberg, MIT Technology Review, ABC 7—Los Angeles, San Francisco Chronicle, France 24, San Diego Union Tribune, UCI Podcast, Utility Dive, Cal Matters, and an innovation and sustainability town hall meeting with Assemblywoman Cottie Petrie-Norris.

UCI Grand Slam Finalist—March 2021
APEP graduate student Ying Huang was selected as a UCI Grand Slam finalist for her research on making catalysts in fuel cells less expensive. Ying is also interested in diversifying energy options and decreasing greenhouse gases emissions.

Hot Water Forum—March 2021
The UCICL was represented at the 2021 Hot Water Forum by Research Specialist Dr. Yan Zhao. Dr. Zhao's presentation, "Hydrogen-fueled Impacts on Residential Equipment: Simulation and Testing Results," discussed decarbonizing the gas grid and focused on hydrogen blending for water heating.

American Society of Engineering Education—April 2021
APEP graduate student Alejandra Hormaza-Mejia was named a finalist for the American Society of Engineering Education - Pacific Southwest Section Graduate Student Award for her strong commitment to engineering education. She is currently creating an introductory engineering course for non-engineering students in order to make engineering more accessible to all.

Hydrogen Fuel Cell Boating Vessel—April 2021
APEP has partnered with Zero Emission Industries for a first-of-its-kind hydrogen fuel cell powered small-fast harbor craft. The data collected from the project will inform the most effective path toward eliminating maritime emissions for the small fast vessel market.

U.S. Department of Energy Funding—April 2021
The UCICL received DOE funding for a project that will advance the capability of an existing fossil asset serving the UCI microgrid to store energy in the form of hydrogen and to consume hydrogen as fuel with production and use cycles optimized.

NSF Grant Decarbonization Technologies—May 2021
NFCRC Associate Director Iryna Zenyuk was awarded an International Research Experience for Students (IRES) grant from the National Science Foundation to focus on decarbonization technologies. For 10 weeks each summer, the students participating will travel to Germany to conduct research related to decarbonization of energy sectors and enabling a carbon-free economy.

UC Irvine Hydrogen Refueling Station (Single-Day Record)—May 2021
The UC Irvine hydrogen refueling station reached a new single-day record of 409 kg dispensed into fuel cell electric vehicles on April 29 and 403 kg on May 4.

U.S. Department of Energy Solar District Cup—May 2021
The UC Irvine team led by APEP graduate students won second place in the U.S. Department of Energy Solar District Cup national competition of 2020-2021.

Department of Defense Fellowship—June 2021
APEP graduate student Adrien Steijer received a fellowship from the U.S. Department of Defense that will provide her funding support to understand the processes behind Lithium-ion battery degradation.

Society of Women Engineers, Orange County—June 2021
APEP graduate students Madeline Talebi, Pegah Mottaghizadeh, and Turna Barua were awarded scholarships from the Society of Women Engineers. The scholarship awards application was open to graduate and undergraduate students at universities in Orange County.

UC Irvine Hydrogen Refueling Station Record—June 2021
The UC Irvine hydrogen refueling station dispensed a total of 10,199 kg in the month of May, making it the first time that more than 10,000 kg was dispensed in one month.

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

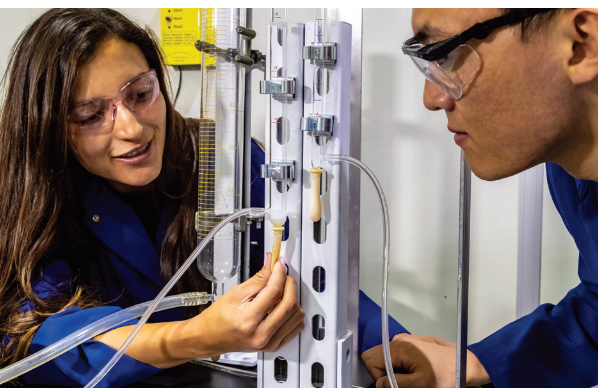
NONPROFIT ORG.
U.S. POSTAGE
PAID
Santa Ana, CA
Permit No. 1106

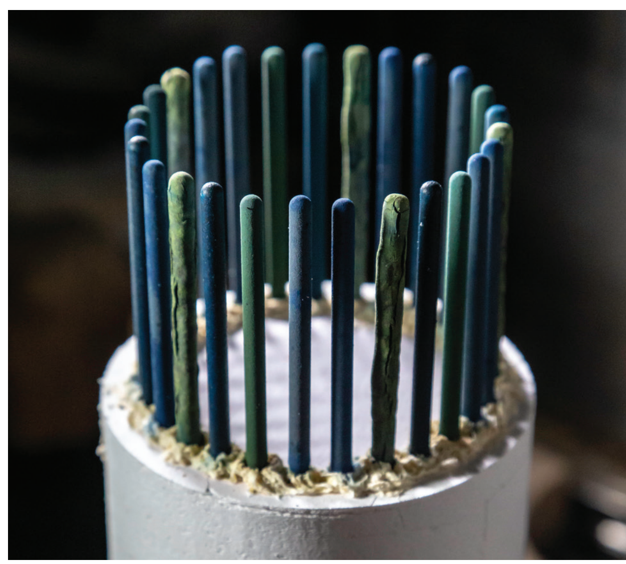
www.apep.uci.edu

The 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.

For additional information, please contact:
William Gary, Manager, Outreach & External Relations
Advanced Power and Energy Program
949 824.7302 x11131, wmg@apep.uci.edu

PRINTED ON RECYCLED PAPER • PRINTED ON RECYCLED PAPER •