Annual Report | Volume 11 | 2023

CLEAN ENERGY INSTITUTE

BRIDGING

Clean Energy for Everything and Everyone

Hydrogen Gas Turbines for Decarbonization

CLEAN ENERGY INSTITUTE
UNIVERSITY OF CALIFORNIA, IRVINE

DIRECTOR'S **MESSAGE**

Professor Jack Brouwer
Director, Clean Energy Institute

I am pleased to report on the Clean Energy Institute launch and the initial successes of the Institute at the University of California, Irvine. Leveraging the talents and skills of our faculty, post-doctoral researchers, students, and staff we have been able to garner unprecedented awards and recognition in 2023.

We are pleased to include two U.S. Department of Energy (DOE) Energy Frontier Research Centers, the Ensembles of Photoelectrochemical Nanoreactors (EPN) directed by Prof. Shane Ardo and the Center for Closing the Carbon Cycle (4C) directed by Prof. Jenny Yang among our affiliated research centers. These important centers join with the National Fuel Cell Research Center (NFCRC), directed by Prof. Iryna Zenyuk, UCI Combustion Laboratory (UCICL), directed by Prof. Vince McDonell, and Horiba Institute for Mobility and Connectivity (HIMaC), directed by Prof. Vojislav Stamenkovic, in our mission to provide clean energy for everything and everyone.

We have established ***"Clean Energy for Everything and Everyone"*** as the motto for the Clean Energy Institute because we know that all applications and end uses must be decarbonized and depolluted to make energy conversion sustainable, and that renewable and clean primary energy is more equitably available to everyone in all nations around the world.

This year, we celebrate the $1.2 billion that the U.S. DOE awarded to the Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES), the California regional hydrogen hub. This award is matched by more than $11.7 billion from the state of California, industry partners, port and transit fees, and private finance to invest almost $13 billion to begin developing hydrogen infrastructure at scale throughout California. We are thankful for unprecedented contributions from faculty, students, and staff throughout every campus of the University of California, from the California Governor's Office, the UC Office of the President, Lawrence Berkeley National Lab, and so many others among the 430 organizations participated in this effort. ARCHES is the largest of the seven regional hydrogen hubs supported by U.S. DOE, through which, together with the production tax credit and investment tax credit passed by Congress and signed into law by the Biden administration, hydrogen and its features will begin to be demonstrated at scale to produce and deliver clean and renewable hydrogen at prices so low it will become the end of fossil fuels.

We are incredibly grateful for the important and impactful work that so many graduates of our program and companies that we have worked and are working with are accomplishing around the world in academia, national labs, industry, entrepreneurialism, advocacy, and consulting. The most important thing that we do is mentor and educate all of you, who change the world and make it a better and more sustainable world for us and our posterity.

In this 11th edition of "**Bridging**," the first in which the Clean Energy Institute features several projects that are developing **clean energy for everything and everyone**, we include: (1) hydrogen for gas turbines, (2) the new director of the NFCRC, Prof. Iryna Zenyuk, (3) the ARCHES award, (4) connected communities, (5) hydrogen electric vehicle research, (6) air quality impacts of CA state policy, (7) the 2023 SoCal Electrochemistry Conference for Students, and more.

We are very proud of our graduate student accomplishments during the 2022-2023 academic year, which includes 5 MS graduates, 5 Ph.D. graduates, and 7 internships with diverse entities such as: **Blue Origin, Naval Air Weapons Station, Southern California Gas Company, and IMI Critical Engineering.**

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

Jack Brouwer

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Hydrogen Gas Turbines are Important for Decarbonization

The 100 Percent Clean Energy Act of 2018 (SB 100) requires California to source 100 percent of electricity from zero-carbon resources. Research conducted by the UCICL in collaboration with Collins Aerospace and Solar Turbines aims to explore the use of hydrogen and hydrogen/natural gas (NG) blends as a replacement for traditional NG within gas turbine engines. About 45% of NG consumption in the state is from power generation; reducing greenhouse gas (GHG) emissions from this sector would allow the state to make significant progress toward its zero-carbon goal.

While the use of hydrogen has some clear benefits, many challenges to its adoption remain. Hydrogen has a higher adiabatic flame temperature (AFT) than NG at the same equivalence ratio, which can lead to an increase in nitrogen oxide (NOx) emissions under certain conditions. Additionally, many modern gas turbine engines employ the use of dry low emissions (DLE) combustors, which premix the fuel and air to reduce the AFT of the reaction and therefore the NOx emissions. Hydrogen combustion increases the risk of flashback, which is when the flame propagates upstream into this premixing chamber, causing possible failure as the laminar flame speed of hydrogen is roughly 5 times greater than NG.

In efforts led by UCICL Director Professor Vince McDonell, the lean direct injection concept was tested at atmospheric conditions to determine its ability to mitigate both flashback and NOx generation. To establish the optimal injector geometry, a Box Behnken design of experiments was used to vary the fuel swirl, air swirl, and air split (the ratio of inner to outer air) amongst 13 additively manufactured Inconel injectors.

It was revealed that an increase in the air swirl and an decrease in the air split led to better mixing of the air and fuel, which leads to smaller and less frequent hot spots within the flame regime. Measured NOx emissions for pure hydrogen were able to reach entitlement levels established for NG combustor designs for a given flame temperature.

Additional testing is being conducted at higher pressures and with clusters of injectors to further evaluate this concept for hydrogen combustion within gas turbines.

Figure 1: Visible Light Image of Lean Direct Injected Hydrogen/Natural Gas Flame

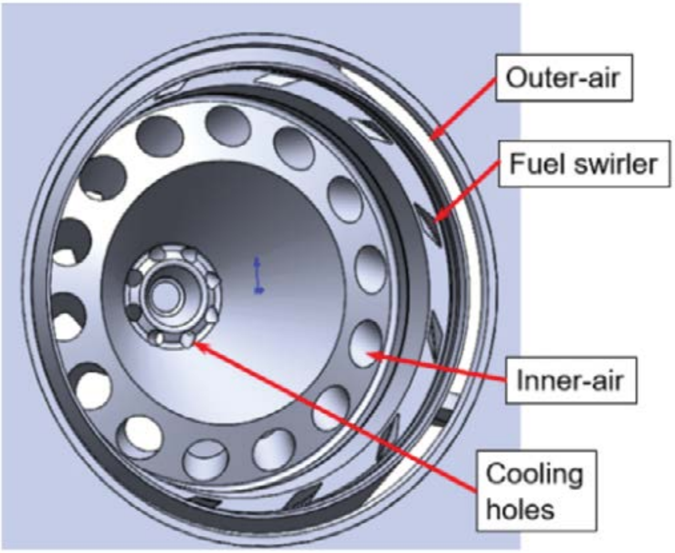


Figure 2: Schematic Drawing of a Collins Aerospace Fuel Injector with the LDI Concept

"Measured NOx emissions for pure hydrogen were able to reach entitlement levels established for NG combustor designs."

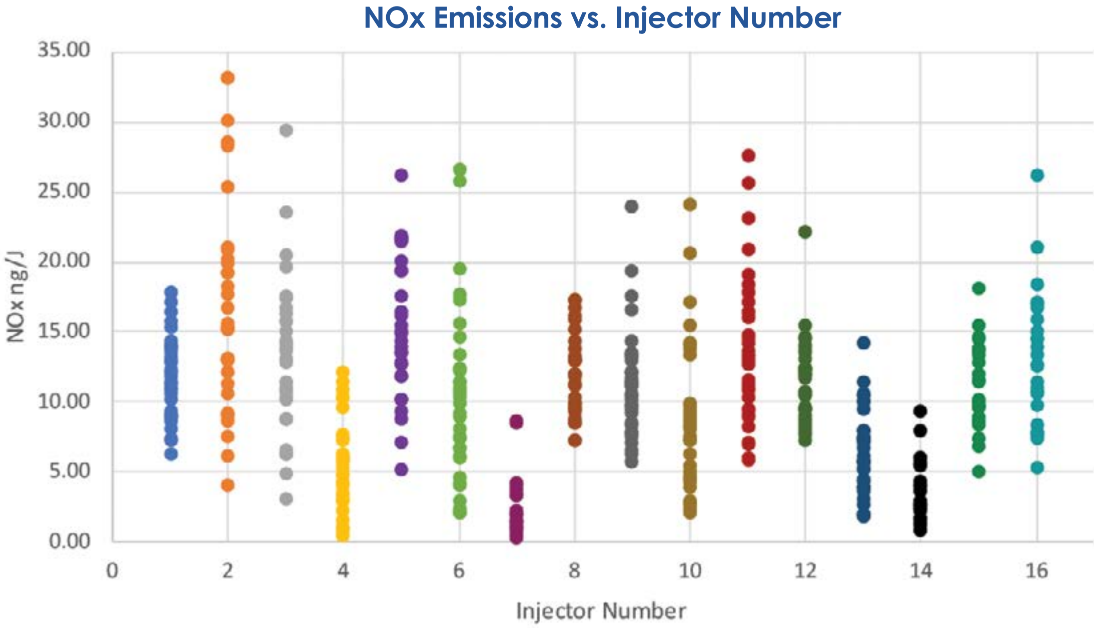
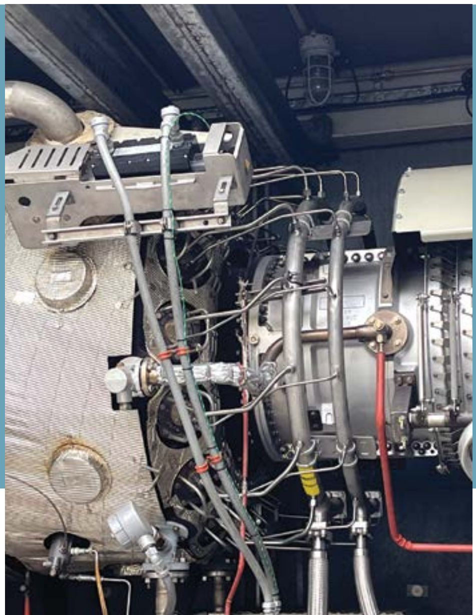


Figure 3: NOx Generation for the Various LDI Injectors



UCI has also been conducting work relative to the operation of practical gas turbines on hydrogen blends. In one example, as much as 4% hydrogen was blended into natural gas, feeding the campus's 13 MW gas turbine during a test campaign. The results illustrated no signficant change in performance or emissions.

In another study, UCI worked with Capstone Green Energy to configure a 65 kW commercial engine to operate on 100% hydrogen. Tests were done in early 2022 and repeated in 2023 and the engine was able to operate from start to full load while maintaining full power output. The work demonstrated that a practical gas turbine can be operated on pure hydrogen with only a change in the fuel injectors. Ongoing work with SoCalGas, EPRI, and the CEC will drive towards NOx emissions that are at or below that attainable with natural gas through changes in the injectors and combustion liner.

Solar Titan 130 Gas Turbine

Physics of **Liquid Films** in Steam Turbines

Steam turbines are widely used to produce electricity from various heat sources. Coupled with gas turbines, the steam turbine is a key part of a combined cycle plant that approaches 65% efficiency. Within the steam turbine, fascinating phenomena occur that remain hidden from the casual observer. Current research at the University of California, Irvine Combustion Laboratory (UCICL) sponsored by Mitsubishi Heavy Industries is investigating the intricate process of water atomization from the edge of a steam turbine blade, unraveling the process of liquid flow and its connection to efficiency.

As viewed through the lens of a high-speed camera, astonishing behavior of liquid gracefully flowing parallel with air on the surface of the turbine blade is observed (Fig. a). The video reveals the beauty of fluid dynamics in action. Of particular interest is the relationship between the liquid film flowing on the surface and its accumulation and atomization downstream along the trailing edge.

By employing different experimental methods, we measured the film thickness, ligament length, and spray concentration. Through careful analysis, we derived the dominant frequencies associated with each of these properties. The findings reveal an astonishing consistency among the dominant frequencies, pointing to a robust link between the variables examined (Fig. b). This discovery provides compelling evidence of the connection between the liquid film, its breakup, and the resulting spray, shedding new light on the underlying dynamics at play.

By comprehending these dynamics, engineers can enhance the performance of steam turbines by designing strategies to minimize droplet sizes and thereby mitigating turbine blade erosion or failure.

Figure B

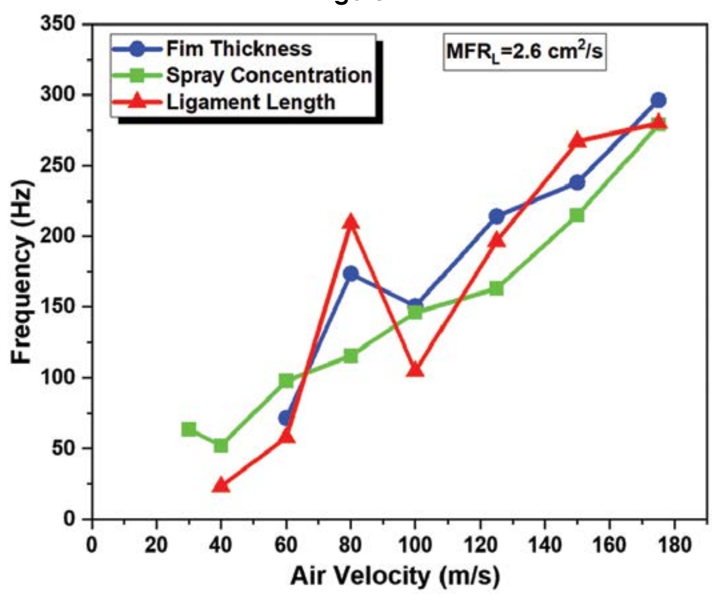
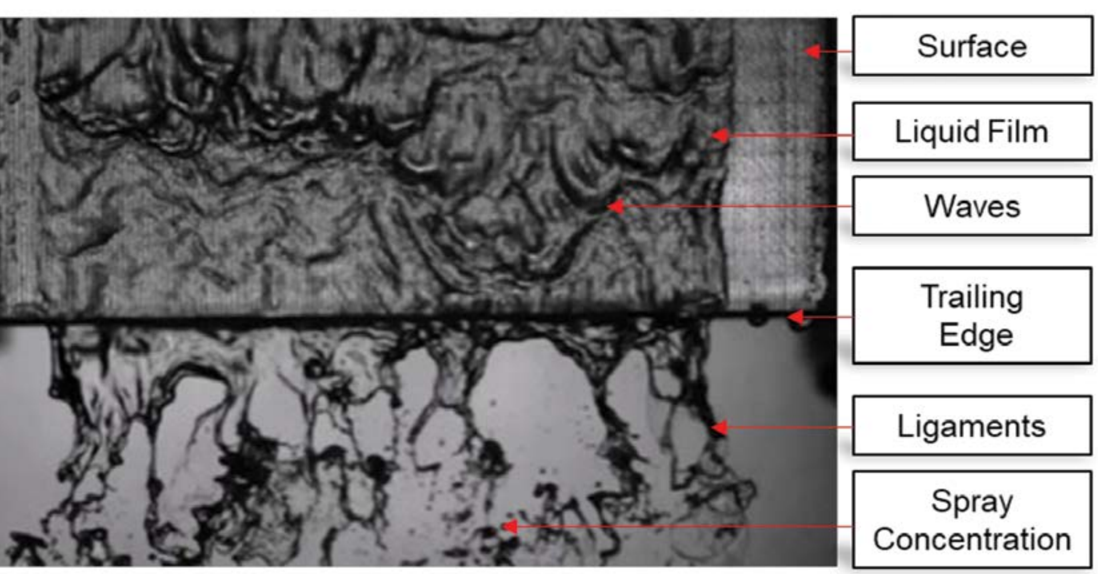


Figure A



Support of the **2022 Scoping Plan** for Carbon Neutrality

During this past year, the Clean Energy Institute supported the California Air Resources Board (CARB) on the most recent update of the Scoping Plan. The Scoping Plan describes the steps across society and the economy to reduce carbon emissions and achieve California climate targets. CARB is required by Assembly Bill 32 to update the Scoping Plan every five years. The 2022 Scoping Plan, released in November 2022 and officially adopted in December 2022, is the third update to the original Scoping Plan approved in 2008.

The 2022 Scoping Plan lays out the sector-by-sector strategy for California to achieve carbon neutrality by 2045, outlining a technologically feasible, cost-effective, and equity-focused path to achieve the state's climate target. Prompted by AB 617 and distinct from previous versions, the 2022 Scoping Plan includes for the first time an assessment of the air pollution health benefits that the Plan will achieve, including a detailed quantification of those benefits occurring within socially and economically disadvantaged communities where they are needed most. Dr. Michael MacKinnon managed this Clean Energy Institute effort in collaboration with Dr. Shupeng Zhu and Professor Scott Samuelsen.

Results show that the measures within the 2022 Scoping Plan would substantially improve air pollution in California and result in annual health benefits of $78 billion in 2035 and $199 billion in 2045. The benefits often coincide with important locations. For example, they are highest in the South Coast Air Basin due to its pre-existing air quality challenges, the significant presence of emission sources, and the large, dense urban population. Notable benefits also occur in the Central Valley, S.F. Bay, Sacramento, and San Diego regions of the state. Most importantly, the plan provides important benefits to populations that live in disadvantaged communities, which will reach $22 billion in 2035 and $61 billion in 2045. These results demonstrate the enormous co-benefits that meeting the State's climate targets will achieve and support the development and deployment of strategies to maximize those benefits in the communities that need it the most.

"…2022 Scoping Plan lays out the sector-by-sector strategy for California to achieve carbon neutrality by 2045…"

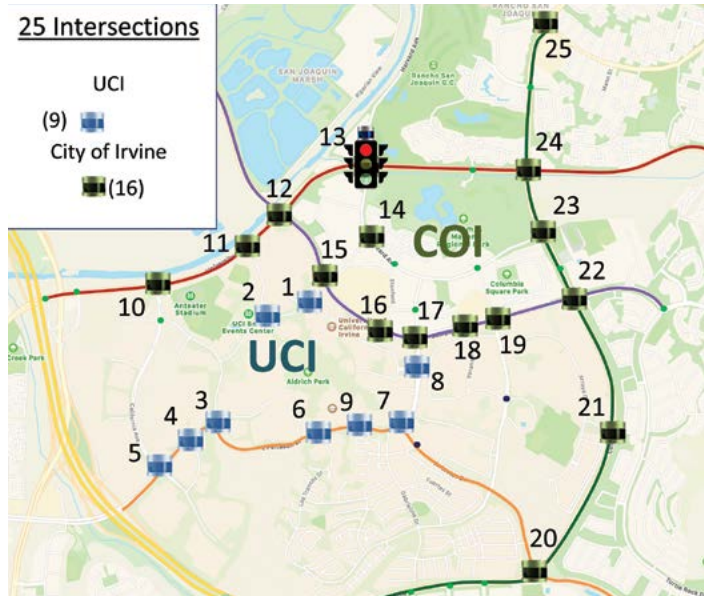
The 2022 Scoping Plan

Governor's Office Summary of the Plan

Connected and Autonomous Vehicle Field Platform

The HORIBA Institute for Mobility and Connectivity (HIMaC), in collaboration with the UCI Institute of Transportation Studies (ITS) and the City of Irvine, has established a Public Road Network Platform comprised of 25 intersections in the City of Irvine and UCI to (1) provide a platform to test and evaluate emerging connected and autonomous vehicle (CAV) technologies; (2) assess the evolution of AI-based mobility monitoring in real-world transportation applications; (3) provide needed insight into key use cases of AI-based systems to enhance energy efficiency and safety; and (4) quantify system-level impact of an AI-based system technology at multiple scales.

"The AI-based CAV technology deployed at each intersection, comprised of an automated mobility monitoring lidar coupled with a data analytics processor, is generating a portfolio of backbone traffic data needed to meet the traffic efficiency, safety, and economic goals to which cities aspire," according to the Principal Investigator, UCI Engineering Professor Scott Samuelsen. "The public-private partnership catapults Irvine as a leading international contributor to the future of connected and autonomous transportation."



The Public Road Network Platform

Funded by the U.S. Department of Energy Vehicle Technology Office, the demonstration pilot encompasses a mult-disciplinary partnership comprised of Ouster (providing the AI-based technology), the Southern California Association of Governments (supporting outreach to cities throughout the region), Saddleback College (supporting the development of workforce training), and Pony.ai (exploring the response of autonomous vehicles to the technology), Kia and Toyota (providing test vehicles), and both the Orange County Transit Authority and UCI Anteater Express (evaluating the impact on transit operations). Professor Vojislav Stamenkovic, HIMaC Director, serves as a co-PI along with Professor Stephen Ritchie, Director of ITS. Dr. Blake Lane is the Project Manager.

Lidar AI-Based Technology at University Drive and Culver Drive

Professor Zenyuk Becomes NFCRC Director

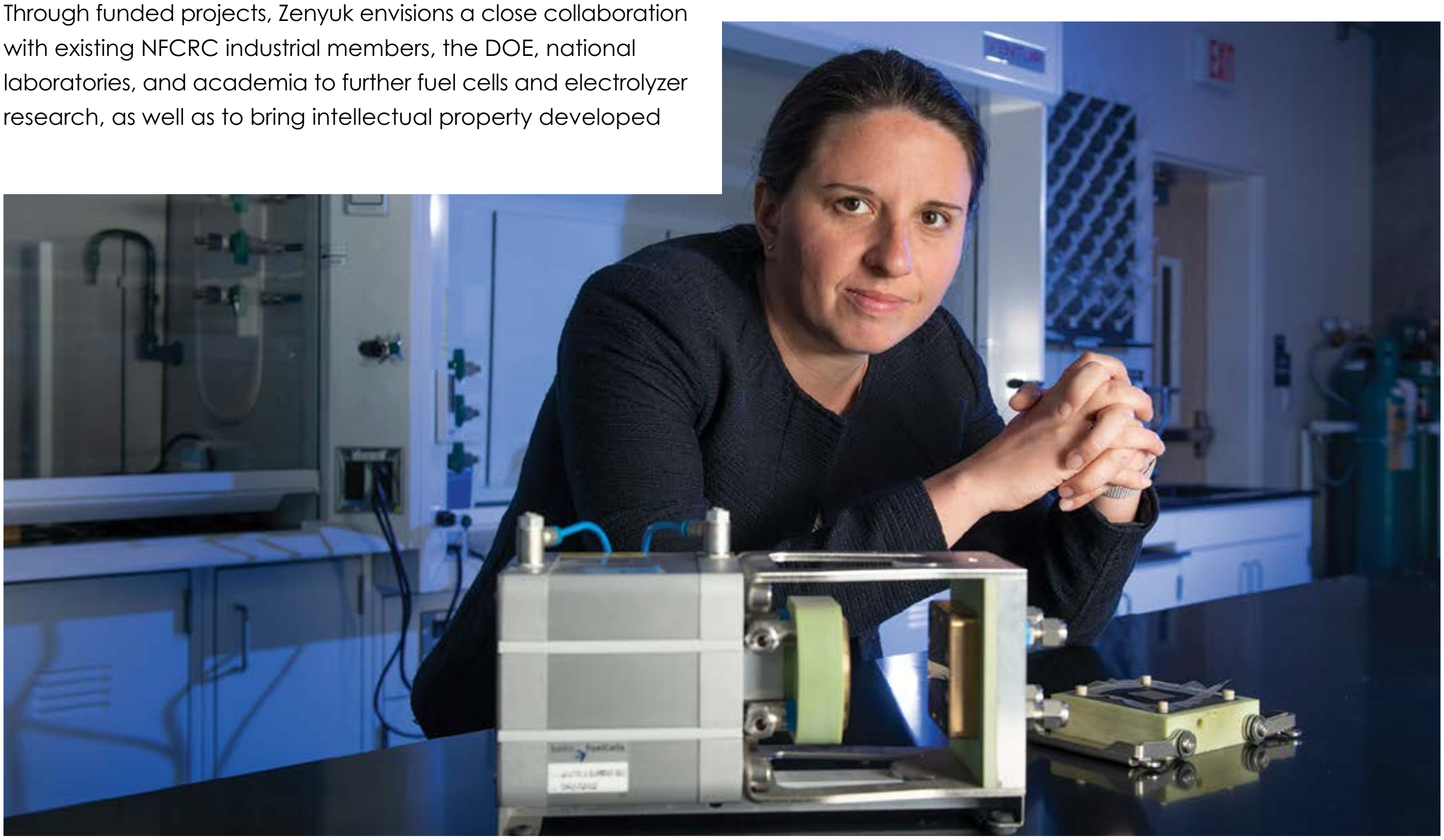
The National Fuel Cell Research Center (NFCRC) has appointed a new director, Professor Iryna Zenyuk, as of October 1st 2023. Zenyuk, who is also an Associate Professor in Department of Chemical and Biomolecular Engineering (CBE), has 14 years of experience working in proton exchange membrane (PEM) fuel cells and electrolyzers.

Stepping in as director on the 24th year since the center was established, she envisions the future of the center to focus on research activities that address the problems of technologies' cost and durability. The center's mission is closely aligned with the targets set by the Department of Energy (DOE) for 2050, and Zenyuk believes that the center is well-positioned to meet these goals in a timely manner.

The key to this effort is the NFCRC's unique expertise among affiliated faculty that bridges catalyst development, their integration into membrane electrode assemblies (MEA), testing them in sub-scale devices, and upscaling these materials into real stacks and systems. The NFCRC is equipped with the capabilities to scale the process from nanoscale to meters scale.

Through funded projects, Zenyuk envisions a close collaboration with existing NFCRC industrial members, the DOE, national laboratories, and academia to further fuel cells and electrolyzer research, as well as to bring intellectual property developed at the NFCRC to marketplace. In addition, the NFCRC will continue supporting research in high and low temperature fuel cells. Zenyuk is also invested in infrastructure to enable higher throughput testing. Zenyuk said, "It is time for hydrogen now. We have the unique opportunity to enable the deployment of hydrogen in sectors of heavy-duty transportation, shipping, aviation, and the chemical industry." To achieve decarbonization in these sectors, a strong reliance on hydrogen is imperative.

"It is time for hydrogen now. We have the unique opportunity to enable the deployment of hydrogen in sectors of heavy-duty transportation, shipping, aviation, and the chemical industry."



National Science Foundation Supports NFCRC Student International Collaboration

Decarbonization of the energy sector is a critical component of enabling a carbon-free economy. Renewable energy sources, like solar and wind, require flexible demand and energy storage to transform the power grid. Electrochemical techniques offer solutions for a reliable electricity grid and enable the decarbonization of manufacturing and transportation sectors.

Six students from NFCRC traveled to Berlin, Germany to conduct research at the Technical University of Berlin (Strasser group) and the Fritz Haber Institute of Max Planck Society (Roldan Cuenya group) as part of a three-year NSF-International Research Experiences for Students (IRES) grant. Prof. Iryna Zenyuk is the grant PI with co-PIs Prof. Plamen Atanassov, Prof. Jacob Brouwer, and Prof. Vojislav Stamenkovic. The first cohort of students are: Hung-Ming Chang, Giovanni Ferro, Christopher Liu, Eamonn Murphy, Magnolia Pak and Patrick Yang. For 10 weeks, the students conducted research projects in areas of hydrogen technologies and carbon dioxide reduction technologies. At the end of the 10 weeks, the students attended the International Society of Electrochemistry Regional Meeting in Prague.

NFCRC students at Technical University of Berlin worked on synthesizing and testing MOF-based (metal organic framework) alkaline HER catalysts and on developing membrane electrode assemblies (MEAs) for the reduction of CO_2 to CO.

NFCRC students at the Fritz Haber Institute studied water dissociation catalysts in bipolar membranes, optimized catalyst loading for low temperature proton exchange membrane (PEM) reversible fuel cells, analyzed single atom M-N-C catalysts via X-ray absorbance spectroscopy, and worked on developing electrocatalysis of the nitrate reduction reaction using Cu-Pd alloys.

HIMAC Advances Science of Hydrogen Electric Vehicles

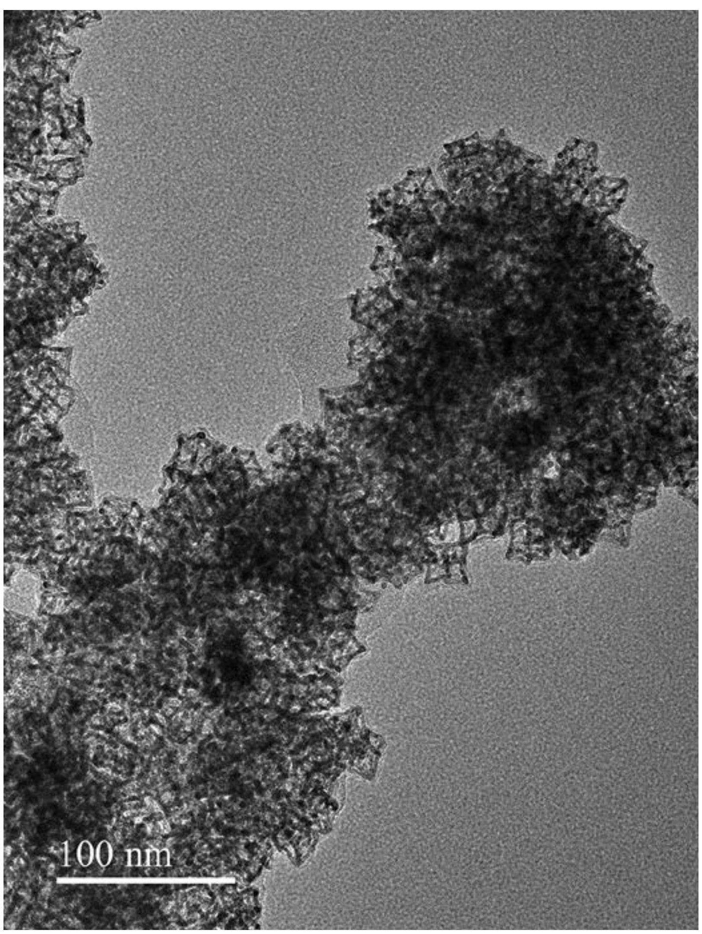
Hydrogen electric vehicles are projected to gain significant market share in the coming years. Current commercially available vehicles employ system-level limitations and high catalyst loadings for fuel cells to counteract poor understanding of atomic level dissolution processes. Reducing this dissolution by limiting voltage (and thus performance) at the system level works against the inherent catalyst efficiency as the system is forced to operate within an inefficient potential range to protect poorly designed catalysts.

Intelligent materials design can widen the potential window of operation, reducing reliance on system level architecture. To improve both power density and durability of fuel cell stacks, enhancements in the understanding of atomic scale processes are necessary to support intelligent materials design. Improvements of this type can be made through systematic studies of model surfaces and rigorous use of advanced analytical techniques.

Setup for In-Situ Monitoring of Catalyst Dissolution with ICP-MS Elemental Analysis

The Stamenkovic group (SG) works on studying model surfaces. Through this, it is possible to change single experimental parameters and thus gain new fundamental knowledge, which can then be applied to a highly controlled synthesis of new catalysts for electrochemical applications.

To overcome the dissolution of catalytic surfaces, inductively coupled plasma mass spectrometry (ICP-MS) is combined with well-controlled electrochemical experiments to correlate atomic level dissolution of either model surfaces or designed catalyst materials to reaction conditions in real time, providing insight into how changes in synthesis procedure, catalyst design, and environment affect stability. Succeeding this, successful implementation of new intelligent catalyst design is done by the SG realizing the benefits of atomic scale understanding in practical systems.



Synthesized Fuel Cell Catalyst

Guiding Policy with Monetized Lifecycle Analysis

Energy is one of the primary drivers of economic development and growth. However, the production and use of power and fuel causes damages to the environment through pollutant emissions, waste products, and land and resource use. Lifecycle analysis (LCA) is a formal process for evaluating environmental impacts across roughly a dozen distinct factors, covering air emissions of several types, land and water impacts, health impacts, and resource depletion. Interpreting results for purposes of maximizing societal value can be challenging, however, because environmental impacts are measured in many different units of measure such as tons of carbon, grams of selenium-equivalent mineral depletion, or reduced human lifespan.

An emerging approach to assessing environmental impacts on a common basis is a technique called monetized lifecycle analysis. In this approach, a monetary value is assigned to each of the various units of environmental impact. The overall monetary damage to the environment from a process, such as production and use of a given fuel, can then be assessed. There are a number of methods used to convert lifecycle impacts to monetary units. The most common approaches are estimated damage costs and estimated cost to mitigate the environmental impact. Figure 1 below shows an example comparing the full societal cost of diesel fuel to renewable hydrogen for heavy-duty trucking. The figure shows that in spite of the higher cost to produce renewable hydrogen, when environmental costs are considered, renewable hydrogen is the lower cost fuel.

Clean air, water and land are "public goods", meaning that they have a quantifiable value to which there are no property rights. Ideally the cost of environmental damage would be included in the price to the buyer. This can be done through things like carbon taxes. However, full internalization of environmental damage cost is unlikely. Given that, monetized LCA can give policymakers powerful insight into where to apply incentives and mandates.

Initial analysis of monetized environmental damages of incumbent fossil fuels relative to renewable hydrogen shows significant reduction in environmental damage (societal benefit) for renewable hydrogen in key applications.

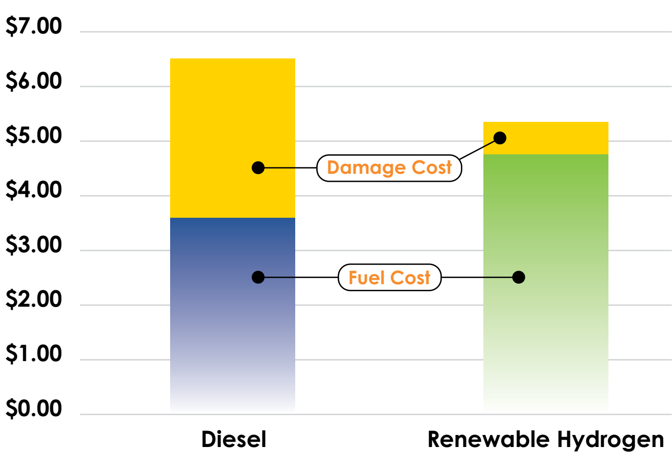


Figure 1. Full Cost per Diesel Gallon Equivalent of Diesel versus Renewable Hydrogen – Illustrative

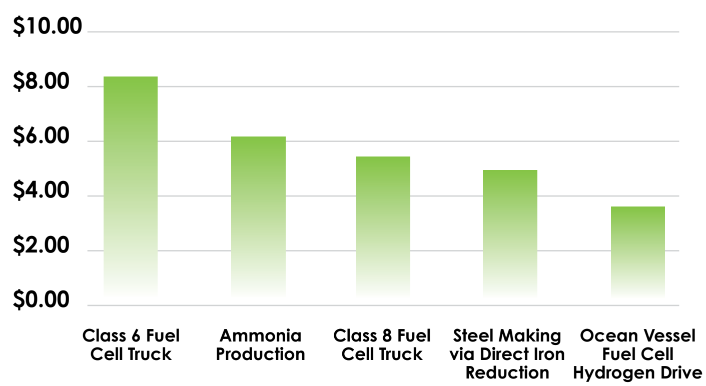


Figure 2. Monetized Societal Benefit of Selected Renewable Electrolytic Hydrogen Uses

GRADUATES AND INTERNSHIPS

M.S. Graduates

Iker Gomez

Alexandra Huff

Kengyuan Li

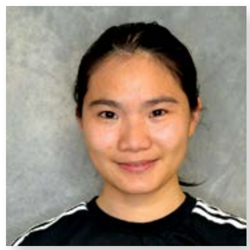
Madeline Talebi

Britney Tran

Ph.D. Graduates

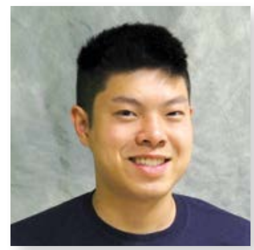
Sahand Faraji

Alejandra Hormaza Mejia



Ying Huang

Kaustubh Khedekar



Clinton Thai

Internships 2022-2023

Christien Gabarda
Naval Air Weapons Station, China Lake

Kyle Horiuchi
Naval Air Warfare Center Weapons Division, China Lake

Malcolm Overbaugh
Southern California Gas Company

Joshua Prince
SoCalGas

Christian Rose
IMI Critical Engineering

John Stansberry
Southern California Gas Company

Britney Tran
Blue Origin

2022-2023 JOURNAL PUBLICATIONS

INTEGRATED SOLID OXIDE FUEL CELL, SOLAR PV, AND BATTERY STORAGE SYSTEM TO ACHIEVE ZERO NET ENERGY RESIDENTIAL NANOGRID IN CALIFORNIA (2022). Applied Energy, Vol. 323, pp. 119577ff (Pegah Mottaghizadeh, Faryar Jabbari, and Jack Brouwer). DOI: 10.1016/j.apenergy.2022.119577

A FRAMEWORK FOR THE REPLACEMENT ANALYSIS OF A HYDROGEN-BASED POLYMER ELECTROLYTE MEMBRANE FUEL CELL TECHNOLOGY ON BOARD SHIPS: A STEP TOWARDS DECARBONIZATION IN THE MARITIME SECTOR (2022). Energy Conversion and Management, Vol. 267, pp. 115893ff (Simona Di Micco, Luca Mastropasqua, Viviana Cigolotti, M. Minutillo, and Jack Brouwer). DOI: 10.1016/j.enconman.2022.115893

COMMENT ON "HOW GREEN IS BLUE HYDROGEN?" (2022). Energy Science & Engineering (Matteo C. Romano, Cristina Antonini, André Bardow, Valentin Bertsch, Nigel P. Brandon, Jack Brouwer, Stefano Campanari, Luigi Crema, Paul E. Dodds, Stefania Gardarsdottir, and Matteo Gazzani).

SIMULATION-INFORMED MACHINE LEARNING DIAGNOSTICS OF SOLID OXIDE FUEL CELL STACK WITH ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY (2022). Journal of The Electrochemical Society, Vol. 169, No. 3, pp. 034530ff (Giang Tra Le, Luca Mastropasqua, Jack Brouwer, and Stuart B. Adler). DOI: 10.1149/1945-7111/ac59f4

THERMODYNAMIC AND DYNAMIC ANALYSIS OF A WIND-POWERED OFF-GRID INDUSTRIAL BUILDING INTEGRATED WITH SOLID OXIDE FUEL CELL AND ELECTROLYZER FOR ENERGY MANAGEMENT AND STORAGE (2022). Journal of Electrochemical Energy Conversion and Storage, Vol. 19, No. 3, pp. 031003ff (Pegah Mottaghizadeh, Mahshid Fardadi, Faryar Jabbari, and Jack Brouwer). DOI: 10.1115/1.4052856

REAL-TIME DETECTION OF ELECTRICAL LOAD ANOMALY THROUGH HYPERDIMENSIONAL COMPUTING (2022). Energy (Xinlin Wang, Robert Flores, Jacob Brouwer, and Marios Papaefthymiou). DOI: 10.1016/j.energy.2022.125042

EXPERIMENTAL AND THEORETICAL EVALUATION OF A 60 KW PEM ELECTROLYSIS SYSTEM FOR FLEXIBLE DYNAMIC OPERATION (2023). Energy Conversion and Management, Vol. 277, pp. 116622ff (Elena Crespi, Giulio Guandalini, Luca Mastropasqua, Stefano Campanari, and Jacob Brouwer). DOI: 10.1016/j.enconman.2022.116622

DEVELOPING AND TUNING A COMMUNITY SCALE ENERGY MODEL FOR A DISADVANTAGED COMMUNITY (2023). Energy and Buildings, Vol. 285, pp. 112861ff (Robert Flores, Sammy Houssainy, Weixi Wang, Joseph Robertson, Khanh Nguyen Cu, Ben Polly, Ramin Faramarzi, Jim Maclay, and Jack Brouwer). DOI: 10.1016/j.enbuild.2023.112861

DECARBONIZING A SOLAR PV AND GAS TURBINE MICROGRID WITH HYDROGEN AND BATTERIES (2023). Energy Conversion and Management, Vol. 292, pp. 117391ff (Clinton Thai and Jack Brouwer). DOI: 10.1016/j.enconman.2023.117391

NUMERICAL ANALYSIS OF THE RELATION BETWEEN THE POROSITY OF THE FUEL ELECTRODE SUPPORT AND FUNCTIONAL LAYER, AND PERFORMANCE OF SOLID OXIDE FUEL CELLS USING COMPUTATIONAL FLUID DYNAMICS (2023). International Journal of Hydrogen Energy (Krystian Machaj, Jakub Kupecki, Anna Niemczyk, Ziemowit Malecha, Jack Brouwer, and Dominika Porwisiak). DOI: 10.1016/j.ijhydene.2023.06.166

COMPARATIVE LEVELIZED COST ANALYSIS OF TRANSMITTING RENEWABLE SOLAR ENERGY (2023). Energies, Vol. 16, No. 4, pp. 1880ff (Clinton Thai and Jack Brouwer). DOI: 10.3390/en16041880

TIME-PHASED GEOSPATIAL SITING ANALYSIS FOR RENEWABLE HYDROGEN PRODUCTION FACILITIES UNDER A BILLION-KILOGRAM-SCALE BUILD-OUT USING CALIFORNIA AS AN EXAMPLE (2022). International Journal of Hydrogen Energy, Vol. 47, No. 66, pp. 28224-28243 (Jeffrey Reed, Emily Dailey, Amber Fong, and Scott Samuelsen). DOI: 10.1016/j.ijhydene.2022.06.179

THERMO-ECONOMIC ANALYSIS OF A SOLID OXIDE FUEL CELL-GAS TURBINE HYBRID WITH COMMERCIAL OFF-THE-SHELF GAS TURBINE (2022). Applied Energy, Vol. 324, pp. 119745 (Fabian Mueller and Scott Samuelsen). DOI: 10.1016/j.apenergy.2022.119745

DECARBONIZATION WILL LEAD TO MORE EQUITABLE AIR QUALITY IN CALIFORNIA (2022). Nature Communications, Vol. 13, pp. 5738 (Shupeng Zhu, Michael Mac Kinnon, Andrea Carlos-Carlos, Steven Davis, and Scott Samuelsen). DOI: 10.1038/s41467-022-33295-9

TECHNICAL NOTE: GAS TURBINE PRICE PROJECTION FOR N-TH PLANT EQUIPMENT COST (2022). The Engineering Economist, Vol. 67, Issue 4, pp. 325-330 (Fabian Rosner, Dandan Yang, Ashok Rao, and Scott Samuelsen). DOI: 10.1080/0013791X.2022.2048330

DEPLOYMENT PLANNING TOOL FOR ENVIRONMENTALLY SENSITIVE HEAVY-DUTY VEHICLES AND FUELING INFRASTRUCTURE (2022). Energy Policy, Vol. 171, pp. 113289 (Blake Lane, Michael Mac Kinnon, Brendan Shaffer, and Scott Samuelsen).

POTENTIAL HEALTH IMPACT ASSESSMENT OF LARGE-SCALE PRODUCTION OF BATTERIES FOR THE ELECTRIC GRID (2022). REWAS 2022: Developing Tomorrow's Technical Cycles in The Minerals, Metals & Materials Series, Vol. 1, pp. 417-425 (Cham Springer, Haoyang He, Shan Tian, Chris Glaubensklee, Brian Tarroja, Scott Samuelsen, Oladele A. Ogunseitan, and Julie M. Schoenung). DOI: 10.1007/978-3-030-92563-5_43

TECHNO-ECONOMIC ANALYSIS OF MATERIAL COSTS FOR EMERGING FLOW BATTERIES (2022). REWAS 2022: Developing Tomorrow's Technical Cycles in The Minerals, Metals & Materials Series, Vol. 1, pp. 449–460 (Cham Springer, Haoyang He, Shan Tian, Brian Tarroja, Branden Schwaebe, Scott Samuelsen, Oladele A. Ogunseitan, and Julie M. Schoenung). DOI: 10.1007/978-3-030-92563-5_46

EMISSIONS AND AIR QUALITY IMPLICATIONS OF ENABLING ON-ROAD VEHICLES AS FLEXIBLE LOAD THROUGH WIDESCALE ZERO EMISSION VEHICLE DEPLOYMENT IN CALIFORNIA (2022). Transportation Research Record, Vol. 2677, Issue 3 (Kate Forrest, Blake Lane, Brian Tarroja, Michael Mac Kinnon, and Scott Samuelsen). DOI: 10.1177/03611981221121259

ASSESSMENT OF THE GREENHOUSE GAS, EPISODIC AIR QUALITY AND PUBLIC HEALTH BENEFITS OF FUEL CELL ELECTRIFICATION OF A MAJOR PORT COMPLEX (2022). Atmospheric Environment, Vol. 275, pp. 118996 (Shupeng Zhu, Michael Mac Kinnon, James Soukup, Andre Paradise, Donald Dabdub, and Scott Samuelsen). DOI: 10.1016/j.atmosenv.2022.118996

POTENTIAL EVOLUTION OF THE RENEWABLE HYDROGEN SECTOR USING CALIFORNIA AS A REFERENCE MARKET (2023). Applied Energy, Vol. 331, No. 1, pp. 120386 (Jeffrey Reed, Emily Dailey, Brendan Shaffer, Blake Lane, Robert Flores, Amber Fong, and Scott Samuelsen). DOI: 10.1016/j.apenergy.2022.120386

NANO-POROUS TRANSPORT MEMBRANE CONDENSER FOR FLUE GAS WATER RECOVERY: MODELING AND PARAMETRIC MEMBRANE DESIGN ANALYSIS (2023). International Journal of Thermal Sciences, Vol. 192, Part A, pp. 108365 (Fabian Rosner, Chun Yin Chan, Brandon Paul, and Scott Samuelsen). DOI: 10.1016/j.ijthermalsci.2023.108365

UNEXPECTED DETERIORATION OF O3 POLLUTION IN THE SOUTH COAST AIR BASIN OF CALIFORNIA: THE ROLE OF METEOROLOGY AND EMISSIONS (2023). Environmental Science & Technology, Vol. 330, pp. 121728 (Kai Wu, Shupeng Zhu, Michael Mac Kinnon, and Scott Samuelsen). DOI: 10.1016/j.envpol.2023.121728

UTILIZATION OF BATTERY ELECTRIC BUSES FOR THE RESILIENCY OF ISLANDED MICROGRIDS (2023). Applied Energy (Special 2022 Microgrid Issue), Vol. 347, No. 1, pp. 121295 (Jennifer Lee, Ghazal Razeghi, and Scott Samuelsen). DOI: 10.1016/j.apenergy.2023.121295

TECHNO-ECONOMIC ANALYSIS OF SOFC-GT HYBRID SYSTEMS FOR STATIONARY POWER APPLICATIONS USING RENEWABLE HYDROGEN (2023). Energies, Vol. 16, pp. 4955 (Fabian Rosner, Chun Yin Chan, and Scott Samuelsen). DOI: 10.3390/ en16134955

IMAGING SENSITIVE CATALYST ACTIVE SITE STRUCTURE BY 30 KEV ELECTRON PTYCHOGRAPHY (2022). Microscopy and Microanalysis, Vol. 28, Supplement S1, pp. 484-486 (Michael J. Zachman, Hasnain Hafiz, Dong Young Chung, Vojislav Stamenkovic, Edward F. Holby, and David A. Cullen). DOI: 10.1017/S1431927622002598

SPONTANEOUS AEROBIC AGEING OF FE-N-C MATERIALS AND CONSEQUENCES ON OXYGEN REDUCTION REACTION KINETICS (2023). Journal of Power Sources, Vol. 564, pp. 232829 (Keyla Teixeira Santos, Kavita Kumar, L. Dubau, Hongxin Ge, Sandrine Berthon-Fabry, Carlos Sant'Ana Vasconcellos, Fabio Lima, Tristan Asset, Plamen Atanassov, Viktoriia A. Saveleva, Pieter Glatzel, Xiaoyan Li, Frederic Jaouen, Frederic Maillard). DOI: 10.2139/ssrn.4237763

EXCHANGE CURRENT DENSITY AS AN EFFECTIVE DESCRIPTOR OF POISONING OF ACTIVE SITES IN PLATINUM GROUP METAL-FREE ELECTROCATALYSTS FOR OXYGEN REDUCTION REACTION (2023). ACS Catalysis, Vol. 13, pp. 2162-2175 (Valerio C.A. Ficca, Carlo Santoro, Ernesto Placidi, Fabrizio Arciprete, Alexey Serov, Plamen Atanassov, and Barbara Mecheri). DOI: 10.1021/acscatal.2c05222

INSIGHTS ON DESIGNING NON-PGM CATALYST LAYERS AT LOW HUMIDITY (2023). Journal of Power Sources, Vol. 562, pp. 232741 (Yongwook Kim, Luis P. Urbina, Tristan Asset, Marc Secanell, Plamen Atanassov, Jake Barralet, and Jeff T. Gostick). DOI: 10.1016/ j.jpowsour.2023.232741

METAL-NITROGEN-CARBON CATALYSTS BY DYNAMIC TEMPLATE REMOVAL FOR HIGHLY EFFICIENT AND SELECTIVE ELECTROREDUCTION OF CO2 (2023). ACS Applied Energy Material, Vol. 6, pp. 678-691 (Laurent Delafontaine, Alessio Cosenza, Eamonn Murphy, Yuanchao Liu, Jiazhe Chen, Baiyu Sun, and Plamen Atanassov). DOI: 10.1021/ acsaem.2c02811

PROMOTING ELECTROLYSIS OF CARBON MONOXIDE TOWARDS ACETATE AND 1-PROPANOL IN FLOW ELECTROLYZER (2023). ACS Energy Letters, Vol. 8, pp. 935-942 (Shengyuan Guo, Yuanchao Liu, Ying Huang, Hanson Wang, Eamonn Murphy, Laurent Delafontaine, Jiazhe Chen, Iryna V. Zenyuk, and Plamen Atanassov). DOI: 10.1021/ acsenergylett.2c02502

NOVEL ACID-FREE PROCESS INTENSIFICATION FOR THE SYNTHESIS OF NON-PRECIOUS METAL-NITROGEN-CARBON ELECTROCATALYSTS FOR OXYGEN REDUCTION REACTION (2023). Journal of Power Sources, Vol. 556, pp. 232382 (Alessio Cosenza, Laurent Delafontaine, Alvin Ly, Hanson Wang, Eamonn Murphy, Yuanchao Liu, Stefania Specchia, and Plamen Atanassov). DOI: 10.1016/j.jpowsour.2022.232382

POTENTIAL EVOLUTION OF THE RENEWABLE HYDROGEN SECTOR USING CALIFORNIA AS A REFERENCE MARKET (2022). Applied Energy, Vol. 331, pp. 120386 (Jeffrey Reed, Emily Dailey, Brendan Shaffer, Blake Lane, Robert Flores, Amber Fong, and Scott Samuelsen). DOI: 10.1016/j.apenergy.2022.120386

ASSESSMENT OF ENVIRONMENTAL, HEALTH, AND SAFETY ISSUES RELATED TO THE INTRODUCTION OF ALTERNATIVE ENERGY (2022). EPRI Report 3002019994 (Jeffrey Reed and Kate Forrest).

TIME-PHASED GEOSPATIAL SITING ANALYSIS FOR RENEWABLE HYDROGEN PRODUCTION FACILITIES UNDER A BILLION-KILOGRAM-SCALE BUILD-OUT USING CALIFORNIA AS AN EXAMPLE (2022). International Journal of Hydrogen Energy, Vol. 47, Issue 66, pp. 28224-28243 (Jeffrey Reed, Emily Dailey, Amber Fong, and Scott Samuelsen). DOI: 10.1016/j.ijhydene.2022.06.179.

GROUND BASED GAS TURBINE COMBUSTION (2022). In Renewable Fuels: Sources, Conversion, and Utilization (Vince G. McDonell and B. Noble).

EFFECTS OF FULL TRANSIENT INJECTION RATE AND INITIAL SPRAY TRAJECTORY ANGLE PROFILES ON THE CFD SIMULATION OF EVAPORATING DIESEL SPRAYS-COMPARISON BETWEEN SINGLEHOLE AND MULTI HOLE INJECTORS (2022). Energy, Vol. 263, Part C, pp. 125796 (Safiullah, Samir Chandra Ray, Keiya Nishida, Vincent McDonell, and Yoichi Ogata). DOI: 10.1016/j.energy.2022.125796

EVALUATION OF MULTI-HOLE DIESEL INJECTOR SPRAY UNDER EVAPORATING CONDITIONS: EFFECTS OF ADJACENT SPRAY PLUMES ON THE MACROSCOPIC AND MIXTURE CHARACTERISTICS OF TARGET SPRAY (2022). Proceedings of the Institution of Mechanical Engineers Part D Journal of Automobile Engineering (Safiullah, Samir Chandra Ray, Keiya Nishida, Vincent G. McDonell, Aftab Ahmed, and Yoichi Ogata). DOI: 10.1177/09544070221133880

INCORPORATION OF FILM THEORY IN SINGLE DROPLET COMBUSTION MODEL FOR PREDICTION OF PRECURSOR RELEASE IN FLAME SPRAY PYROLYSIS (2023). Proceedings of the Combustion Institute, Vol. 39, Issue 2, pp. 2553-2563 (Musa Najimu, Vicki Baghdassarian, Scott Leask, Vincent McDonell, Bihter Padak, and Erdem Sasmaz). DOI: 10.1016/j.proci.2022.12.001

A COMPILATION OF OPERABILITY AND EMISSIONS PERFORMANCE OF RESIDENTIAL WATER HEATERS OPERATED ON BLENDS OF NATURAL GAS AND HYDROGEN INCLUDING CONSIDERATION FOR REPORTING BASES (2023). International Journal of Hydrogen Energy, Vol. 48, Issue 51, pp. 19733-19749 (Ethan Basinger, Brendan Hickey, and Vincent McDonell). DOI: 10.1016/j.ijhydene.2023.02.018

ELECTROCHEMICAL CELLS AND METHODS OF USING THEREOF (2023). U.S. Patent App. 17/566,340 (Susan J. Babinec, Timothy Fister, Pietro Papa Lopes, and Vojislav Stamenkovic).

ROLE OF CATHARTIC CONVERSIONS OF ETHYLENE CARBONATE, WATER, AND HF IN FORMING THE SOLID-ELECTROLYTE INTERPHASE OF LI-ION BATTERIES (2023). ACS Catalysis, Vol. 13, Issue 13, pp. 9289-9301 (Milena Martins, Dominik Haering, Justin G. Connell, Hao Wan, Katrine L. Svane, Hao Wan, Katrine L. Svane, Bostjan Genorio, Pedro F.B.D. Martins, Pietro P. Lopes, Brian Gould, Filippo Maglia, Roland Jung, Vojislav Stamenkovic, Ivano E. Castelli, Nenad M. Markovic, Jan Rossmeisl, and Dusan Strmcnik). DOI: 10.1021/acscatal.3c01531

CONTROL OF NANOSTRUCTURE AND ACTIVITY BY ALLOYING AND/OR SEGREGATION (2023). U.S. Patent 11,679,377 (Rongyue Wang, Krzysztof Pupek, and Vojislav Stamenkovic).

SEGREGATION INDUCED CORE-SHELL STRUCTURE (2023). U.S. Patent 11,628,427 (Rongyue Wang, Vojislav Stamenkovic, Gregory K. Krumdick, and Krzysztof Pupek).

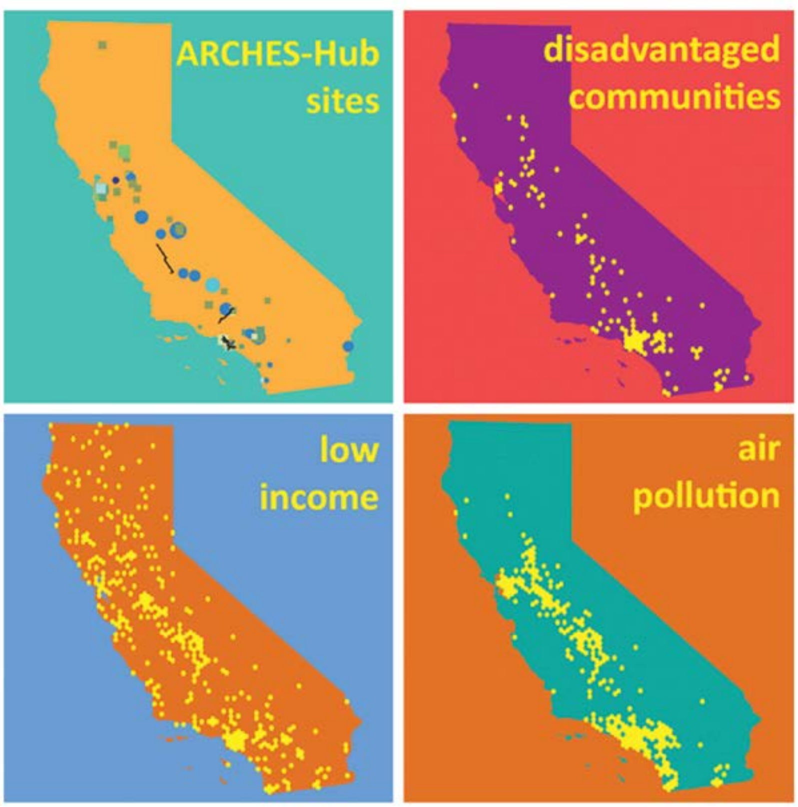
SCALABLE PT CLUSTER AND RUO2 HETEROJUNCTION ANODE CATALYSTS (2023). U.S. Patent 11,596,928 (Vojislav Stamenkovic, Rongyue Wang, and Dusan Strmcnik).

MELAMINE MODIFICATION OF FUEL CELL ELECTRODES (2023). U.S. Patent 11,552,302 (Dusan Strmcnik, Pedro F.B.D. Martins, Milena Zorko, L.V. Haifeng, and Vojislav Stamenkovic).

California Regional Hydrogen Hub selected by U.S. DOE

We are very pleased to announce that the U.S. Department of Energy has selected the Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES) proposal for an award of up to $1.2 billion in federal dollars. The proposal includes support from the state of California and industry that will provide more than a 10:1 match for a total award amount of about $13 billion. These funds will be primarily directed towards hydrogen infrastructure to reduce greenhouse gas and pollutant emissions to improve the air quality in ports, heavy-duty freight, and bus transportation.

The team at UCI played a key role in the vision for this regional hub, the intellectual underpinnings of this hub, the organizing of the UC system, the organizing of industry partners, the writing of the proposal, and more. We are so thankful for the wonderful support of so many people throughout UCI, UCOP, other UC campuses, LBNL, and the State. We look forward to the "new era" that these hubs will introduce to the U.S., which will include the distinct possibility of a fossil fuel free and zero emissions (both greenhouse gas and air pollutant emissions) world!



The careers and air quality improvements of ARCHES will mostly accrue to low income and disadvantaged communities (identified by EJ40 database and CalEnviroScreen).

ARCHES Alliance for Renewable Clean Hydrogen Energy Systems

"We look forward to the "new era" … which will include the distinct possibility of a fossil fuel free and zero emissions … world!"

ECS@UCI: 2023 SoCal Electrochemistry Conference for Students (SCECS)

In April 2023, the Electrochemical Society (ECS) Student Chapter at the University of California, Irvine (ECS@UCI) hosted students from neighboring institutions such as USC, UC Santa Barbara, UC San Diego, Caltech, and Cal State Long Beach for the 2023 SoCal Electrochemistry Conference for Students (SCECS). The conference was initiated, planned, and executed by students. It began with a series of questions, the first being: how can they create a community of student researchers in electrochemistry? That is, a community of theorists and experimentalists, a community of fuel cell engineers, bio-electrochemists, transport modelers, and catalyst designers, a community of advisors, mentors, and bright new students. Second, how could they create a community that would last during and beyond graduate (or undergraduate) studies, and throughout their professional careers as electrochemists and electrochemical engineers? And lastly, how could they create a community that is ready to accept the next generation of electrochemists and electrochemical engineers? Science and engineering becoming increasingly accessible. That said, this accessibility could give way to doubt and being overwhelmed without mentorship, a support system, or a community. But, if they did it right, they have a chance to build something beautiful and both personally and intellectually rich: a history that can outlive them.

With Dr. Adam Weber of the Lawrence Berkeley National Laboratory and Prof. Kimberly See of Caltech as keynote speakers, 20 student talks, 20 student posters, and over 80 attendees, the students designed this conference to cover a diverse range of topics and to connect students from different subfields in electrochemistry. Between the talks and presentations, the conference was designed to include plenty of time for attendees to connect with each other over refreshments and research posters. Overall, the 2023 SCECS was met with substantial enthusiasm from attendees, due to its student-centric nature and reasonable attendee size.

The National Fuel Cell Research Center, the Clean Energy Institute, and the Electrochemical Society provided funding for the 2023 SCECS, and will host the SCECS again in Spring 2024.

2022-2023 HIGHLIGHTS

FALL

September 2022—CEI Director Jack Brouwer was named a UC Irvine Chancellor's Fellow. Professor Brouwer is recognized for his achievements and research in alternative energy and will receive an award of up to $25k/year for 3 years in support of his work.

September 2022—CEI Director Jack Brouwer was featured in a CBS-LA news segment, where he discussed UC Irvine's partnership with the DOE and SCE to install smart grid technology in faculty homes to test the performance of the electrical grid and the need for H2 fueling stations.

October 2022—NFCRC Director Iryna Zenyuk hosted U.S. Representative Katie Porter to discuss new technology advances in H2/fuel cell research. Rep. Porter also had the opportunity to tour NFCRC labs and visited the new HIMaC facility focused on transportation.

November 2022—HIMaC Director Vojislav Stamenkovic was selected as a 2022 Highly Cited Researcher by Clarivate.

WINTER

December 2022—ICEPAG 2022 was held in conjunction with the World Fuel Cell Conference and was held virtually/in-person at the UC Irvine Samueli School of Engineering.

March 2023—Then NFCRC Associate Director Iryna Zenyuk co-hosted the 2nd Telluride Innovation Workshop on the Decarbonization of Cement.

March 2023—UCICL hosted the Gas Turbine Combustion Short Course for professionals involved in research, design, and development of gas turbine combustion systems. Attendees engaged in a series of lectures as well as a tour of APEP research facilities!

SPRING

April 2023—CEI celebrated the success of HORIBA for 50 years in Irvine and honored the long-standing relationship between APEP/CEI and HORIBA.

May 2023—NFCRC Director Iryna Zenyuk was featured in Irvine Standard's article highlighting the innovators making an impact today. Professor Zenyuk was recognized for her work in electrochemical energy and efforts to reduce the world's carbon footprint.

SUMMER

June 2023—CEI Director Jack Brouwer was featured in a PBS segment clarifying the distinction between different EVs in the market today and demonstrating the differences/similarities of fuel cell EVs and their battery counterparts.

June 2023—In collaboration with the U.S. DOE, we formally opened two self-supporting microgrid communities in Menifee, CA on May 22. As a first-of-its-kind residential microgrid technology project with KB Home, SunPower, Southern California Edison, and Schneider Electric, this project aims to test and enhance energy reliability, resiliency, and efficiency within residential homes. The homes in the microgrids can also act as virtual power plants, supplying electricity to help keep the grid stable during spikes in demand.

June 2023—The U.S. DOE awarded $3.75 million to HIMaC for research in clean hydrogen technologies. Led by HIMaC Director Vojislav Stamenkovic, the team's research would enable the widespread commercialization of H2 and fuel cell technology in medium- and heavy-duty trucks.

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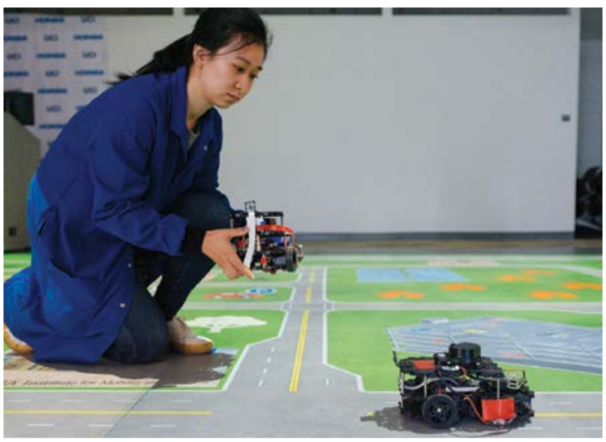

The UCI Clean Energy Institute (CEI) encompasses five organizational elements: the National Fuel Cell Research Center, the UCI Combustion Laboratory, the Horiba Institute for Mobility and Connectivity, the Ensembles of Photoelectrochemical Nanoreactors, and the Center for Closing the Carbon Cycle.

CEI advances the development and deployment of efficient, environmentally- sensitive, and sustainable power generation, storage, and conservation. At the center of CEI'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 CEI's research to practical application is achieved through our close collaboration with industry, national agencies, and laboratories to "bridge" engineering science and practical application.

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

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