Annual Report | Volume 8 | 2020

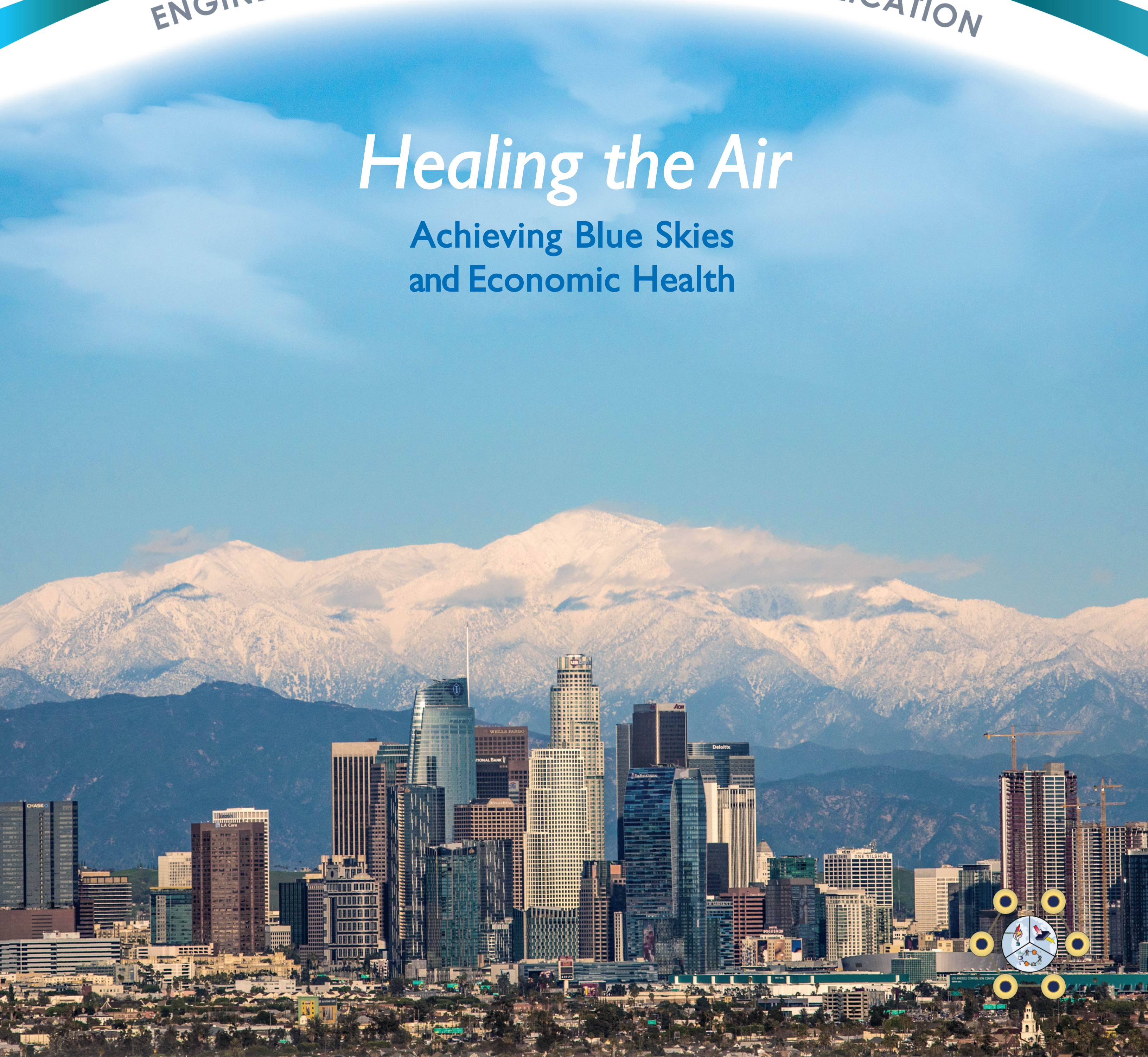
ADVANCED POWER AND ENERGY PROGRAM

BRIDGING

ENGINEERING SCIENCE TO PRACTICAL APPLICATION

Healing the Air

Achieving Blue Skies and Economic Health



Director's Message

Professor Scott Samuelsen, Ph.D.

Director, Advanced Power and Energy Program (APEP)

Around the globe, air quality dramatically improved with self-sheltering in response to COVID-19, providing an unexpected, refreshing, and affirming moment in which we experienced the air quality projected to emanate in the future from the transition to zero-emission renewable fuels and zero-emission power generation.

Not only did the quality of the air improve, but the earth experienced a substantial and immediate reduction in emitted carbon, albeit for a short moment in time. During that moment, we pondered "what if" we were able to transition from fossil to renewable fuels with the same tenacity that we responded to COVID-19. The world of course is trying to transition from fossil fuels, but over decades rather than weeks…even though the impact on public health and quality of life is arguably comparable to that of COVID-19.

While the transition to renewable fuels is not as straight forward as self-sheltering, neither does it compromise the quality of life. In fact, the opposite. APEP is dedicated to breaking down the hurdles and accelerating the transition.

For this, our eighth annual edition of "**Bridging**," we feature APEP's continuing work on (1) air quality and climate change, including our research on air pollution health effects under COVID-19, and (2) technologies and pathways to eventually eliminate the emission of air pollutants and carbon. Notable accomplishments during the past year include:

- An APEP roadmap for the scaling and build-out of the renewable hydrogen production in California, published in a final report by the **California Energy Commission (CEC)**.
- An APEP life-cycle environmental and human health impact assessment of emerging flow battery chemistries, completed under **CEC** sponsorship by a combined **UCI** expertise in energy systems, materials science, and public health.
- A National Fuel Cell Research Center (NFCRC) partnership with **Robert Bosch LLC** to advance fuel cell power train technologies for freight aligned with **Department of Energy** (DOE) targets.
- A UC Irvine Combustion Lab (UCICL) initiative to establish a reference spray for measurement quality control for industry and academic communities worldwide.
- The commencement of constructing the **"HORIBA Institute for Mobility and Connectivity^2 (HIMaC^2)"** with operation projected for August 2020.

We are especially proud of the accomplishments of our students during the 2019-2020 academic year, which includes 3 MS graduates, 4 Ph.D. graduates, and 4 internships with diverse entities such as: **174 Power Global, Schneider Electric, Southern California Edison, and Disney Imagineering**.

I am pleased to announce that Professor Jack Brouwer became the APEP Director on 1 July 2020, a role that will be rotated every three years with Professor Vince McDonell. Professor Brouwer assumes the Directorship of a center that began with the UCICL in 1970, and the dedication of the NFCRC three decades later through the Pacific Rim Consortium on Energy, Combustion, and the Environment (PARCON), a UCICL led initiative in collaboration with Southern California Edison, Southern California Gas, and HORIBA, Ltd. Founded in 2000, APEP encompasses the power generation and transportation sectors within which combustion technology is an established pillar and fuel cell technology is an emerging pillar. Under APEP, the combustion and fuel cell science and technology pillars are complemented by pillars in renewable fuels, energy storage, and energy systems integration and impacts. Today, the APEP family exceeds 130 including doctoral (19) and master of science students (26), undergraduate students (31), administrative and research staff (20), professional consulting associates (2), visiting scholars (2), post-doctoral scholars/specialists (2), exchange students (3), faculty leaders (5), and affiliated faculty (20).

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

Scott Samuelsen

CONTENT

1 - 2 **COVER** STORY: Healing the Air

3 Renewable Hydrogen as a Platform for Sustainability

4 Improving the Environmental Benefit of Emerging Energy Storage Technologies through Life Cycle Analysis

5 Fuel Cell Technologies for Heavy Duty Transportation

6 UCI Hydrogen Refueling Station History

7 Reference Spray for Aligning the Spray Community

8 HIMaC^2 Update

9 Outreach Student Experience

10 Graduates and Internships

11 Publications

12 Highlights of the 2019-2020 Academic Year

HEALING THE AIR

The devastating effects of the novel coronavirus pandemic have impacted every aspect of our society, disrupting entrenched patterns of human behavior and changing how we live, work, and travel. While the crisis is overwhelmingly harmful, it does provide a unique opportunity to examine aspects of our world with novel insights and from an altered perspective.

In this regard, one of the most prominent insights is pollution in the air, a byproduct of the fossil fuel-based energy systems that currently power society. As factories have closed, cars and trucks removed from the roads, and aircraft grounded, pollutant emissions from these and other impacted sources have fallen significantly. The result has been noteworthy reductions in the atmospheric concentrations of the particle and chemical species that we collectively refer to as air pollution. This was first observed in China, as extensive actions to combat viral spread led to reductions in pollution including notable drops in particulate matter (PM), a particularly detrimental pollutant from a human health standpoint.[1] Similar reductions are being seen in urban areas worldwide including Madrid, Milan, Paris, and New Delhi. These trends are also clearly evident in the U.S. including Los Angeles, which has experienced an estimated 30 percent decrease in PM and oxides of nitrogen (NO_x) in the weeks following the announcement of stay-at-home orders.[2] The clearing of the air has been remarkable and attained widespread attention as it manifests around the globe. The suddenly clean skies have given Indian citizens a view of the Himalayas not seen for decades; a poignant reminder of the natural beauty that lay hidden behind clouds of pollution.[3] The tone of those interviewed was surprise, or perhaps even astonishment. It serves to highlight that we may not always be aware of the sacrifices that degraded air quality entail and have awoken to a sudden realization of them.

However, the most important outcome by far is the corresponding improvements in human health, or, perhaps better stated as the avoidance of deleterious health effects that would have occurred if the pollution had not been reduced. Exposure to air pollution has long been associated with a myriad of health consequences including heart attacks, strokes, and episodes of other serious disease burdens.[4] In fact, it has been conservatively estimated that the cleaner air provided by the pandemic may have prevented up to 20 times more deaths than was caused by the virus itself in China.[5] Besides the gravity of avoiding premature mortality, cleaner air also means fewer people will require hospitalizations or other medical treatments. Similarly, fewer employees will need to miss work due to illness, or to care for ill children unable to attend school.

While most have some recognition that air pollution is damaging to health, what is less commonly understood is that avoiding these health incidences attains remarkable monetary savings. For example, the cost of a hospital stay for someone experiencing an air pollution induced illness can range from $400 to $28,000.[6] When these avoided costs are aggregated across an exposed population, they are often orders of magnitude higher than the cost of implementing measures to improve air pollution.[7]

Of course, under no circumstances should it be rationalized that the COVID-19 pandemic is even indirectly beneficial given the devastation it has wrought on societal health and well-being, including the severe economic damages that further contribute health detriments. Rather, the insight it provides is that we have a tendency to ignore or accept environmental degradations that lack immediate and obvious health consequences. Often, healthy environments have been sacrificed in the name of progress, economic growth, and the expansion of our societal machinations.

[1] http://www.g-feed.com/2020/03/covid-19-reduces-economic-activity.html
[2] https://www.washingtonpost.com/weather/2020/04/09/air-quality-improving-coronavirus/
[3] https://www.cnn.com/travel/article/himalayas-visible-lockdown-india-scli-intl/index.html
[4] https://ourworldindata.org/air-pollution
[5] http://www.g-feed.com/2020/03/covid-19-reduces-economic-activity.html
[6] http://www.ahdbonline.com/articles/652-article-652
[7] https://www.epa.gov/clean-air-act-overview/benefits-and-costs-clean-air-act-1990-2020-second-prospective-study

"Exposure to air pollution has long been associated with a myriad of health consequences including heart attacks, strokes, and episodes of other serious disease burdens.[4]"

But it does the raise the pivotal question, can we have both economic prosperity and clean air? The answer is yes, although the achievement will certainly not be on the same rapid time scale. The replacement of our current fossil fuel-based energy systems with clean, renewable fuels and zero-emission end-use technologies represents a true path to sustainable pollution-free air. APEP research over the past two decades has demonstrated quite emphatically that switching to zero-emission vehicles powered by batteries and fuel cells in tandem with transitions to renewable electricity and hydrogen is an effective strategy to diminish atmospheric pollution burdens. Figure 1 shows the reductions in ozone from a long-term energy scenario (High H_2 scenario) incorporating electrification and transitions to hydrogen within all major energy sectors resulting in deep reductions in GHG and pollutant emissions. The air quality improvements are dramatic and have a pronounced effect in highly populated southern California, which emphasizes the associated health benefits. Indeed, lowering the pollution levels leads to health savings of $590 million and $428 million per ***10-day episode*** during peak formation periods in summer and winter, respectively. Such transitions can be made effectively and economically in the coming decades and represents the ultimate solution for removing the risk associated with exposure to air pollution.

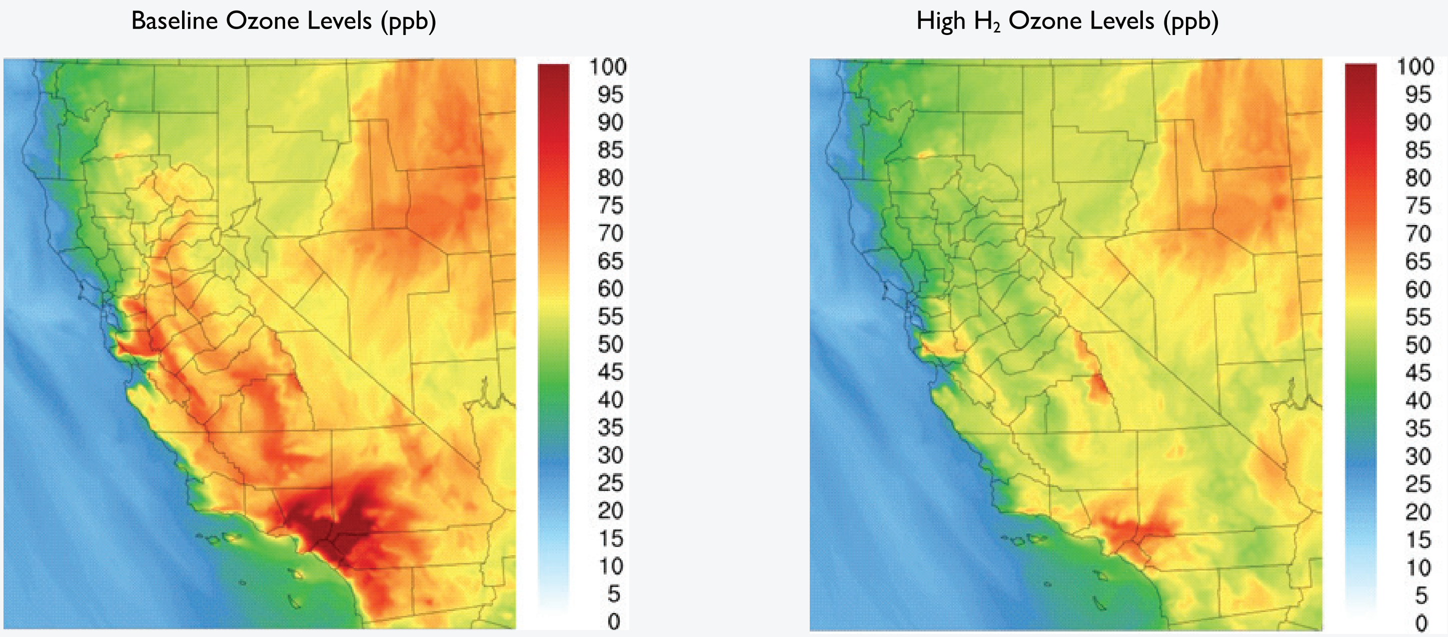


Figure 1. Ozone concentrations for business-as-usual energy systems and for an economy based on the use of renewable electricity and hydrogen and zero-emission batteries and fuel cells in all major economic sectors.

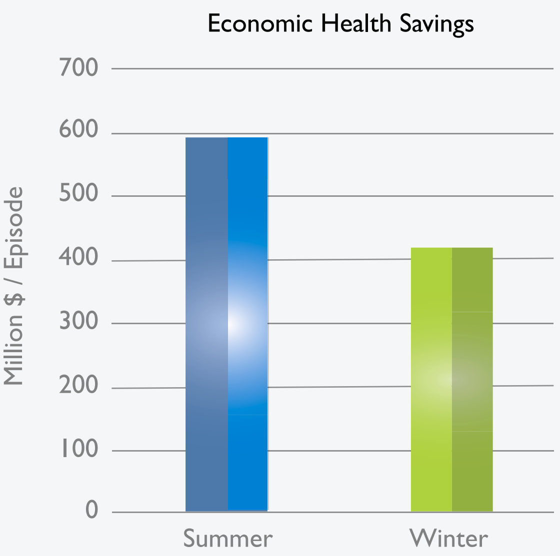
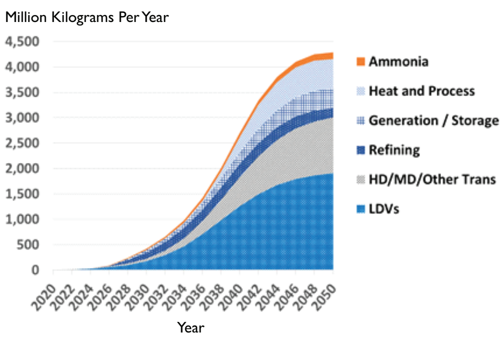


Figure 2. The estimated value of health benefits from AQ improvements for the High H2 Scenario for a 10-day pollutant formation episode.

Simply stated, the remarkable quality of air around the world associated with the pandemic has provided unique and invaluable insight into the air environment to which we aspire with the transition from fossil to renewable fuels. Equally profound, but not as evident, is the dramatic reduction in carbon emission, a requirement to reverse the damaging economic and environmental impacts associated with climate change. This indeed is a unique glimpse of the environmental quality which current policy goals are attempting to achieve in the second half of this century, and causes us to wonder if the goal could not be achieved much sooner through an improbable, but *not impossible* consensus of global leadership.

RENEWABLE HYDROGEN
AS A PLATFORM FOR SUSTAINABILITY

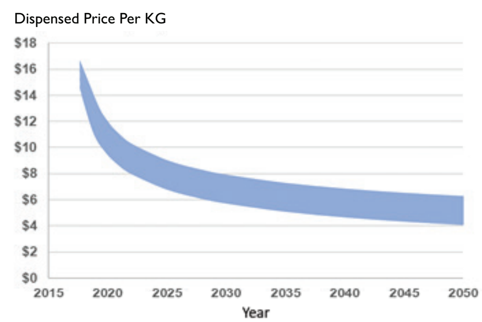
There is growing global consensus among energy experts that renewable hydrogen (RH2) can be a key foundation in decarbonization strategies, serving as a flexible source of renewable energy available on demand and storable in massive quantities. The Advanced Power and Energy Program (APEP) recently completed 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. Potential uses for renewable hydrogen include fuel for transportation of all types, refining, fertilizer production, firming of renewable power generation, and process heat and domestic heating. Hydrogen is a clean and versatile energy carrier that, when produced from renewable feedstock: creates no greenhouse gas emissions and has ultra-low conventional emissions in most applications. However, production capacity for renewable hydrogen is currently minimal in California and hydrogen pump prices for fuel cell vehicles, the foundational, early-market demand source, are above $16 per kilogram (the energy equivalent of one gallon of gasoline). Even with a fuel economy 2.5 times better than conventional combustion engine vehicles, the price per kilogram must be reduced. So, can renewable hydrogen production and supply chain costs come down to the point where the renewable hydrogen sector can be self-sustaining? The APEP research investigation concluded that the answer is yes and the demand for renewable hydrogen in California could exceed 4.2 billion kilograms per year by 2050.



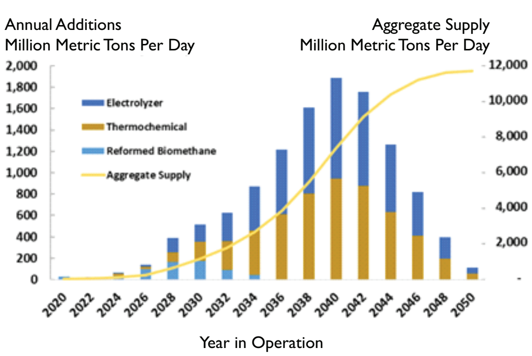
California Renewable Hydrogen Demand

Renewable Hydrogen Production Technology Pathways and Cost Outlook

Renewable hydrogen can be produced in a variety of ways. The three primary pathways considered in the roadmap were: 1) water splitting via electrolysis powered by renewable electricity; 2) gasification of woody biomass; 3) anaerobic digestion of high-moisture-content organic material to produce biomethane followed by steam methane reforming (SMR). Establishing the current cost of producing renewable hydrogen and forecasting costs out to 2050 was a key part of the RH2 production roadmap analysis. A variety of methods were used to triangulate the estimates including expert input, learning-curve analysis and other methods. The net result of the analysis is that renewable hydrogen produced by either electrolysis or gasification can reach a cost point below $2 per kilogram in the 2030 time frame and the full dispensed cost of hydrogen for fueling vehicles can reach a cost point of under $5 per kilogram over the long term.



Evolution of Renewable Hydrogen Pump Price



Renewable Hydrogen Facility Build-out

Building Out a New Sector

A major construction program will be needed to meet the future demand for renewable hydrogen. Hundreds of new facilities will be needed by 2050. Facility siting will be driven by access to feedstock: wind and solar for electrolysis, woody biomass for thermochemical systems, and wet organic waste for reformed biomethane.

The Path Forward

Renewable hydrogen can be an important, in fact critical, part of a broad decarbonization strategy for California and the world. Action is needed to make this a reality. Research and development are needed to advance key technologies such as electrolysis and thermochemical biomass conversion. Policy and regulatory action are needed to adapt electric rate structure to support electrolysis and to recognize and enable the unique cross-sectoral benefits of renewable hydrogen fueling multiple applications. apep.uci.edu/rh2whitepaper

Improving the Environmental Benefit of Emerging Energy Storage Technologies through Life Cycle Analysis

As the electricity system transitions from dependence on fossil fuels and towards renewable energy resources, various stakeholders are recognizing the need for energy storage systems to enable higher use of variable wind and solar generation. The incumbent energy storage solution for shifting variable wind and solar generation over a period of a few hours is lithium-ion battery technology due to its high efficiency, decreasing cost, and high energy density, with significant development experience from their use in electric vehicles. With the increasing adoption of variable renewable energy resources and evermore ambitious state wide electricity decarbonization goals, the need for energy storage systems that can shift variable renewable generation across longer durations will be needed.

Flow batteries represent a promising technology for electrical energy storage systems that can potentially fill the need to shift renewable generation on multi-day timescales. These flow battery systems store energy in liquid electrolytes housed in tanks that are physically separated from the electrodes. When undergoing charging and discharging processes, these electrolyte solutions are pumped and flowed through the anodes and cathodes as needed. These characteristics are in contrast to conventional batteries (such as lithium-ion), where energy is stored in an electrolyte solution that is physically packaged in the same unit as the electrodes.

Flow batteries enable energy storage installations to size their power capacity and energy capacity independently of each other and to be tailored for specific applications. Expanding power capacity involves installing more reaction plate areas, whereas expanding energy capacity involves installing more electrolyte storage. Therefore, these systems can be sized to provide multi-day energy storage at potentially lower costs than conventional batteries.

Both conventional and flow batteries enable reductions in environmental impacts by allowing the electric grid to absorb more renewable electricity generation. These systems also contribute towards environmental impacts from the materials extraction, manufacturing, and end-of-life stages of their life cycle. While significant research data exists for characterizing these impacts for conventional battery chemistries, a similar understanding does not yet exist for flow battery chemistries. Given that flow batteries may fulfill an important role in enabling the development of a highly renewable electric grid in the future, it is critical to gain an understanding of their life cycle environmental impacts and compare these to the environmental benefits these systems provide during their use on the electric grid.

The Advanced Power and Energy Program (APEP) was awarded a California Energy Commission research grant for a 3-year project to perform life cycle environmental and human health impact assessment of emerging flow battery chemistries. The project involves expertise across UC Irvine on energy systems, materials science and footprinting, and public health. APEP has worked with input from three flow battery manufacturers representing three different flow battery chemistries: Vanadium Redox (UniEnergy Technologies), Zinc-Bromide (Primus Power), and Iron (ESS Inc.) to obtain material composition and supply chain data.

To date, the project has discovered that all three flow battery chemistries provide similar levels of environmental benefits during their use, but have widely ranging environmental impacts from other stages of their life cycle and have key materials that are largely responsible for those impacts. For example, the vast majority of environmental impacts from the Vanadium Redox flow battery are due to the sourcing and production of Vanadium Pentoxide used to produce the battery electrolyte. However, different pathways for producing these compounds can significantly increase or decrease the extent of impacts from this technology. In general, materials selection was found to be a key sensitivity for the environmental impact results for these technologies.

The project is due to be completed in the second half of 2020. The data from this project will allow policymakers and decision-makers a better understanding of the life cycle environmental impacts of these emerging technologies, which can be compared to those of conventional battery technologies. This will also provide flow battery manufacturers insight into how to improve their supply chain, manufacturing processes, and materials selection to reduce the environmental impacts associated with their products in current and future product iterations.

"The Advanced Power and Energy Program (APEP) was awarded a California Energy Commission research grant for a 3-year project to perform life cycle environmental and human health impact assessment of emerging flow battery chemistries."

Fuel Cell Technologies for Heavy Duty Transportation

The energy industry is comprised of four major sectors that include residential, commercial, industrial and transportation. The transportation sector consumes the largest amount of energy at the lowest efficiency. Electrification of the transportation sector is needed to reduce its reliance on fossil fuels and to reduce greenhouse gas emissions. In the United States, more than 70 % of freight is carried by trucks [1]. Medium- and heavy-duty trucks (Class 3-8) use 25 % of yearly fuel used by all vehicles [2]. Most heavy-duty trucks are currently powered by diesel engines that emit nitrogen oxides and high levels of particulates. The Energy Information Administration (EIA) projects that freight trucks travel will increase by 54 % by 2050 [3]. To meet the increased demand for truck freight and to reduce fossil fuel energy dependency, battery electric and hydrogen-powered fuel cell electric freight trucks pose as a viable solution.

Fuel cell electric freight trucks utilize hydrogen as a fuel and offer a much higher specific energy than batteries. Freight trucks that use hydrogen produced from renewable energy, have a well-to-wheels (upstream emissions due to electricity and hydrogen production) emissions of 0. Fuel cells also offer high efficiency and fast fueling time, as well as fuel storage for long range medium- and heavy-duty trucks. The current challenge is understanding the existing freight trucks drive cycle and designing a fuel cell stack for these driving conditions with a demanding durability requirement, of which up to one million miles for the lifetime of the stack is needed for medium- and heavy-duty trucks. In addition, longer operation time and greater mileage range require efficient fuel consumption and therefore operation of fuel cells at higher efficiencies (higher voltage, lower current densities).

To address these challenges, the National Fuel Cell Research Center (NFCRC) Associate Director Professor Zenyuk and her team partnered with Robert Bosch LLC, based in Sunnyvale, CA, to advance fuel cell technologies for freight truck use. The team have set the goal to achieve fuel cell efficiency of >65% and durability of 30,000 hours that are aligned with the Department of Energy (DOE) targets, while keeping platinum (Pt) loading in cathodes below 0.2 mg/cm^2. These targets will be achieved by using novel catalysts, catalyst support, advanced diagnostic, modeling and development of accelerated stress tests (ASTs) that simulate the drive-cycle of medium- and heavy-duty trucks. Durability and efficiency are two design criteria that guide development of membrane electrode assembly (MEAs) for medium-duty and heavy-duty trucks. MEAs are at the heart of fuel cell technologies and consist of polymer electrolyte membrane (PEM) and catalyst layers that are made up of Pt or Pt-alloy electrocatalyst, carbon black support, and ionomer. Fuel cell durability losses are due to Pt dissolution and agglomeration during drive cycle, in addition to carbon-support corrosion. These losses are more pronounced at high potentials. Therefore, the design of a robust catalyst layer and MEAs is much needed to satisfy the 30,000 hour target. The NFCRC will use graphitized carbon black supports that are more corrosion resistant, as well as using other additives that can protect Pt from dissolution. Efficiency is a measure of fuel utilization, which scales with V/1.25 (V), based on a lower heating value (LHV) of hydrogen. A larger flexibility of fuel cell stack design for heavy-duty application allows more relaxed targets on Pt loadings but more stringent requirements for voltage and Faradaic efficiencies. To achieve higher efficiencies (>65%), we will target operation at lower current densities (higher potential) and higher temperatures. However, operation at these higher temperatures is not well understood, but it is known that degradation mechanisms are accelerated and the NFCRC and partners will study support corrosion rates as well as Pt dissolution. The team will also work on developing ASTs at these higher temperatures, to better understand the fundamentals of degradation mechanisms and to design MEAs that are efficient, durable and meet the ambitious goals set by the DOE.

[1] U.S. Department of Transportation, Bureau of Transportation Statistics and Federal Highway Administration, Freight Analysis Framework, version 4.4.1, 2018, https://www.bts.gov/topics/freight-transportation/freight-shipments-mode

[2] Oak Ridge National Laboratory, 2017. Transportation Energy Data Book 36, tables 4.1, 4.2, 5.1, and 5.2.

[3] U.S. Energy Information Administration, 2018. Annual Energy Outlook 2018, Transportation Sector Key Indicators and Delivered Energy Consumption Table (Reference Case), accessed May 10, 2018

UCI Hydrogen Refueling Station History

Since 2003, the National Fuel Cell Research Center (NFCRC) has operated the first U.S. publicly accessible hydrogen refueling station (HRS). During this period, the UCI HRS supported all vehicle manufacturers in the early, pre-commercialization years evaluating the fuel cell electric vehicle (FCEV).

The inaugural station ("GEN I"), funded by Toyota, featured (1) an Air Products & Chemicals, Inc. (APCI) "SFC-2" fueling system with a two-fill-per-day design capacity at a fueling pressure of 350 MPa, (2) a gaseous hydrogen supply from a locally sited 280 kg capacity tube trailer, and (3) an enclosed and secured 10-foot high screened perimeter fence. Drivers were required to wear personal protective equipment and ground the vehicle before dispensing fuel. Reliability issues were common, and a total of 76 successful fills were completed before the station was upgraded.

The second-generation station ("GEN II"), also funded by Toyota, was commissioned in November 2003 with an APCI "Series 100" fueling system that featured an increased capacity of 2-3 fills-per-day, and a smaller, more space efficient tube trailer with a 110 kg hydrogen storage capacity. The dispenser was updated to simulate a gasoline dispenser, and that station provided hundreds of successful fills before it was retired in June 2006.

The third-generation station ("GEN III") opened in November 2006 (Figure 1). Funded by the South Coast Air Quality Management District, the U.S. Department of Energy, Toyota, Honda, and BMW, the station was the first in California to feature both 350 bar and 700 bar fueling. While the station was designed to dispense 25 kg per day, dispensing up to 60 kg on peak days was common. Unlike the first two generations, hydrogen was delivered and stored at the station as a liquid. As needed, the liquid was vaporized and delivered to an APCI "Series 200" fueling system featuring a main compressor to fill the storage tubes, and a booster compressor to achieve the 700 bar fills. Aesthetically, the third-generation station simulated a retail fueling station with a dispensing island and canopy to provide station users protection from the elements. The station provided in excess of 18,000 successful fills, and supported FCEVs in the NFCRC fleet.

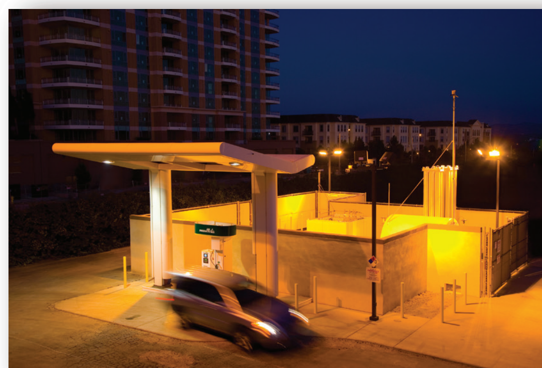


Figure 1. GEN III Hydrogen Refueling Station at Night (Photo Credit: Paul Kennedy)

OEM test fleets from Toyota, GM, Hyundai, Honda, Mercedes-Benz, BMW, and Mazda. Figure 2 shows the annual number of fills and quantity of hydrogen dispensed for the third and fourth generation UCI HRS.

The fourth-generation station ("GEN IV") opened for retail sales in November 2015. The station design, implemented (1) infrared wireless communication for 700 bar fills to replace a wired communication cable, (2) a dispenser with a retail-ready point-of-sale (POS) capability, and (3) a 180 kg per day design capability compliant with SAE J2601. In addition to light-duty passenger vehicles (LDV), the station has also served two hydrogen fuel cell electric buses (FCEBs), one operated by the UCI student "Anteater Express" bus service and the other operated by the Orange County Transportation Authority.

The GEN IV station has supported the first five years of FCEV commercialization with daily hydrogen dispensed increasing to levels exceeding 300 kg, a maximum one day record of 397 kg, over one hundred vehicles per day on average, and often two fuel FCEBs filled per day. Designed for 180 kg/day with one fueling position, the station has been understandably taxed. This notwithstanding, the early adopters of FCEVs have been remarkably supportive and accommodating given the various issues with fueling availability and dependability that are inevitable at this formative stage.

Planning for GEN V HRS is underway with a design goal to dispense up to 1200 kg daily with two dispensers and four fueling positions.

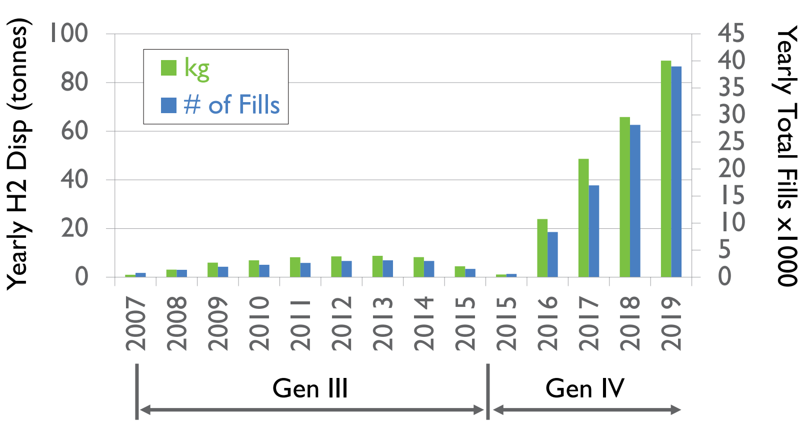


Figure 2. UCI HRS historical hydrogen dispensed and total fills in each year since 2007 across two generations of HRS equipment installed at UCI

Reference Spray for Aligning the Spray Community

In nearly all applications that involve complex devices or difficult to measure quantities, it is important to have a means of establishing accuracy of the measurement system. The spray generated by high pressure injection of a liquid through an atomizer or small orifice is no exception. With no first principle approach available to determine the resulting size distribution, a heavy reliance on measurements is necessary. Yet with many methods to measure features of the spray (e.g., droplet size, velocity, concentration) available, it is difficult to ascertain accuracy. To this end, the concept of a reference spray has been put forth by the spray community with leadership by the UC Irvine Combustion Laboratory (UCICL). Figure 1 presents the overall assembly.

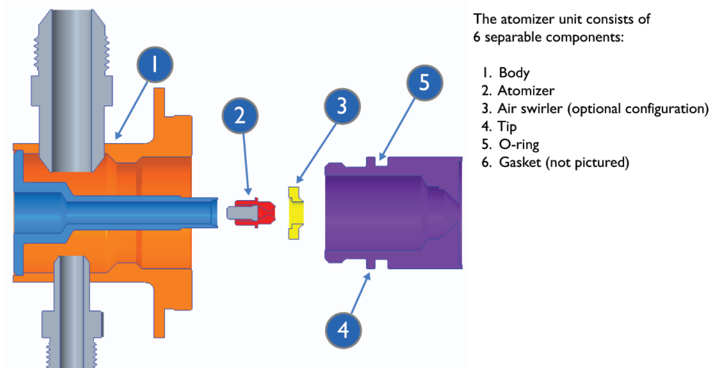


Figure 1. Exploded View of Reference Spray [1].

The main intention is to have a portable device available to the spray community that produces a repeatable spray that can be used to evaluate 1) different measurement methods, 2) measurements obtained by different users with the same method and/or 3) measurements from different laboratories. Furthermore, the internal geometry of the device is available so that researchers conducting simulations can compute the internal and external liquid flow and breakup. By having a common device with which to apply experimental and numerical methods, a consensus on the resulting spray characteristics can be established, helping to bolster confidence in both.

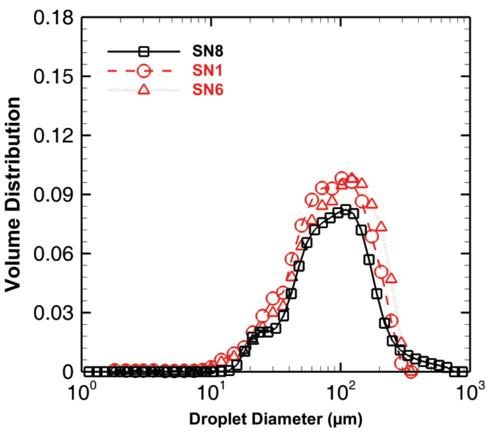


Figure 2. Comparison of Measurements of Three Individual reference sprays (SN1, 6, 8) and two laboratories (Red and Black) [2]

With an available database, results from new users or new methods can be compared against a body of knowledge to gain confidence in the resulting information. Figure 2 presents an example in which two laboratories applied laser diffraction (a well-established line of sight drop size measurement method which has been developed into commercial instruments by several manufacturers) at a particular condition and location to sprays produced by 3 of the 10 available "identical" atomizers. As shown, consensus is reached regarding the average size produced by the three individual atomizers and the comparison between the laboratories also yields satisfying agreement as well despite different users, different commercial instruments, and different laboratories. Since introduction of this concept by the UCICL in 2018, other groups are starting to populate a database for certain conditions [3] creating a consensus for some of the difficult to assess characteristics.

> *By having a common device with which to apply experimental and numerical methods, a consensus on the resulting spray characteristics can be established, helping to bolster confidence in both.*

References

[1] Thistle, A.G., McDonell, V.G., and Halls, B., Standard Simplex Atomizer Program Status and Expectations, ICLASS 2018, Chicago, IL, July, 2018

[2] Leask, S.B., Li, A.K., McDonell, V.G., and Samuelsen, G.S., Preliminary Development of a Measurement Reference using a Research Simplex Atomizer, ASME Journal of Fluids Engineering, Vol 141, pp 121407.

[3] GEOMETRY AND SPRAY CHARACTERISTICS OF STANDAR SIMPLEX ATOMIZERS (2020). Sforzo, B., Tekawade, A., Kastengren, A., Powell, C., Leask, S., Li, A., and McDonell, V. AIAA Scitech Forum, DOI: 10.2514/6.2020-0912, Orlando, FL

HORIBA Institute for Mobility and Connectivity^2

UPDATE

Last year in Bridging (2019), we introduced the plan for constructing and launching the "HORIBA Institute for Mobility and Connectivity^2 (HIMaC^2)," a joint initiative of HORIBA and APEP to provide an advanced research and educational platform to address the critical grand challenges at the nexus of energy and the environment. "Mobility" encompasses the future of transportation with the evolution of zero-emission vehicles operating on plug-in electricity, hydrogen, and a combination of plug-in electricity and hydrogen. "Connectivity" encompasses the following two distinct research thrusts in the future of mobility:

- The emerging paradigm of "connecting" mobility with the electric grid (e.g., G2V, V2G), and "connecting" hydrogen with the electric grid for (1) long-duration of energy storage and (2) providing fuel for both mobility and power generation.
- The communication "connection" between vehicles (V2V), and vehicles and the infrastructure (V2I).

When opened, the Institute will encompass the following four laboratories in addition to a grand main entrance and reception:

- A Vehicle Evolution Laboratory (VEL) to address the development and deployment of next-generation zero-emission vehicles;
- A Grid Evolution Laboratory (GEL) to explore the next-generation smart, 100% renewable electric grid and, in combination with the VEL, explore the emerging paradigm of connecting mobility to the electric grid;
- A Connected and Autonomous Mobility Laboratory (CAML) for state-of-the-art research in V2V and V2I connectivity as well as sensors and perception; and
- An Analytic Laboratory (AL) with the latest instrumentation in support of electrochemical materials research associate with zero-emission vehicles, and zero-emission distributed energy power generation and storage.

COVID-19 has not slowed the construction of the four laboratories, main entrance, and reception. However, the commissioning of equipment may be delayed a few months due to travel restrictions.

Outreach Student Experience

Graduate student researchers (GSRs) at the Advanced Power and Energy Program (APEP) volunteer their time at Elementary, Middle School, High School, and Community Colleges around the region for presentations at career days, science fairs, classroom visits, and other programming events. The GSRs provide information on APEP's clean energy research and on careers in Science, Technology, Engineering, and Math (STEM). Each graduate student that participates in these visits not only provides valuable information for their audience but returns to APEP with new insights and experiences "outside the lab." GSR's shared the impact these events can have on themselves and the audience, and provided insight into these experiences:

"In my first year as a Graduate student at APEP, I had the opportunity to attend a Career Day at Richard L. Graves Middle School in Santa Fe Springs. We presented on STEM career opportunities and how the research we perform in our lab has a positive impact on society and the environment.

While presenting to the group, I mentioned that I did my undergrad back in Mexico at CETYS University. Suddenly a student exclaimed with excitement, 'That's where my mom did her undergrad too!'

The atmosphere of the classroom changed. We made a connection with the students on another level and they were more curious and engaged about our presentation—we successfully piqued their interest. We continued with the presentation on the hydrogen economy and a plethora of questions quickly arose. The students came to the realization: why hadn't we adopted hydrogen already?

In the end, we left the school with an incredible sense of satisfaction and realized that representation for underrepresented groups really matters. Why is this so important? As a member of a minority group, seeing yourself reflected in someone that is positively impacting society is meaningful in its effect to empower oneself to pursue great achievements.

Representation of underrepresented groups benefits society as a whole. A diverse group of people ensures a variety of perspectives that lead to better decisions. The renewable energy economy will benefit those who are disadvantaged by lowering pollution and empowering them with local power, autonomy, and more control of their own lives." **–Melina Arrizón**

"One of my favorite outreach moments was in 2019 when we hosted Columbus Tustin Middle School's magnet program, of which I am a graduate. It took a couple months of planning on both sides, but we were able to bring over 30+ students to APEP for a tour and presentations on APEP research. Before coming onto campus, the teachers had tasked the students to research different sustainable energy topics ranging from fuel cells to alternative fueled vehicles, so they came poised with lots of questions. It was so exciting to see their interest in renewable energy and sustainability. Not only did my fellow graduate students and I share our research, we also talked about our individual journeys to graduate school and engineering as a career. It was such a rewarding experience to give back to my community and hopefully inspire the next generation of engineers." **–Kate Forrest**

"As I sat at a desk in the crowded gym of a school on Ask-A-Scientist Night, a budding young sixth grade scientist approached and sat down, flanked by their parents and younger sibling. This was the student's chance to ask me for advice on their Science Fair project before the final judging a few months away. The student began to explain their project idea: a trash sorter that could separate food waste from recyclables and other categories of trash.

My first thought was: 'This is a wonderful idea that some of the smartest people in the world are working on, but I'm afraid the scope might be a bit too aggressive for a single sixth grade student to accomplish in the next four months.' I held that thought back and started to engage with the student and was immediately impressed by the depth of planning they had already done. Things like machine learning and image processing were all part of the plan. They clearly understood the general approach to solving the problem.

At this point, I started to make some suggestions to narrow the scope. Each little suggestion I made, the student would eagerly come back with a way to accomplish the general goal in a more-achievable manner. The student was hungry to get to back at the design and could not wait to make a working prototype for the Science Fair. That sense of discovery was beautiful to see, and I could tell the parents were proud as well.

Unfortunately, I never did get to see the final project. However, I am confident that no matter how it evolved, the student will continue to work hard at solving the world's problems and inspire others to do the same just like they inspired me." **–Blake Lane**

Graduates and Internships

2019-2020

Master of Science

Graduates

Alice Li

An Experimental Investigation of
High-Velocity Non-Spherical
Polydisperse Particle-Laden Flows

Shan Tian

Environmental Benefit-Detriment
Thresholds for Flow Battery
Energy Storage Systems

Alejandra Hormaza Mejia

Experimental Investigation of
Hydrogen and Hydrogen/Methane
Mixture Leakage from Low-Pressure
Natural Gas Infrastructure

2019-2020

Ph.D.

Graduates

Van Vifvat

Zero Emission Shared-Use
Autonomous Vehicles: A
Deployment Construct and
Associated Energy Grid and
Environmental Impacts

Blake Lane

Alternative Light- and Heavy-Duty
Vehicle Fuel Pathway and
Powertrain Optimization

Kate Forrest

Zero-Emission Heavy-Duty Vehicle
Integration in Support of a 100%
Renewable Electric Grid

Laura Novoa

Optimal solar PV, battery storage,
and smart-inverter allocation in
zero-net-energy microgrids
considering the existing power
system infrastructure

2019-2020

Internships

Matthew Clower

Disney Imagineering (2019-2020)

Jennifer Lee

Southern California Edison (Summer 2020)

Alireza Saeedmanesh

174 Power Global (Summer 2020)

Sarah Wang

Schneider Electric (Spring 2020)

JOURNALS

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KINETIC ISOTOPE EFFECT AS A TOOL TO INVESTIGATE THE OXYGEN REDUCTION REACTION OF Pt-BASED ELECTROCATALYSTS. PART I: HIGH-LOADING Pt/C AND Pt EXTENDED SURFACE (2020). ChemPhysChem, Vol. 21, Issue 6, pp. 469-475 (T.Y. George, T. Assed, A. Avid, P. Atanassov, and I.V. Zenyuk)

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2019-2020 ACADEMIC YEAR HIGHLIGHTS

SUMMER 2019

US National Combustion Conference — June 2019

The UC Irvine Combustion Laboratory participated in the 11th U.S. National Combustion Conference held in Pasadena, CA. The UCICL students presented papers on an array of combustion research topics.

APEP Hosts Student Tours — July 2019

Students from Mark Keppel High School and Alhambra High School visited the UC Irvine Combustion Lab for a presentation and tour of the UCICL test laboratories.

UC Global Climate Leadership Council — July 2019

Members of the UC Global Climate Leadership Council visited the Advanced Power and Energy Program for a presentation on research and a tour of APEP's connectivity lab, power-to-gas research, and the BluGen integrated SOFC system.

FALL 2019

Korean Electric Power Corporation — September 2019

Representatives from Korean Electric Power Corporation (KEPCO) visited the Advanced Power and Energy Program for a combination of lectures on vehicle electrification, hydrogen for transportation, and tours of the APEP laboratories and the APEP-UCI power-to-gas demonstration site.

Camp TechTrek — October 2019

Camp TechTrek students visited the Advanced Power and Energy Program for a lab tour and hands-on experiments to learn about Hydrogen/Fuel Cells.

Scialog Fellow Award — November 2019

NFCRC Associate Director Iryna Zenyuk was selected for a third year as a Scialog Fellow and attended an invitation only workshop titled "Scialog: Advanced Energy Storage" by Research Corporation for Science Advancement (RCSA). The workshop provided a platform for 50 junior and mid-career faculty to collaborate on innovative energy-storage projects; the top projects were selected and then awarded funding. Professor Zenyuk's team was selected by RCSA and its funding partner, the Alfred Sloan Foundation, for an award on their project titled "Data-Driven Discovery of Bifunctional Metal Air Battery Cathodes." This project will open new routes to the design of energy storage interfaces and improve the efficiency of zinc-air batteries.

WINTER 2020

UC Irvine Fuel Cell Bus — December 2019

The UC Irvine Fuel Cell Bus was featured on the U.S. Department of Energy's website for the Hydrogen and Fuel Cells Program. The bus was part of the first ever zero-emission bus fleet in California.

International Symposium on Solid Oxide Fuel Cells — January 2020

The NFCRC participated in the 16th International Symposium on Solid Oxide Fuel Cells in Kyoto, Japan. Graduate student researchers presented research on the integration of solid oxide fuel cells.

UC Irvine Hydrogen Fuel Station Record Year — January 2020

For 2019, a total of 89,007 kilograms of hydrogen were dispensed, which is 23.6% more output than in 2018. The majority of the output was into light duty fuel cell electric vehicles.

SPRING 2020

Norwegian University of Science and Technology — February 2020

The NFCRC hosted Professor Odne Burheim from the Norwegian University of Science and Technology for a presentation and talk on the use of electrochemical technologies in Norway and technical details of thermal conductivity measurements.

Career Exploration Day — February 2020

APEP graduate student researchers participated in a career exploration day at Richard L. Graves Middle School in Whittier. The GSRs presented on the importance of STEM workers and sustainable growth in developing countries.

UCI Sustainability — March 2020

UCI Sustainability undergraduate students visited the Advanced Power and Energy Program for research presentations on the UCI Microgrid, blending hydrogen with natural gas in cooking and heating appliances, and fuel cells for data centers.

California Air Resources Board Delegation — March 2020

A delegation from the California Air Resources Board that included representatives from government and industry visited APEP for an in-depth presentation on fuel cells used for backup power. The group also toured the UC Irvine Hydrogen fueling station and a fuel cell installation at Kaiser Permanente.

SoCalGas and Future Fuels CRC of Australia — March 2020

Representatives from the Southern California Gas Company and Future Fuels CRC of Australia visited APEP for a presentation on research and a discussion on hydrogen innovation projects. The group also toured the NFCRC Fuel Cell lab and UCICL hydrogen blending project.

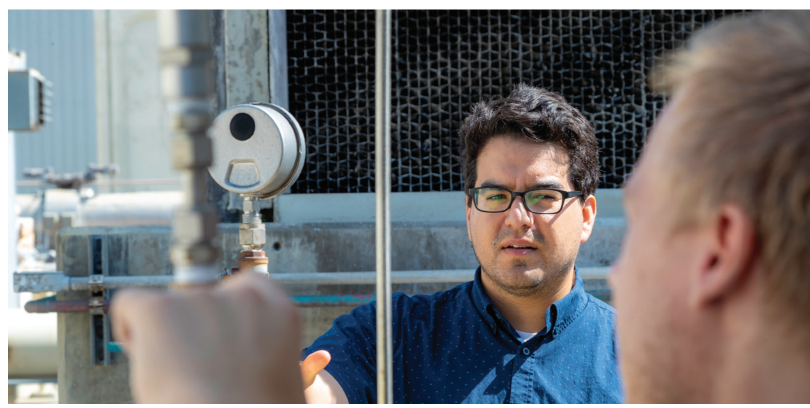
www.apep.uci.edu

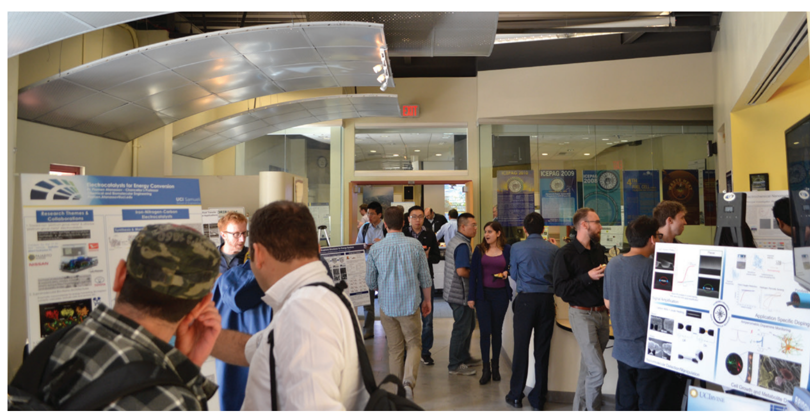
Advanced Power and Energy Program
University of California, Irvine
Irvine, California 92697-3550

The Advanced Power and Energy Program (APEP) encompasses three organizational elements: the National Fuel Cell Research Center, the UCI Combustion Laboratory, and the Pacific Rim Consortium on Combustion, Energy, and the Environment.

APEP advances the development and deployment of efficient, environmentally sensitive, and sustainable power generation, storage, and conservation. At the center of APEP's efforts is the creation of new knowledge brought about through fundamental and applied research and the sharing of this knowledge through education and outreach.

The connection of APEP's research to practical application is achieved through our close collaboration with industry, national agencies, and laboratories to "bridge" engineering science and practical application.





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

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