NETL EDGE

Vol. 03/ 2021 Issue 02

A Publication of the U.S. Department of Energy's National Energy Technology Laboratory

DECARBONIZING OUR ENERGY FUTURE

NATIONAL ENERGY TECHNOLOGY LABORATORY

NETL EDGE

Vol. 03/ 2021 Issue 02

NATIONAL ENERGY TECHNOLOGY LABORATORY

ON THE COVER

NETL is applying its expertise and skill to advancing technologies needed to mitigate the climate crisis and meet the Biden Administration's goals calling for a net-zero carbon emission electricity sector by 2035 and economy-wide net-zero emissions by 2050. Carbon mitigation technologies like direct air capture, as depicted here, are central to this effort.

DIRECTOR'S MESSAGE

Across the nation, scientists and engineers are working hard to deliver solutions to the global climate crisis and meet the Biden Administration's decarbonization goals calling for a net-zero carbon emission electricity sector by 2035 and economy-wide net-zero emissions by 2050.

The aggressive targets to transition our energy sector present tremendous opportunities as we reimagine what the energy of the future looks like, including the pathway to decarbonization.

NETL's work fits at the crux of environmental sustainability and prosperity. We're ensuring affordable, abundant and reliable energy that drives a robust economy and national security, as we develop technologies to manage carbon across the full life cycle and enable environmental sustainability for all Americans.

We've historically had a long effort in carbon management, including a carbon capture and storage program that has advanced the technologies over the last 25 years to where they are today, ready for wider-scale deployment.

In this issue of NETL Edge, we feature a few of the ways we at NETL are approaching the pathway to decarbonization, including:

- A proposed test center for direct air capture that will enable research, development, demonstration and deployment projects to advance and commercialize technologies to remove CO_2 directly from the air on a significant scale.
- Workforce training programs with the Appalachian Regional Commission that are addressing regional worker shortages while helping to decarbonize our economy.
- Efficient and cost-effective technologies to convert CO_2 emitted by power and industrial sources into chemical building blocks.

As you'll read in this issue of NETL Edge, the pathway we envision to decarbonization includes a robust blend of technology, including carbon capture and storage, hydrogen and hydrogen-related fuels, and I'm proud of NETL's forward-looking efforts to drive innovation. Our vision is to be the nation's premier technology laboratory, delivering integrated solutions to enable transformation to a sustainable energy future. After reading this issue of NETL Edge, I think you'll agree we're well on our way.

Brian J. Anderson, Ph.D.
Director, NETL

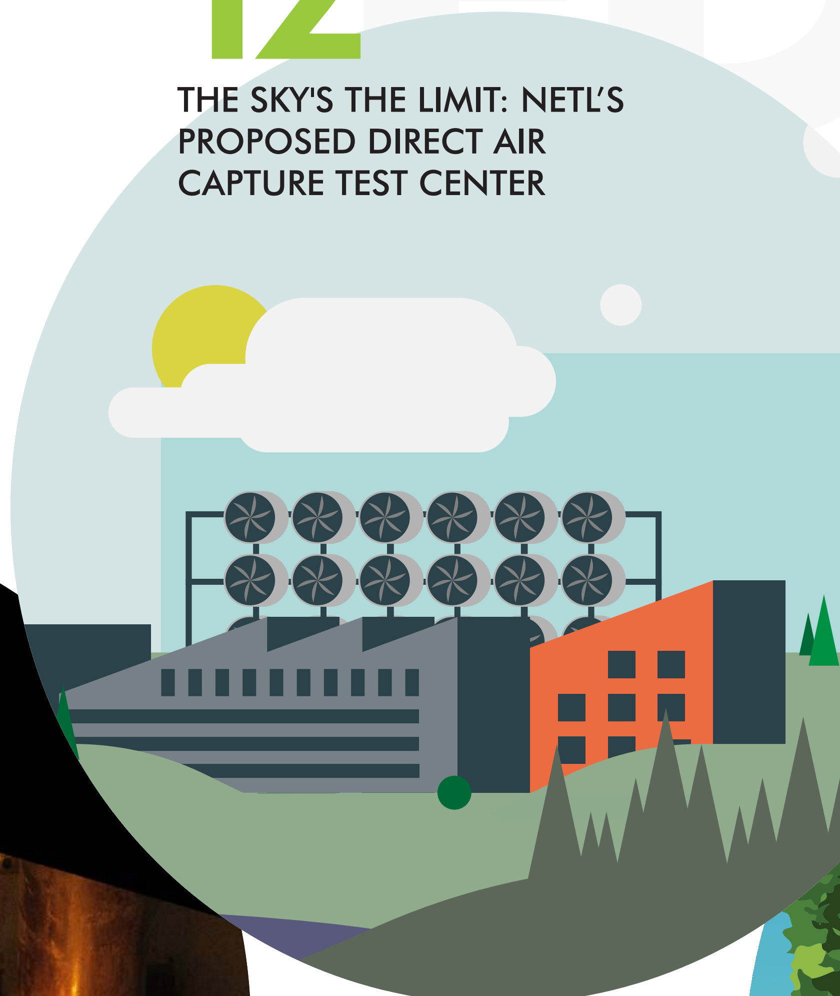
TABLE OF CONTENTS

12

THE SKY'S THE LIMIT: NETL'S PROPOSED DIRECT AIR CAPTURE TEST CENTER

06

NETL SUPPORTS EFFORTS TO ADDRESS REGIONAL WORKER SHORTAGE AND CLIMATE CHANGE SIMULTANEOUSLY



20
HYDROGEN HOPES: AN INSIDE LOOK WITH ENERGY CONVERSION ENGINEERING SENIOR FELLOW NATHAN WEILAND

16
NETL ADVANCES GREEN RECIPE FOR HYDROGEN PRODUCTION

BY CONOR GRIFFITH

NETL SUPPORTS EFFORTS TO ADDRESS REGIONAL WORKER SHORTAGE AND CLIMATE CHANGE SIMULTANEOUSLY

NETL is taking an active role to ensure the next generation of energy workers are prepared to sustain the industries of tomorrow as America undergoes its next energy transformation.

Continued on page 8

PRESSING NEEDS,

NEAR AND LONG TERM

From military applications to automotive, aerospace and construction, welding is an essential pillar of the U.S. economy. However, the American Welding Society is anticipating a shortage of 400,000 welders by 2024. The average age of a welder in the U.S. is 55, and fewer than 20% are under the age of 35. More and more welders are retiring, and new welders are not being trained quickly enough to keep up.

One of the most important needs is training welders to handle and work with superalloys and advanced materials that will be used in the next generation of clean energy power plants. As the nation takes steps to fight climate change and dramatically reduce levels of greenhouse gas in the atmosphere, a new generation of superalloys is needed that can survive in the advanced ultra-supercritical conditions found in highly efficient, clean-energy power plants. The development of heat- and corrosion-resistant alloys is imperative to expand the use of wind and solar energy to power the grid. And the greater use of renewable energy resources will lower emissions of carbon dioxide while keeping the nation supplied with reliable and affordable electricity. Welders who know how to work with these superalloys and possess the necessary skills to use them are needed to service and maintain the existing fleet and new clean power plants.

The U.S. Department of Energy (DOE), by way of NETL, partnered with the Appalachian Regional Commission (ARC) to help address these issues by creating much-needed employment opportunities and a pipeline of new welders via the Advanced Welding Workforce Initiative (AWWI).

Anthony Armaly, who serves as federal coordinator for the NETL Regional Workforce Initiative, explained that, under the DOE-led partnership, ARC provided guidance related to technical education while NETL contributed valuable insights about the use of new alloy, high-performance materials and manufacturing processes.

"By collaborating with our strong Appalachian and fossil energy stakeholder networks, together with ARC, we selected five regional technical education programs that will prepare workers for rewarding careers in growing industries where starting wages for certified welders are about $23 per hour plus benefits," Armaly said.

In total, the DOE-ARC partnership provided $1 million to pay for program planning, training and equipment at five schools in the Appalachia region to implement specialized AWWI curricula and learning modules in welding, robotics, process control and advanced manufacturing techniques. DOE provided $750,000 with ARC providing the remaining $250,000.

"Our immediate goals are to bring awareness about the urgent need for welders and provide information to those interested about job opportunities, training opportunities and wage information," Armaly said.

With the training of welders now underway, the AWWI exemplifies NETL's success in synergizing with industry and academia to solve economic challenges as well. While this initiative is focused on Appalachia specifically, Armaly noted that, if successful, the model could one day be replicated throughout the country.

The selected AWWI schools that will provide advanced welding training and their funding amounts are:

- Robert C. Byrd Institute at Marshall University, Huntington, West Virginia ($336,796)
- Belmont College, St. Clairsville, Ohio ($281,603)
- Calhoun Community College, Decatur, Alabama, ($198,000)
- Southeast Kentucky Community and Technical College, Cumberland, Kentucky ($105,281)
- Westmoreland County Community College, Youngwood, Pennsylvania ($78,320)

Armaly said these schools were selected because they met the requirements for the DOE-ARC funding opportunity and had the best overall proposals for leading a successful training program in advanced welding.

Key to the initiative's success is the participation of business and industry representatives, who provided information about specific workforce needs and built relationships with the schools that will result in apprenticeships and job placements.

Continued on page 10

MEETING THE NEEDS OF NEW INDUSTRIES

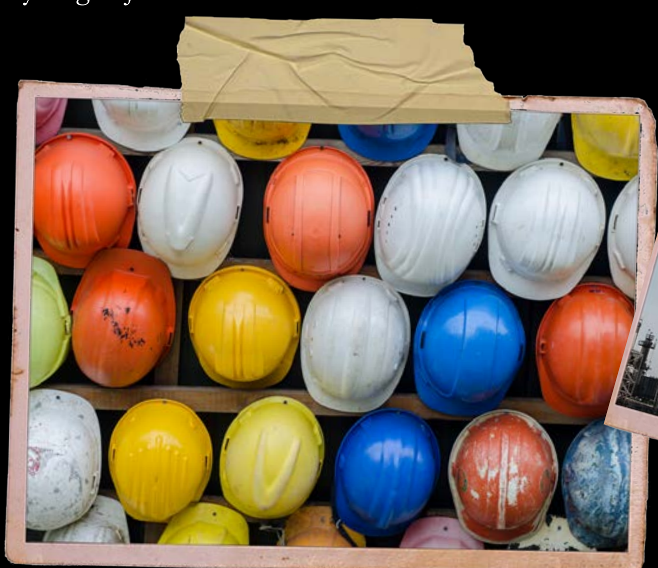
THE HYDROGEN ECONOMY WORKFORCE

"A number of relevant hydrocarbon workforce skills can be brought to bear on a blue/green hydrogen workforce and economy, up and down the production supply chain," Armaly said. "These also have a number of end uses, including transportation, industrial and manufacturing."

Implementing clean hydrogen can reduce emissions and accelerate the Biden Administration's goal of net-zero carbon emissions by 2050 while creating good-paying union jobs and growing the economy — but hurdles remain to deploying clean hydrogen at scale.

DOE recently announced the Hydrogen Shot, part of the Energy EarthShots initiative, designed to reduce the cost of clean hydrogen and establish a framework and foundation for clean hydrogen deployment.

Making hydrogen cost-competitive may also require a ready and able supply of hydrogen workers. A hydrogen workforce funding opportunity could concentrate on transitional jobs that require little upskilling for future hydrogen jobs.



Appalachian Regional Commission

Interagency Working Group on Coal & Power Plant Communities & Economic Revitalization

CARBON CAPTURE AND STORAGE WORKFORCE

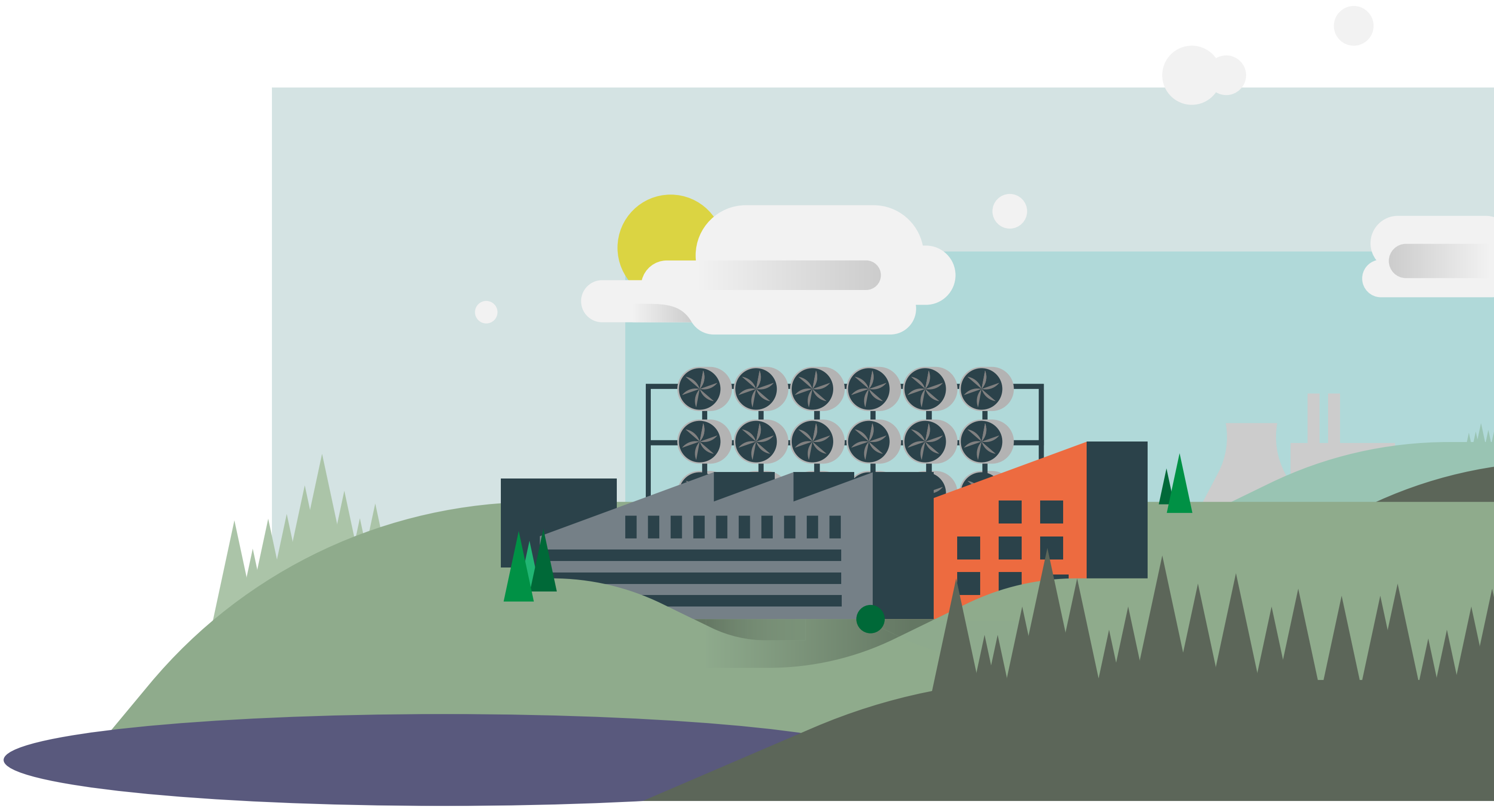
Jobs and workforce applications exist up and down the carbon capture and storage (CCS) supply chain and research pipeline, and the creation of a strong CCS workforce is hyper-relevant to NETL's mission and the existing hydrocarbon workforce in the Appalachian region. A well-trained CCS workforce would pay dividends while also amplifying the potential of CCS technologies.

In this area, NETL is building on past success. In 2009, with American Recovery and Reinvestment Act funding, the Lab facilitated seven regional technology training centers that focused on promoting CCS knowledge sharing and training opportunities. The centers largely focused on developing a professional workforce, with potential for expanding to other skills and upskilling as needed for technical and vocational jobs. These opportunities could include those workers already working in hydrocarbon union and non-union employment, or those transitioning from carbon ore-related employment.

The Sky's the Limit

NETL's Proposed Direct Air Capture Test Center

By Joe Golden



NETL has developed a wide range of transformative carbon capture and storage technologies to significantly reduce point-source carbon dioxide (CO_2) emissions. These efforts have served as a key strategy in the battle against climate change for many years, but the nation must accelerate and broaden its decarbonization efforts to meet the Biden Administration's goals of economy-wide net-zero carbon emissions by 2050.

Direct removal of CO_2 from the atmosphere, commonly referred to as direct air capture (DAC), is an emerging area of research that could reduce atmospheric CO_2 concentrations and help balance out emissions from hard-to-decarbonize sectors such as aviation. NETL is preparing for the future of DAC by planning a revolutionary new test center that, if funded, will enable research, development and demonstration of advanced technologies to support eventual deployment of capture technologies that remove CO_2 directly from the air on a significant scale.

Planning for the DAC Test Center, which is subject to fiscal year 2022 congressional funding, involves convening experts from all corners of the Lab, including NETL personnel involved in facility operations, finance and acquisition, strategic planning, process design, life cycle and technoeconomic analyses, data management, program management, and research and development. Going forward, external stakeholder input will also be sought to ensure the center's success.

A Research Facility for Government, Industry and Academia

The DAC Test Center will accelerate the development and deployment of DAC technologies by offering a highly instrumented research facility for prototyping and qualification. As planned, the center will operate over a wide variety of conditions (e.g., temperature, pressure, relative humidity and inlet CO_2 fraction), a feature that will help developers understand how their technologies respond in different climates, from summer to winter and arid to tropical.

Such a facility would be valuable to any organization seeking to develop DAC technologies, including universities, research institutions and U.S. industries, which do not typically have the resources or experience to construct, operate or comprehensively analyze the results of DAC tests at the scale envisioned for NETL's DAC Test Center. The advanced instrumentation available in the facility will allow technology developers to validate models of their materials and processes, as well as collect the data necessary to refine their technoeconomic projections and overall value proposition.

Other federal agencies, as well as organizations within DOE focused on reducing greenhouse gas emissions, will also benefit from the proposed DAC Test Center, which will serve as a bridge between bench scale and commercial scale, avoiding the so-called "valley of death" that often claims technology development between these stages. In addition to agency-wide collaborations, NETL plans to implement the DAC program for DOE's Office of Fossil Energy and Carbon Management, including managing extramural research projects, which will provide ready-made partnerships to amplify the Lab's technology development and maximize taxpayer dollars.

Continued on page 14

Convening a Wide Range of NETL Expertise

to Plan the DAC Test Center

In an exemplary team effort, NETL experts from diverse areas of the Lab are working together to assist in the designing and scoping of the proposed DAC Test Center.

NETL has significant expertise in lab-scale process design and testing, as evidenced by its past support to DOE in the test and evaluation of industry and research organization technologies. Examples include the testing of direct fuel-to-electrical energy conversion technologies and the competitive performance testing of power conversion technologies.

NETL also has significant expertise in the design and synthesis of a variety of novel carbon capture materials, molecular dynamics modeling, and process design and analysis. These competencies will provide significant technical insight leading to successful projects hosted at the center.

Through NETL's Systems Engineering and Analysis expertise, the Carbon Capture Simulation Initiative and the Institute for the Design of Advanced Energy Systems, NETL has the most authoritative team of scientists for carbon capture process analysis in the world. Because of this expertise, NETL is uniquely equipped to provide technoeconomic and life cycle analyses for projects that are tested at the DAC center. As a result, the Lab's modeling team is playing a key role in the design of the DAC center, ensuring that the experimental design is compatible with the Lab's suite of modeling tools.

Preserving, protecting and publishing DAC Test Center data and software tools is critical for the proposed center. Data management is essential to reduce security risks, minimize data loss, maintain data quality and improve collaboration. To that end, the DAC center will leverage NETL's Science-based AI/ML Institute (SAMI) capabilities, which include a smart data platform, standards and approaches. The smart data platform incorporates community- and government-approved sets of data management supporting data curation throughout the entire project life cycle. Thereby, the DAC Test Center and its stakeholders will be able to readily share information while protecting intellectual property rights. With these capabilities in place, DAC technology decision making will be based on complete, consistent and valid data sets and tools.

Getting to Net Zero

While the DAC Test Center is still in the planning and design phase and subject to congressional funding, it's clear that DAC technologies will be needed to help meet the nation's decarbonization goals in the future. The proposed DAC Test Center will focus on process design and data collection, specifically demonstrating process reliability, component lifetimes, energy consumption, capture efficiency and parameters needed to determine economic viability.

With this planning effort, NETL is committed to fully leveraging all its experience and expertise toward accelerating this emerging technology. No easily available and accessible facility currently exists to test these emerging technologies between the bench and pilot scales, and NETL's proposed DAC Test Center will help fill this gap when it's needed most as the nation steps closer to a clean energy economy.

NETL ADVANCES GREEN RECIPE FOR HYDROGEN PRODUCTION

BY MARTIN KINNUNEN

NETL is developing efficient and cost-effective technologies to convert carbon dioxide (CO_2) emitted by power and industrial sources into chemical building blocks such as formic acid, an organic compound that's used in applications across many sectors.

"Formic acid is a simple combination of hydrogen (H_2) and CO_2 that exists as a liquid under normal conditions. This means it could integrate smoothly into existing fuel transport infrastructure and more readily than hydrogen gas," said Douglas Kauffman, a research scientist at NETL.

Continued on page 18

"Our technological advancements are creating a transformational shift in which CO_2, the most prevalent form of greenhouse gas emitted by human activity, will transition from a waste product that contributes to climate change to a highly useful commodity."

"Formic acid can function as a liquid H_2 carrier that is easier to store and transport than compressed H_2 gas. In fact, one liter (0.3 gallons) of liquid formic acid contains 53 grams of H_2, which is equivalent to 590 liters (156 gallons) of uncompressed H_2 gas," Kauffman said.

"The ability to transport such large amounts of H_2 in liquid form will greatly reduce associated costs," Kauffman said.

Finding new ways to create and transport H_2 is important because, when consumed in a fuel cell, H_2 produces only water, electricity and heat, making this clean-burning energy source an important part of the nation's new power generation strategy, with potential for use across a broad range of applications.

For some time, H_2 fuel cells have been considered the potential platform to create zero-emission vehicles. One of the drawbacks has been setting up the infrastructure to store and transport H_2 gas. Formic acid produced from greenhouse gas could provide a solution.

"With this process, H_2 could be transported and stored in a liquid form, pumped into a device to extract it as a gas, and then fed into a H_2 fuel cell," Kauffman said.

Today, most H_2 manufactured in the U.S. is made via steam-methane reforming, a mature production process in which high-temperature steam (700 degrees Celsius to 1,000 degrees Celsius) is used to produce H_2 from a methane source, such as natural gas. It is an extremely energy-intensive process with a large carbon footprint (the steam-reforming reaction produces 10 tons of CO_2 for every ton of H_2).

Innovative technology developed by NETL such as the formic acid conversion process is addressing those obstacles and moving the creation of an eco-friendly H_2 economy forward.

Patent-pending technology invented by NETL researchers Christopher Marin, Kauffman, Jonathan Lekse and Eric Popczun has enabled a novel system and method for microwave-assisted dry reforming of methane — a process that reacts CO_2, instead of steam or oxygen — with methane to yield H_2 and chemical commodities such as methanol, which can be sold to generate revenue to offset carbon capture costs.

In their pioneering research, the NETL team demonstrated that microwave-assisted catalysis can be used as an enabling technology to promote high-temperature chemical processes.

Unlike traditional thermal heating, microwaves can rapidly heat catalysts to extremely high temperatures without heating the entire reactor volume. This reduces heat management issues of conventional reactors and enables rapid heating/cooling cycles. Ultimately, this can allow reactors to utilize excess renewable energy to promote traditionally challenging, thermally driven reactions for on-demand chemical production.

"The invention consumes 22 tons of CO_2 for every ton of H_2 produced and will be valuable technology to reduce greenhouse gas levels by converting CO_2 into H_2 and other useful chemicals," Kauffman said.

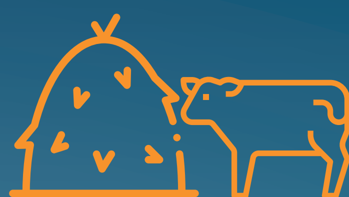
As the nation prioritizes decarbonization efforts, NETL is leading these efforts and others to advance innovative technologies to capture and use CO_2 as a feedstock to produce chemicals, fuels and other high-value materials and lower CO_2 levels in the atmosphere.

"Our technological advancements are creating a transformational shift in which CO_2, the most prevalent form of greenhouse gas emitted by human activity, will transition from a waste product that contributes to climate change to a highly useful commodity," Kauffman said.

NETL's carbon utilization efforts also will play a critical role to achieve the Biden Administration's goals calling for net-zero carbon emissions in the power sector by 2035 and the broader economy by 2050 while generating a host of revolutionary changes to help the environment.

“The invention **consumes 22 tons of CO_2 for every ton of H_2 produced** and will be valuable technology to reduce greenhouse gas levels by **converting carbon dioxide into hydrogen and other useful chemicals.”**

Carbon dioxide (CO_2) emitted into the atmosphere can be captured and converted into a nontoxic pesticide.



Formic acid also is used widely in agriculture as an antibacterial agent. When sprayed on fresh hay or other silage, it arrests decay and causes the feed to retain its nutritive value, making it especially useful in preserving winter feed for cattle.

Deicers made with formate salts are biodegradable and provide a swift and environmentally friendly way to treat slick runways. Plus, they don’t corrode landing gear and other aviation equipment.

Formic acid gels and strips placed in hives eliminate mites that pose a significant threat to honeybees but keep the bees healthy to complete their pollination chores.

Hydrogen Hopes

By Abby Humphreys

An Inside Look with Energy Conversion Engineering Senior Fellow Nathan Weiland

"Eventually, it is envisioned that hydrogen will displace natural gas and coal so that economy-wide, the nation's energy needs are met by either carbon-free electricity or net-zero carbon hydrogen."

As part of the Lab's mission to deliver solutions for an environmentally sustainable energy future, NETL is exploring clean-burning hydrogen to contribute to a carbon-free power sector by 2035 and emissions-free economy by 2050.

Hydrogen produces only water as a waste product when used as a fuel, which, when integrated into various energy sectors, will play an important part in reducing carbon emissions and meeting clean energy goals around the world.

Nathan Weiland, Ph.D., and NETL's senior fellow for Energy Conversion Engineering, is working to discover more about creating and using hydrogen to drive the energy technologies of the future. Since joining NETL 16 years ago, Weiland has worked on hydrogen combustors for low-NO_X gas turbines, co-gasification of coal and biomass, supercritical carbon dioxide power cycles and other novel energy conversion systems.

Read on to hear from this hydrogen expert on the latest technology developments taking place at the Lab and how this clean-burning fuel could revolutionize energy for a zero-carbon economy.

What led you to NETL?

I received a bachelor's degree in mechanical engineering from Purdue University in 1997. During my time at Purdue, I was a co-op student for PSI Energy, a public utility in southern Indiana that is now part of Duke Energy. I had the opportunity to work at a few power plants while I was at PSI Energy, including the new integrated gasification combined cycle power plant at Wabash River, where I first became interested in the power generation sector.

I carried this interest into graduate studies at Georgia Tech and received a master's degree in 2000, along with a Ph.D. in 2004. I started at NETL as a postdoc in the Oak Ridge Institute for Science and Education program in 2005, working on hydrogen gas turbine combustion in the Fundamental Combustion Laboratory at the Lab's Pittsburgh campus. Since then, I have been amazed at the ability of NETL researchers to conduct cutting-edge research and development across such a wide technology and application space.

What innovative hydrogen technology research is NETL focusing on?

NETL has been working in hydrogen for many decades, starting with a significant body of work in gasification systems for hydrogen and hydrogen gas turbine combustion. Since then, the Lab has branched into other research areas that span the entire hydrogen value chain, from production to transport, storage and utilization.

In addition to hydrogen production from gasification of coal, biomass and waste fuels, NETL is also working on advanced methods of hydrogen production from natural gas. This includes chemical looping reforming, microwave-enhanced reforming and methane pyrolysis, as well as water electrolysis from solid oxide electrolyzer cells — essentially solid oxide fuel cells run in reverse to split steam into pure hydrogen and oxygen.

More recent work includes exploring advanced hydrogen combustion processes like rotating detonation combustion, which can increase gas turbine efficiency. We're also looking into hydrogen utilization in solid oxide fuel cells for power production and innovative processes to produce valuable chemical products like ammonia and methanol.

Additionally, the Lab's researchers are working on methods of hydrogen transport and storage to get the clean hydrogen to market, which includes investigating the suitability of saline and other porous rock formations for subsurface storage of hydrogen. We are also working

Continued on page 22

on hydrogen-compatible pipeline materials and sensor technologies to detect hydrogen and maintain safety throughout the hydrogen value chain.

To enable hydrogen deployment, the Lab's capabilities in Strategic Systems Analysis & Engineering allow for comprehensive evaluations of the hydrogen energy system. These provide insight into the potential for new hydrogen technology ideas and analyze how hydrogen systems interact at plant, regional, national and global scales to provide critical input in hydrogen strategic planning.

What is hydrogen's role in building an emissions-free power sector?

The hydrogen combustion research conducted at NETL and other institutions a decade ago has led to commercial availability of large-scale gas turbines that can burn up to 30% hydrogen in natural gas with 100% hydrogen capability by 2030 or earlier.

This research has been a key enabler in recent hydrogen project announcements in Utah, Ohio, New York, Virginia and elsewhere, all of which will burn hydrogen for electric power. In these projects, hydrogen is used as a long-duration energy storage medium, providing anywhere from days to months of energy storage to offset seasonal changes in renewable power production.

However, it is envisioned that hydrogen is ultimately going to play only a small part in building an emissions-free power sector — its largest impact will be in overall decarbonization of the economy, particularly for sectors that are difficult to electrify.

Hydrogen is expected to eventually supplant petroleum products in some parts of the transportation sector, as well as provide a zero-carbon fuel for heavy industries like iron and steel making. Eventually, it is envisioned that hydrogen will displace natural gas and coal so that economy-wide, the nation's energy needs are met by either carbon-free electricity or net-zero carbon hydrogen.

What will clean hydrogen technologies of the future look like?

In a decarbonized economy, hydrogen may play a role in commercial buildings and residential homes. Heating needs and appliances of the future will either be powered by hydrogen or electrically via resistance heating or heat pumps.

In the transportation sector, light-duty vehicles will mostly be battery-powered, though medium and heavy-duty vehicles will likely be powered by hydrogen fuel cells to meet the rapid refueling demands of their associated industries.

Aviation will be among the most difficult sectors to decarbonize due to its need for high energy density fuels, though clean hydrogen may be a key feedstock to innovative fuel production processes that can produce sustainable, low-carbon aviation fuels.

None of these future developments can happen without a significant amount of research, development, analysis and planning. I'm excited about NETL's work across the hydrogen space and in furthering our role as a leader in the economic deployment of hydrogen that is needed to decarbonize our nation's economy.

U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

1450 Queen Avenue SW
Albany, OR 97321-2198
541-967-5892

3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880
304-285-4764

626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940
412-386-4687

Program staff are also located in **Houston, TX** and **Anchorage, AK**.

Visit us: **www.NETL.DOE.gov**

@NationalEnergyTechnologyLaboratory

@netl_doe

@netl_doe

NETL EDGE

www.NETL.DOE.gov

Vol. 03/ 2021 Issue 02

U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY