Vol. 04/ 2022 Issue 01

NETL EDGE

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

BUILDING OUR SUSTAINABLE ENERGY FUTURE

NETL Positioned to Meet Planet-Saving Goals in Historic Legislation

NATIONAL ENERGY TECHNOLOGY LABORATORY

NETL EDGE

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ON THE COVER

NETL is developing a range of potential direct air capture (DAC) technologies. The Lab's DAC center will house test platforms, like the one depicted here, for concurrent, fully integrated operations over a wide variety of relevant conditions. NETL's DAC center will hasten the maturation of technologies from DOE and stakeholders' research, with a focus on reducing costs and uncertainty to pave a path to commercialization and deployment.

DIRECTOR'S MESSAGE

At NETL, we're passionate about innovation, because our research has the power to improve people's lives around the world as we drive innovation and deliver solutions for an environmentally sustainable and prosperous energy future.

In this issue of NETL Edge, we discuss our Lab's contributions toward meeting clean energy goals calling for a net-zero carbon emission electricity sector by 2035 and economy-wide net-zero emissions by 2050. We also outline how our expertise and capabilities are being brought to bear on provisions of the historic Bipartisan Infrastructure Law (BIL).

The goals before us are aggressive, but also urgently needed to address the climate crisis and improve people's lives for decades to come.

NETL is building on its long legacy of success in clean energy innovation. Together with research partners across the nation, we're combining our expertise in science, engineering and project management with our world-class facilities to deliver integrated solutions that will enable transformation to a sustainable energy future. For example, NETL is:

- Positioned to execute major provisions of the BIL to address climate change and generate economic growth by transforming the nation's energy infrastructure.
- Guiding the path toward U.S. decarbonization through a comprehensive, multi-pronged approach for carbon management that involves coupling carbon capture methods with long-duration carbon storage or carbon dioxide utilization/conversion into long-lasting products.
- Playing a major role by using its competencies and project management expertise to move hydrogen research forward and supporting a promising new hydrogen industry in America.

We also feature our efforts to become a net-zero national laboratory by developing and deploying critical climate and clean energy solutions on its research campuses. We also have a conversation with Senior Project Manager Neil Kirschner about his work to develop technologies for attaining net-zero greenhouse gas emissions.

As you'll read in the following pages, NETL has an important role to play as we transition to a clean energy economy and decarbonized energy future.

I'm excited about our Lab's contributions and how our expertise and capabilities are ensuring meaningful opportunities become effective realities.

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

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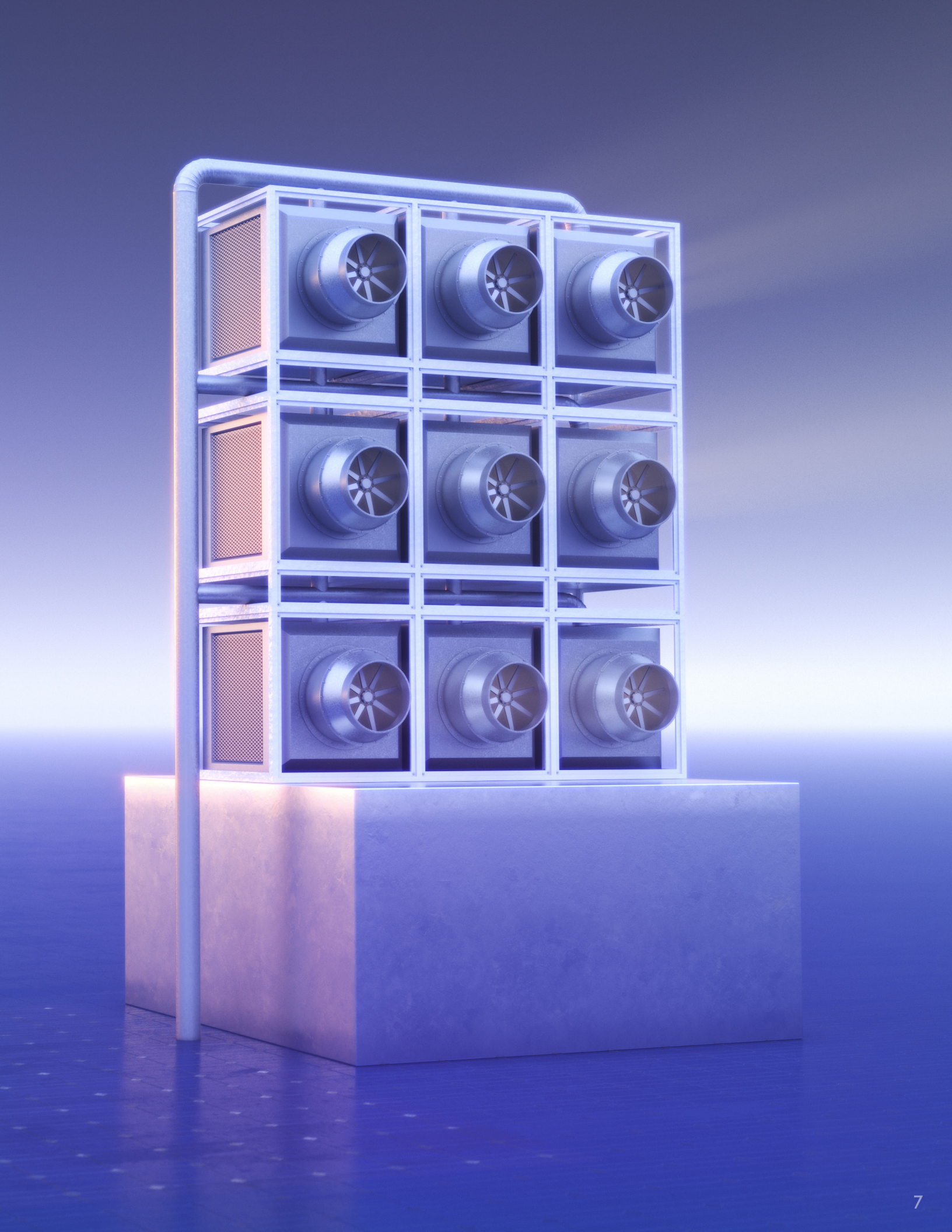
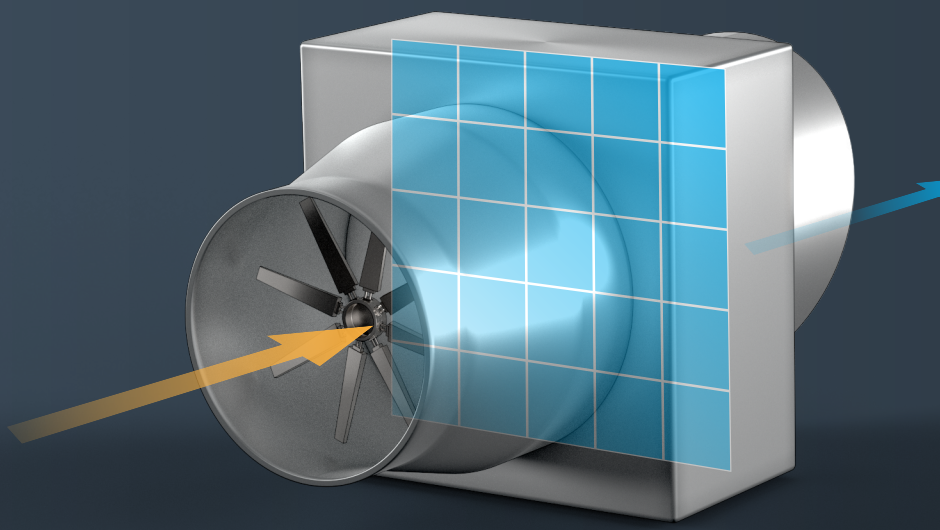
NETL GUIDING THE PATH TOWARD U.S. DECARBONIZATION

By Conor Griffith



DOE's Office of Fossil Energy and Carbon Management (DOE-FECM) and NETL have been at the forefront of carbon management research, development and demonstration (RD&D) for decades. NETL's research and global partnerships support a comprehensive, multi-pronged approach for carbon management that involves coupling carbon capture methods with long-duration carbon storage or carbon dioxide (CO_2) utilization/conversion into long-lasting products.

"NETL is actively pursuing hydrogen power sourced from the nation's fossil resources, because it shows great promise for building a sustainable energy future," said Bryan Morreale, associate laboratory director for Research and Innovation for NETL. "A vital component for success is addressing carbon emissions associated with hydrogen production, and our Lab's top-tier scientists and engineers have been hard at work for years to address this as well."



NETL's Carbon Dioxide Removal (CDR) Program is fostering R&D focused on direct air capture (DAC), with emerging research in the areas of biomass carbon removal and storage, enhanced mineralization and ocean-based and terrestrial CDR approaches to remove CO_2 that has accumulated in the atmosphere and durably store it in geological, bio-based, and ocean reservoirs, or in value-added products, to create negative emissions. Ultimately, these efforts result in more carbon being removed from the atmosphere than is generated.

The development of robust life cycle analysis and monitoring, reporting and verification methods are critical to ensuring effective and permanent CO_2 removal for all CDR approaches. A planned NETL DAC center will serve as a cornerstone of the CDR Program by offering world-class facilities and multi-disciplinary expertise to promote acceleration to demonstration and deployment.

DOE is developing a wide array of CDR approaches to help achieve gigaton-scale removal by 2050 and support the United States in achieving ambitious goals for a greenhouse gas-neutral economy by 2050, a carbon pollution free power sector by 2035, and a 50% reduction from 2005 levels in economy-wide net greenhouse gas pollution by 2030. These efforts contribute to Carbon Negative Shot, the third target within DOE's Energy Earthshots Initiative, that requires multiple CDR approaches to be enabled at scale to achieve the U.S. goal of net-zero emissions by 2050.

The NETL DAC center represents a new multi-phase project for the Lab's Infrastructure Program. The center will house flexible, multi-scale DAC test platforms for concurrent, fully integrated operations over a wide variety of relevant conditions such as temperature, pressure, relative humidity and CO_2 concentration. NETL's DAC center will hasten the maturation of technologies from DOE and stakeholders' research through further discovery and optimization of novel materials that promote rapid CO_2 uptake, with high dynamic CO_2 capacity; structured material systems and component designs; and integrated processes that leverage functional materials' unique characteristics to maximize volumetric CO_2 capture productivity, while reducing pressure drop, heat and power requirements, as well as capital and operating costs.

R&D will focus on advanced process design and data collection, specifically demonstrating process reliability, material performance and durability, energy requirements, capture efficiency and other parameters required to determine economic viability.

The NETL DAC center will be of significant value to DOE scientists and engineers, universities, research institutions, and businesses developing DAC technologies. Typically, these groups would not have the resources or experience on their own to construct, operate, and comprehensively analyze the results of DAC tests at this scale. Emphasis will be placed on the quantification and data acquisition of process parameters that reduce technical risk, minimize uncertainty in technoeconomic and life cycle assessments, and reduce the overall cost of DAC. Reducing costs and uncertainty are critical to attracting public investment and paving a path to commercialization and deployment.

"Before any DAC technology possibilities can be commercialized, they require various phases of testing to ensure their viability," NETL Thermal Science Team Supervisor Ronald Breault explained. "However, there's been a problem: there is a lack of available and easily accessible facilities to test emerging technologies between the bench and pilot scales. NETL's DAC center can fill this role and expedite the process so that these technologies are deployed on a large scale."

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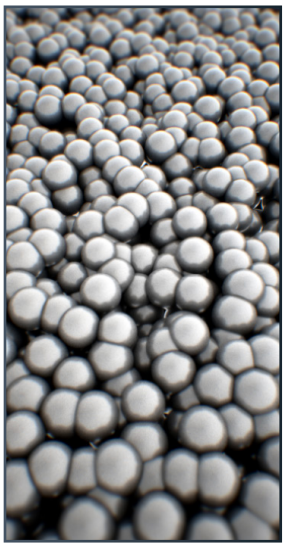
Since the concentration of CO_2 in the atmosphere is so low, around 415 parts per million, enormous amounts of air must be processed. The air needs to be effectively contacted with the adsorbing material, which is then regenerated for cyclic use to maximize the efficiency of the process.

NETL researchers are pursuing two DAC approaches: active and passive. Active contactors use fans or blowers to move the air through the absorbing materials and passive contactors use the movement of air in the natural environment, such as wind, to move the air across the adsorbing material.

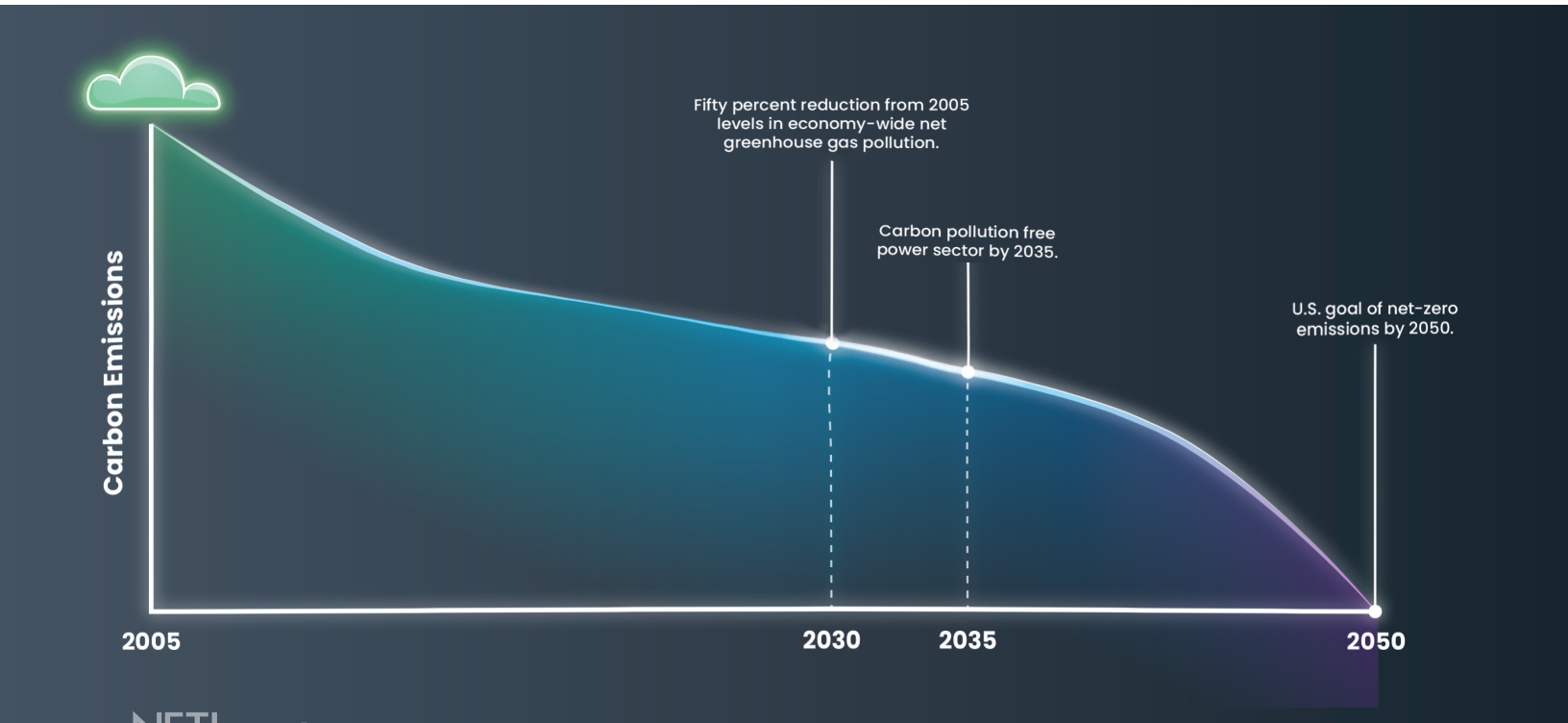
A range of potential DAC technologies are in development.

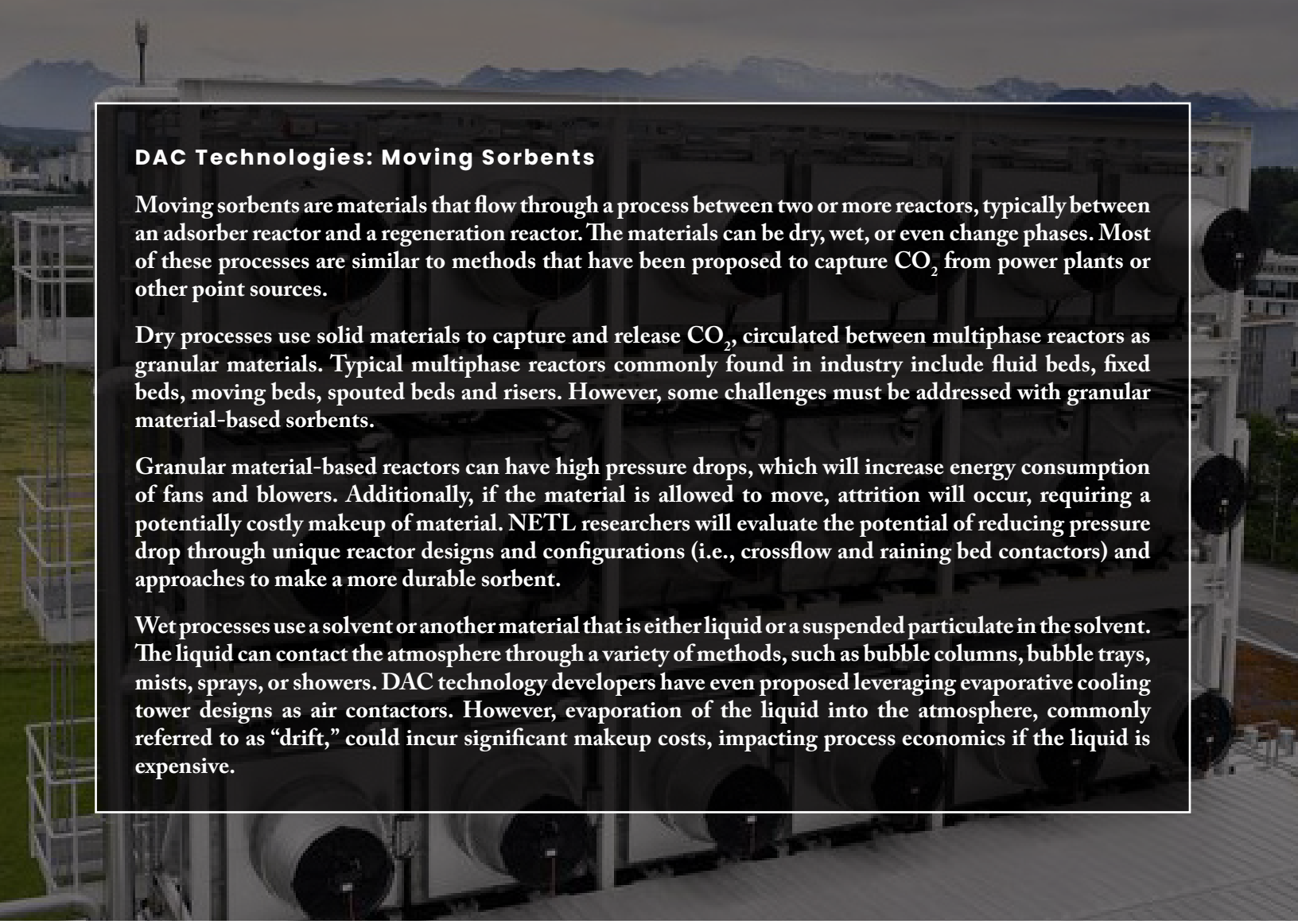


DAC Technologies: Fixed Sorbents

Fixed sorbents are materials held in place with either a channeled monolith, a structured packing, or a bed of particles. The air capture systems operate in a cyclic manner. They adsorb CO_2 for a period of time until the adsorbent is saturated, and the CO_2 passes through the DAC system to the atmosphere. Upon material saturation, external valving is switched to a regeneration mode in which the CO_2 is released from the adsorbent. Typically, steam and a vacuum pump are used to regenerate these materials. The steam can then be easily condensed, resulting in a high-purity CO_2 stream (often 99%) readily available for reuse or storage, depending on the commercial opportunities available.

"The use of amine-based sorbents on a monolith seems to be one of the most promising methods for DAC, due to the availability to manufacture the materials and structures, lower cost power requirements for fans and blowers, and the potential to use low-grade heat for regeneration," Breault said.





DAC Technologies: Moving Sorbents

Moving sorbents are materials that flow through a process between two or more reactors, typically between an adsorber reactor and a regeneration reactor. The materials can be dry, wet, or even change phases. Most of these processes are similar to methods that have been proposed to capture CO_2 from power plants or other point sources.

Dry processes use solid materials to capture and release CO_2, circulated between multiphase reactors as granular materials. Typical multiphase reactors commonly found in industry include fluid beds, fixed beds, moving beds, spouted beds and risers. However, some challenges must be addressed with granular material-based sorbents.

Granular material-based reactors can have high pressure drops, which will increase energy consumption of fans and blowers. Additionally, if the material is allowed to move, attrition will occur, requiring a potentially costly makeup of material. NETL researchers will evaluate the potential of reducing pressure drop through unique reactor designs and configurations (i.e., crossflow and raining bed contactors) and approaches to make a more durable sorbent.

Wet processes use a solvent or another material that is either liquid or a suspended particulate in the solvent. The liquid can contact the atmosphere through a variety of methods, such as bubble columns, bubble trays, mists, sprays, or showers. DAC technology developers have even proposed leveraging evaporative cooling tower designs as air contactors. However, evaporation of the liquid into the atmosphere, commonly referred to as "drift," could incur significant makeup costs, impacting process economics if the liquid is expensive.

NETL Carbon Dioxide Removal Program

The CDR Program is advancing intentional technological interventions to create negative emissions through durable storage. While these approaches differ significantly in their energy use, land use and social implications, they will all require substantial R&D efforts to enable a responsible and efficient CDR industry that is responsive to the climate crisis. Challenges include the dilute concentration of CO_2 in the atmosphere, large water and land use requirements, carbon life cycle effectiveness, low-carbon energy integration, low-cost durable storage, and impacts of process pressure drop on overall energy use and system cost.

"The proposed NETL DAC Center represents one facet of our Lab's efforts to leverage the decades of CO_2 capture RD&D with extensive cost-shared stakeholder support to achieve the administration's goals for a sustainable future," said José Figueroa, Carbon Capture Team Supervisor at NETL.

"Our team of 10 federal project managers responsible for implementing DOE's CDR and Point Source Carbon Capture Programs manages more than 115 active projects with a total project value of over $800 million covering all stages of technology development from discovery to large pilot-scale testing and front-end engineering design studies."

The U.S. strives to be a leader on the world stage in sustainable energy development. The innovations being pioneered by the top-tier scientists and engineers at NETL, along with its partners in business and academia, show that the best of both worlds can be obtained. The latest in decarbonization technologies show that environmental stewardship and exciting new economic opportunities will walk hand-in-hand further into the 21st century.

LEADING BY EXAMPLE:

Transitioning to a Decarbonized Energy Future as Net-Zero Lab

By Jenny Bowman

NETL is the DOE national laboratory charged specifically with advancing technologies for carbon management. The Lab has been at the forefront of energy and environmental innovation for more than 100 years, with high-impact successes including demonstration of technologies that directly reduced carbon dioxide (CO_2) emissions from power and heavy industries. NETL researchers are world leaders in technology solutions for carbon capture, utilization and storage (CCUS) as well as carbon removal strategies, thanks to their extensive expertise in quantifying and mitigating carbon emissions from resource production and energy conversion and use.

Now, as the Lab's research and talent is brought to bear on implementing urgent solutions to the global climate crisis, NETL embraces a powerful opportunity to lead by example and become a net-zero national laboratory.

Embracing Opportunity

President Biden signed Executive Order 14057 on catalyzing American clean energy industries and jobs through federal sustainability Dec. 8, 2021. The executive order and its accompanying Federal Sustainability Plan outline a range of actions to deliver on clean energy goals — calling for a net-zero carbon emission electricity sector by 2035 and net-zero emissions economy-wide by 2050. Furthermore, these initiatives demonstrate how the federal government will lead by example in tackling the climate crisis, including reducing emissions across federal operations, investing in American clean energy and manufacturing, and creating clean, healthy and resilient communities.

NETL will prioritize early adoption of near-term approaches to reduce carbon emissions while pursuing the longer-term capital projects to enable the full realization of the lab's zero-carbon emission goals. By 2035, the Lab aims to eliminate CO_2 emissions produced on-site and emissions that are produced as a result of NETL's purchases of electricity.

David C. Miller, Ph.D., who is leading NETL's Net-Zero program, said one of the challenges in planning NETL's strategy to net-zero is accounting for increased power requirements due to new mission-critical facilities and electrification of its vehicle fleet.

"NETL anticipates three state-of-the-art research facilities to come online within the next five years: The Computational Science and Engineering Center in Morgantown, West Virginia; the Center for Artificial Intelligence/Machine Learning in Pittsburgh; and the Advanced Alloy Signature Center in Albany, Oregon. These facilities will support key laboratory initiatives designed to meet the challenge of economy-wide decarbonization. We also anticipate our baseline consumption to rise as the lab's research computing and data storage capabilities expand." Miller said.

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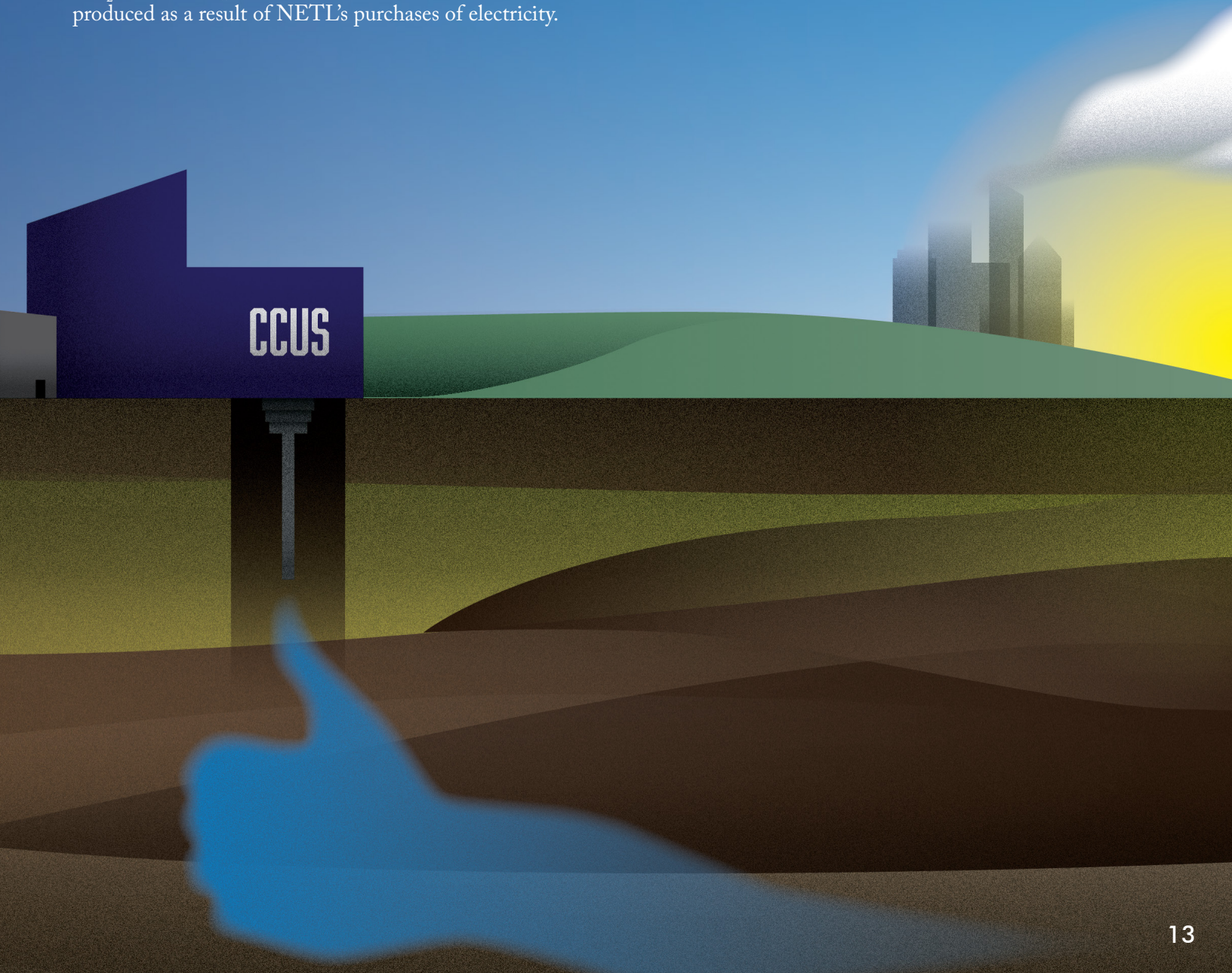

Implementing Technologies for a Sustainable Energy Future

NETL's Net-Zero effort serves as a continuation of NETL's mission to reduce its emissions and strive for sustainable operations. Since 2008, the Lab has followed robust energy conservation measures and renewable energy credit purchases. Now the lab will continue that mission with a focus on carbon management through development and maturation of technologies to reduce fossil energy emissions through CCUS.

"NETL plans to use the Lab's extensive research and analytic capabilities to develop and deploy critical climate and clean energy solutions. We'll become an early adopter of key technologies, and we'll serve as an exemplar for large institutions seeking to reduce their total carbon emissions and equivalent energy and water usage," Miller said.

NETL is kicking off its net-zero transformation with a detailed feasibility study to refine the specific CCUS, hydrogen, direct air capture (DAC) and renewable technologies that will be utilized on campus and develop a detailed roadmap to achieve net-zero by 2035.

"The pathway we're following to achieve net-zero by 2035 considers greenhouse gas reduction opportunities in electricity, natural gas, hydrogen, vehicle fuel for the NETL fleet and negative emissions technologies like direct air capture," Miller explained. "For example, we could potentially generate some of our electricity at one of our sites using biomass with CCS to achieve net negative CO_2 emissions."

NETL will also work with external entities to catalyze decarbonization. For example, the Lab will engage regional power providers to consider options for purchasing carbon-free electricity, which could include fossil with CCS, as well as renewables.

NETL experts will reach out to regional industries, universities and governments to foster collaborative development of regional infrastructure for a CO_2 injection pipeline that would connect regional stakeholders, hydrogen and other transformational technologies.

"As currently envisioned, these efforts will culminate in construction of an on-site integrated energy system demonstration facility to provide power along with a DAC center to demonstrate negative CO_2 emissions technologies. The effort will help de-risk and mature technologies to accelerate widespread deployment of decarbonization technologies throughout the U.S. and world," Miller said.

Reaching a Decarbonized Energy Future

As NETL researchers work to transform the Lab, they also work to improve people's lives — starting with people in their communities.

"In addition to addressing the climate challenge, our net-zero projects also have the potential to benefit local economies," Miller said.

Demonstrating and de-risking new decarbonization technologies will help enable economic revitalization and investment in disadvantaged communities, including those near NETL sites, that formerly relied on coal and power plants. In the near term, these communities will benefit from new job opportunities as the Lab embarks on construction of new facilities and infrastructure. In the longer term, these communities will benefit from new clean energy industries that will turn idled properties, such as brownfields, into new hubs for economic growth.

NETL's major new facilities combined with near-term power purchase agreements specifically designed to incentivize demonstration projects by regional utilities will enable NETL to achieve net-zero emissions by 2035 with a positive impact beyond the Lab's campuses. As a Net-Zero National Lab, NETL will demonstrate the potential to enable decarbonization while also providing a basis for new industries that use hydrogen and CO_2 as feedstock.

"Our goal is for NETL to serve as an example of how we can realize a clean energy future while also redeveloping distressed communities and revitalizing economies," Miller said. "It's an exciting opportunity that builds on NETL's historic strengths."


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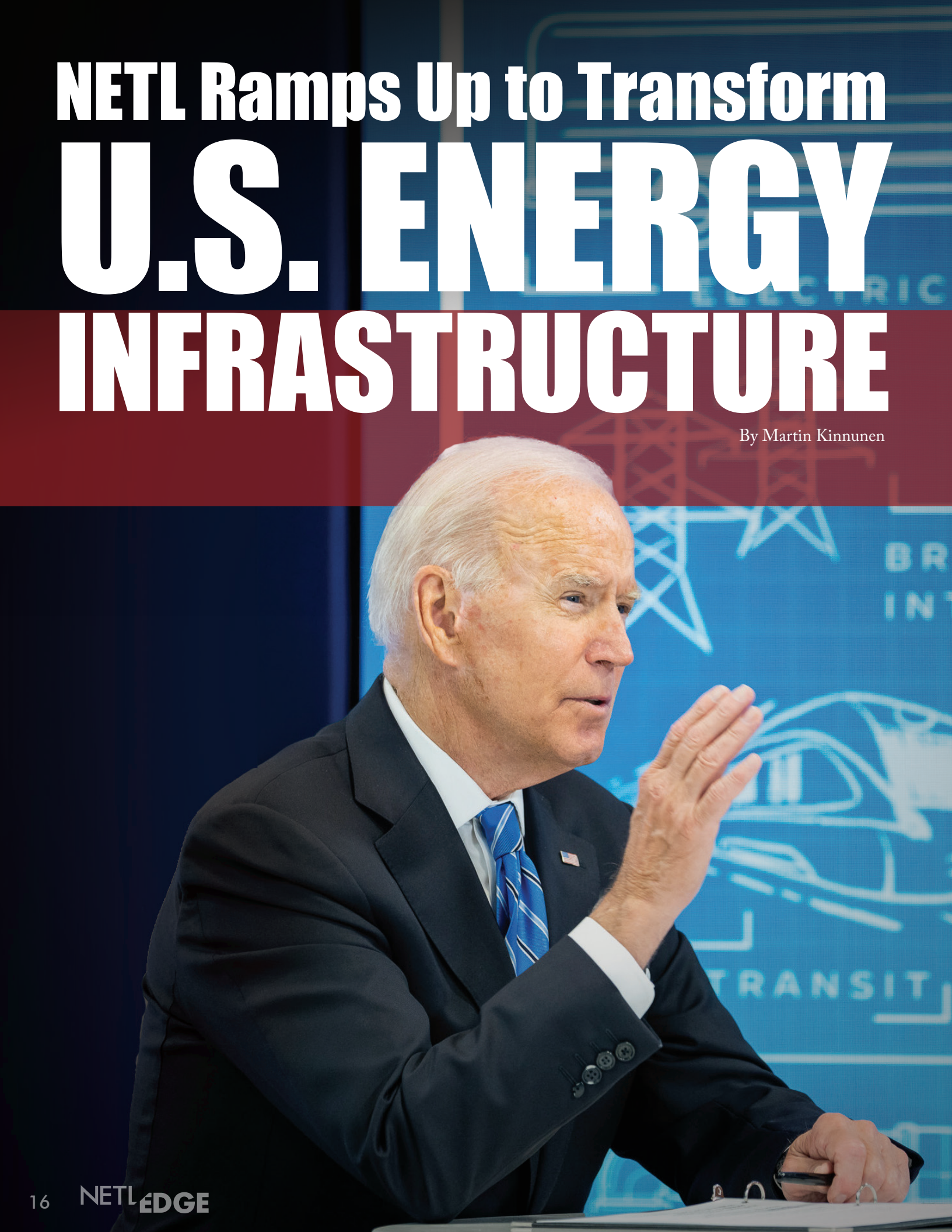
NETL Ramps Up to Transform U.S. ENERGY INFRASTRUCTURE

By Martin Kinnunen



NETL is positioned to execute major provisions of the $1.2 trillion Bipartisan Infrastructure Law (BIL), a once-in-a-generation opportunity to address climate change and generate economic growth by transforming the nation's energy infrastructure.

"The next five years will bring an unprecedented level of federal investment to develop, demonstrate and deploy cutting-edge clean energy technologies to support our transition to a zero-emission economy while creating good-paying jobs in communities across the country," said NETL Director Brian Anderson.

Signed into law by President Biden on Nov. 15, 2021, the legislation boosts funding levels for DOE by the largest amount since it was founded in 1977. Of the $62.5 billion in BIL funding to be allocated to DOE during the next five years, approximately $30 billion will be executed by NETL or used to support the Lab's programs.

In this fiscal year alone, the workload of NETL's Technology Development Center (TDC) and Finance and Acquisitions Center (FAC) will increase significantly as it creates and manages solicitations seeking qualified, innovative cost-sharing partners to complete various clean energy and related projects supported by the BIL.

During fiscal year 2022 and continuing into FY 2023, NETL anticipates executing funding opportunity announcements, non-competitive awards and prize competitions to solicit technology proposals from the nation's forward-thinking energy industry leaders, research organizations and top university research programs.

NETL estimates it will need to fill more than 100 new positions to execute its added responsibilities. Most of those hires will be in the Lab's TDC, FAC and Legal department, which reflects the fact that the majority of the BIL funding executed by NETL will consist of financial assistance distributed to American industry, academia and other recipients to complete energy infrastructure projects with Lab oversight and guidance.

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External Projects

NETL will execute programs run by various DOE program offices, including the DOE Office of Fossil Energy and Carbon Management (FECM) and the Office of Clean Energy Demonstrations (OCED), a new DOE office that will help deliver on President Biden's bold climate agenda, create new, good-paying jobs for American families and workers and reduce pollution while benefitting disadvantaged communities. These programs and their BIL funding levels include:

A. Four Regional Clean Direct Air Capture (DAC) Hubs ($3.5 billion). Funding to establish a program to provide funding for eligible projects that contribute to the development of four regional DAC hubs.

B. Carbon Capture Demonstration Projects Program ($2.537 billion). Funding will establish a carbon capture technology program for the development of six facilities to demonstrate transformational technologies that will significantly improve the efficiency, effectiveness, costs, emissions reductions and environmental performance of coal and natural gas use, including in manufacturing and industrial facilities.

C. Carbon Storage Validation and Testing ($2.5 billion). Funding will establish a program of research, development and demonstration for carbon storage.

D. Carbon Capture Large-Scale Pilot Programs ($937 million). Funding will establish a carbon capture technology program for the development of transformational technologies that will significantly improve the efficiency, effectiveness, costs, emissions reductions and environmental performance of coal and natural gas use, including in manufacturing and industrial facilities.

E. Critical Material Innovation, Efficiency and Alternatives ($600 million). Funding will be used to conduct a program of research, development, demonstration and commercialization to develop alternatives to critical materials (CM), promote their efficient production and use, and ensure a long-term secure and sustainable supply of them.

F. Carbon Utilization Program ($310 million). Funding will establish a grant program for state and local governments to procure and use products derived from captured carbon oxides.

G. Rare Earth Elements Demonstration Facility ($140 million). Funding will be used to demonstrate the feasibility of a full-scale integrated rare earth element (REE) extraction and separation facility and refinery.

H. Rare Earth Security Activities ($127 million). Funding will be used to conduct a program of research and development to improve the security of rare earth elements (REEs).

I. Front-End Engineering and Design Program ($100 million). Funding expands DOE's Carbon Capture Technology program to include a program for carbon dioxide (CO_2) transport infrastructure necessary to deploy carbon capture utilization and storage technologies.

J. Commercial Direct Air Capture Technology Prize Competition ($100 million). Funds to support reauthorization of a program to support large-scale pilot projects and demonstration projects and test carbon capture technologies.

K. Pre-Commercial Direct Air Capture Technology Prize Competition ($15 million). Funds to support reauthorization of a program to advance research, development, demonstration, and commercial application of carbon capture technologies.

L. Critical Material Supply Chain Research Facility ($75 million). Funds will support construction of a CM supply chain research facility.

M. Support Orphaned Well Plugging ($30 million). Funding in support of the U.S. Department of the Interior's effort to establish a program to plug, remediate and reclaim orphaned wells located on federal lands.

N. Battery Manufacturing and Recycling Grants ($3 billion). Funding to provide grants to ensure that the United States has a viable domestic manufacturing and recycling capability to support a North American battery supply chain.

O. Battery Materials Processing Grants ($3 billion). Funding to provide grants for battery materials processing to ensure that the United States has a viable battery materials processing industry. Funds can also be used to expand our domestic capabilities in battery manufacturing and enhance processing capacity.

P. Program Upgrading Our Electric Grid and Ensuring Reliability and Resiliency ($5 billion). Funding to states, tribes, local governments, and public utility commissions to demonstrate innovative approaches to transmission, storage and distribution infrastructure to harden and enhance resilience and reliability, and to demonstrate new approaches to enhance regional grid resilience.

Q. Preventing Outages and Enhancing the Resilience of the Electric Grid ($2.5 billion). Funding to eligible entities, states and tribes to prevent outages and enhance the resilience of the electric grid.

R. Preventing Outages and Enhancing the Resilience of the Electric Grid ($2.5 billion). Funding to utilities to prevent outages and enhance the resilience of the electric grid.

S. Deployment of Technologies to Enhance Grid Flexibility ($3 billion). Funding and expansion of eligible activities under the Smart Grid Investment Matching Grant Program established under section 1306 of the Energy Independence and Security Act of 2007.

T. Activities Under Cybersecurity for the Energy Sector Research, Development, and Demonstration Program ($250 million). Funding to support development and deployment of advanced cyber applications, technologies, and threat collaboration efforts with the U.S. energy sector.

"Given the BIL's focus on maturing and commercializing later-stage technologies, the bulk of NETL's expanded work entails developing and issuing solicitations, evaluating and selecting applications, and negotiating and managing awards," said Jim Wilson, NETL's chief financial officer.

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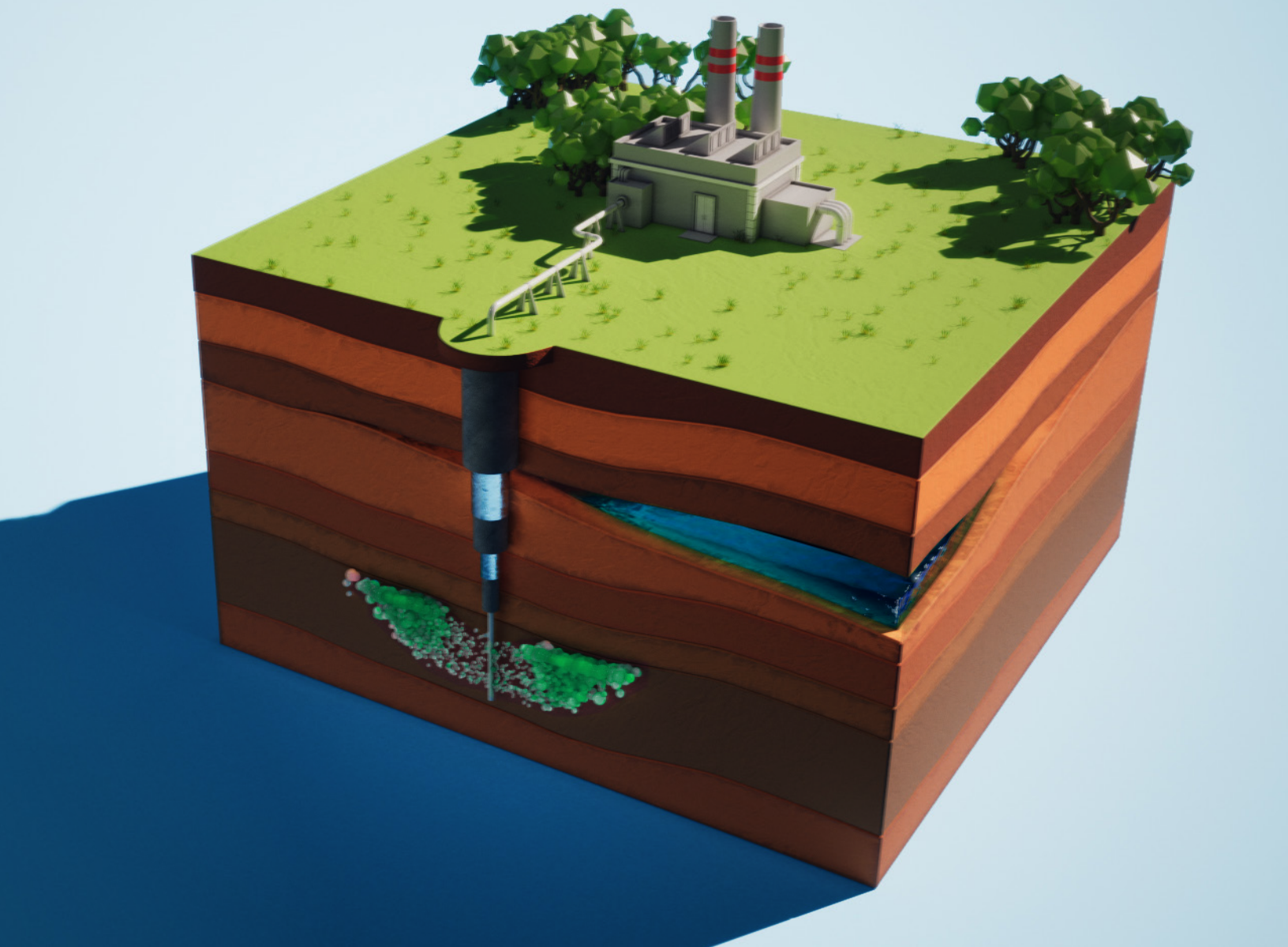


First-of-Their-Kind Facilities

A strong focus has been placed on accelerating the development of technologies already at later stage technology readiness levels so they can be used in commercial applications within five years.

Projects supported by the BIL will also advance first-of-a-kind facilities, including the development of a full-scale refinery to extract REEs and CMs from coal ash, tailings, acid mine drainage and other legacy wastes left behind by coal mining, fossil energy production and related activities.

REEs and CMs are needed to power advanced aircraft, wind turbines, electric vehicles, semiconductors, hydrogen fuel cells and other technologies that are essential for U.S. economic, energy and national security.

When completed, this facility, supported by a $140 million investment from the BIL, will help build a strong domestic supply chain of REEs and CMs and create good-paying, union jobs in emerging clean energy fields while mitigating the environmental impact of fossil fuel use.

DOE's FECM and NETL are currently evaluating information requested from industry, investors, developers, university research programs, government agencies, potentially impacted communities and others on the design, construction, operation and impact of a full-scale integrated REE and CM extraction and separation refinery.

Historic in Scope and Purpose

The BIL allocates funding to more than 350 distinct programs across more than a dozen federal departments and agencies. At the heart of the law are significant funding allocations to modernize the nation's energy infrastructure, advance innovations in clean energy out of the laboratory and demonstrate them at scale and accelerate the country's transformation to a zero-emission economy.

NETL is prepared to help lead this ambitious effort that will create a sustainable energy future for the United States and opportunities for meaningful employment for American workers in new industries.

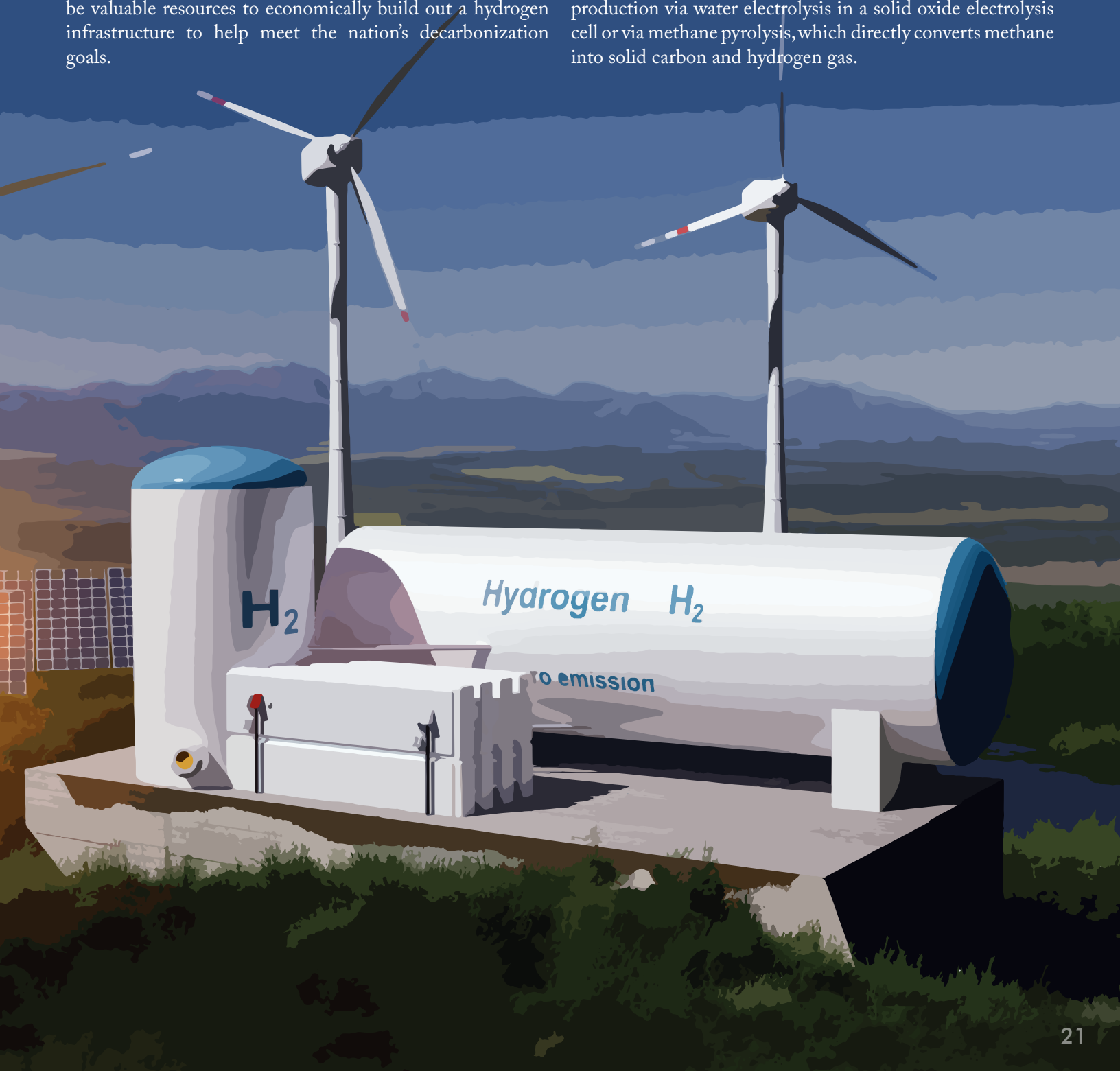
Regional Hydrogen Hubs

Hydrogen provides a game-changing opportunity to decarbonize the energy landscape, transportation and other sectors of the economy. The BIL authorizes an $8 billion program to support the development of at least four regional clean hydrogen hubs.

NETL's and the fossil energy sector's expertise and capabilities in hydrogen production, natural gas pipelines and storage, power production and industrial energy usage will be valuable resources to economically build out a hydrogen infrastructure to help meet the nation's decarbonization goals.

While producing energy from hydrogen results in zero emissions, the production of hydrogen currently relies on steam methane reforming, which is energy intensive and releases CO_2 into the atmosphere. NETL is investigating hydrogen production in combination with carbon capture and storage to produce clean hydrogen with little to no CO_2 emissions.

NETL is also studying alternative pathways of hydrogen production via water electrolysis in a solid oxide electrolysis cell or via methane pyrolysis, which directly converts methane into solid carbon and hydrogen gas.



HYDROGEN INITIATIVE

BY JOE GOLDEN

NETL Hydrogen Initiative: Supporting Critical Bipartisan Infrastructure Bill Investments

As a result of a once-in-a-generation investment of nearly $10 billion, a promising new hydrogen industry is emerging in America that could result in $140 billion in revenues and up to 700,000 jobs by 2030. NETL will play a major role by using its competencies and project management expertise to move research forward.

Hydrogen gas is a versatile, clean and flexible energy carrier that is produced from diverse domestic resources and used in many applications. As the U.S. moves toward achieving net-zero carbon emissions by 2050, DOE has elevated hydrogen as a key enabler of national decarbonization.

NETL's decades of hydrogen-relevant research and development (R&D) and project management experience has positioned the Lab to become a leader in the rapid, cost-effective development of a national hydrogen economy and to support legislation calling for hydrogen research advancements.

The recently enacted Bipartisan Infrastructure Law (BIL) provides funding that includes:

- $8 billion for Regional Clean Hydrogen Hubs, which will create jobs and expand the use of clean hydrogen in the industrial sector and beyond.
- $1 billion for a Clean Hydrogen Electrolysis Program to reduce costs of hydrogen produced from clean electricity.
- $500 million for a Clean Hydrogen Manufacturing and Recycling program.

In response to these priorities, DOE recently published two requests for information to guide potential BIL-related funding opportunity announcements (FOAs), and NETL is prepared to support these projects and programs. In addition, the Lab will directly support hydrogen projects by serving as a clearinghouse for data and providing crucial energy analyses.

Regional Hydrogen Hubs

The regional hydrogen hubs called for in the BIL will be a network of clean hydrogen producers and potential clean hydrogen consumers connected by infrastructure. This co-location of large-scale clean hydrogen production near end users will help accelerate hydrogen economy development in various market segments, which will create both near-term and long-term jobs and tax revenues for regional economies and realize emission reduction benefits.

The hubs will help achieve clean hydrogen production, which means the processes must attribute less than two kilograms of carbon dioxide (CO_2) for each one kilogram of hydrogen produced. Each hub must demonstrate specific aspects of the hydrogen value chain: production, processing, delivery, storage and end use. Success of the regional hydrogen hubs will build a foundation for a national clean hydrogen network to facilitate a clean hydrogen economy.

The BIL requires a diversity of feedstocks for hydrogen production within the hubs and calls for at least one hub that is focused on each of the following: fossil fuel, renewable energy and nuclear energy. Different end uses must also be considered, and at least one hub each must look at hydrogen use in the electric power generation, industrial, residential and commercial heating, and transportation sectors.

The hubs will also leverage geographic diversity and use the various abundant local resources particular to regions across the U.S. This will include at least two hubs in natural gas producing regions. Hubs will also be selected based on capacities to create skilled training and long-term employment for the greatest number of residents.

Research is underway in each of NETL's core research competency areas to enable the creation of hydrogen hubs with low overall costs and emissions. For example, NETL's investigations of large-scale hydrogen storage and natural gas infrastructure R&D can be used in research on hydrogen and hydrogen/natural gas blends.

The Lab also has structural material development and testing capabilities important for materials, coatings and liners that will be used in future hydrogen-related production facilities and infrastructure. The NETL material development expertise will also be applied to work aimed at creating efficient hydrogen separations and purification, catalyst development, and hydrogen sensors for safety in distribution.

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Hydrogen Production, Including Electrolysis

DOE is exploring all paths toward its Hydrogen Shot goal of reducing the cost of clean hydrogen to one dollar per one kilogram in one decade, and NETL is leading several areas of research to make this possible.

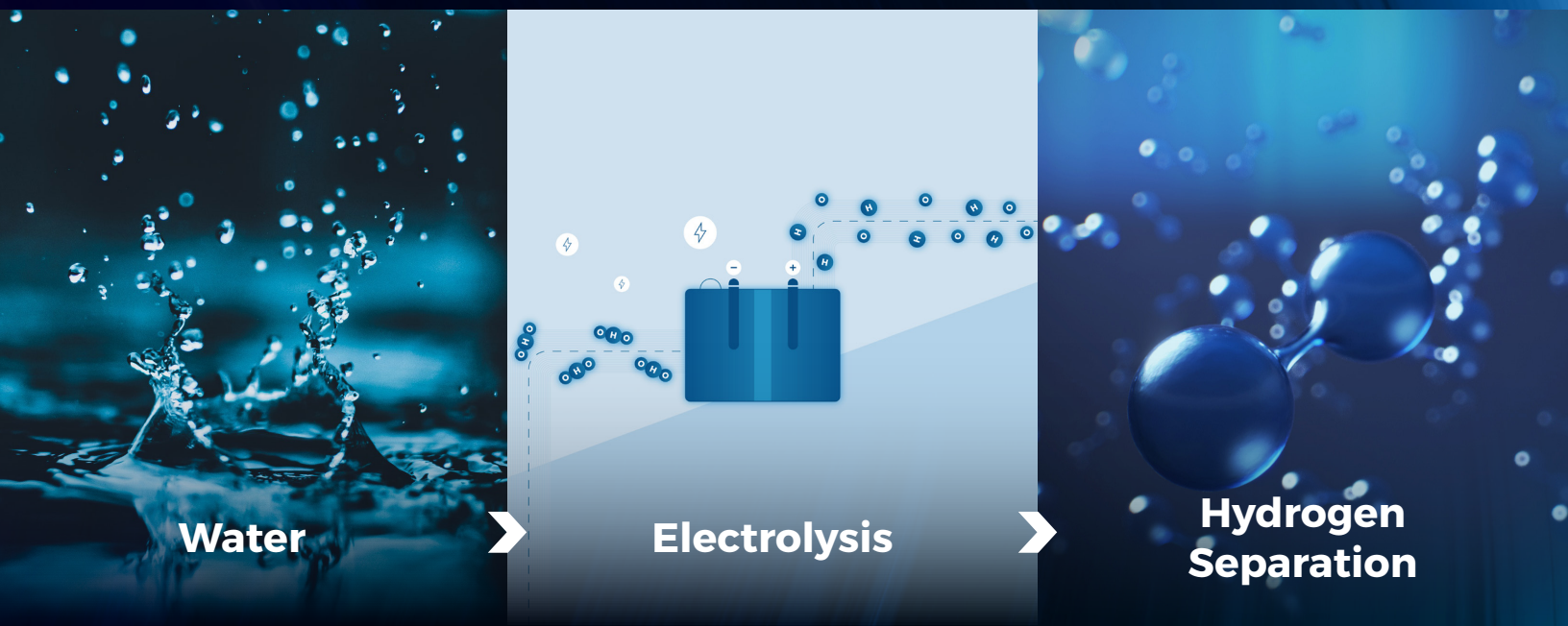
Unlike the nation's vast reserves of natural gas, which can be found in geologic formations, hydrogen must be created. Most of today's hydrogen is produced through a process called steam methane reforming (SMR), in which a feedstock (most commonly natural gas) is reacted with water. However, hydrogen can be produced through other means, including a process called electrolysis, which uses electricity to separate water into oxygen and hydrogen.

When electrolysis employs zero-carbon electricity, such as from nuclear or renewable energy, the resulting hydrogen is clean but significantly more expensive than SMR.

Electrolysis using electricity generated from fossil fuels that employ carbon capture and storage (CCS) systems can help reduce CO_2 emissions while also providing a cost benefit compared to using zero-carbon electricity. NETL has decades of research on CCS, large-scale fossil fuel production infrastructure, and power generating systems.

NETL's R&D is improving the efficiency, cost-effectiveness, and carbon intensity of fossil-based, clean hydrogen production. For example, the Lab is advancing:

- Use of microwaves to assist natural gas reforming and gasification of waste feedstocks to hydrogen.
- Production of hydrogen from water and excess electric power using solid oxide electrolysis cells (SOECs).
- Advancement of multiphase reforming and gasification with inherent CCS, such as with chemical looping.
- Use of methane pyrolysis to create hydrogen and valuable solid carbon co-products such as graphene and carbon black, which also eliminates the need to store carbon underground.
- Co-gasification of coal, biomass and waste plastics.



NETL Management of External Hydrogen Projects

NETL's project management experience is set to be leveraged on future programs and projects created with funding from the BIL. In 2021, DOE announced that $160 million in federal funding will be available to develop and advance technologies for the production, transportation, storage and utilization of hydrogen from traditional fuel sources, with progress towards net-zero carbon emissions. DOE selected 12 projects from that FOA (FOA 2400) that are currently managed by NETL.

The selected projects represent recipients from industry and academia who are working on clean hydrogen production in the following areas:

- SOEC Technology Development for Hydrogen Production.
- Advanced Carbon Capture Utilization and Storage Systems (CCUS) for Steam Methane Reforming Plants.
- Advanced CCUS for Autothermal Methane Reforming Plants.
- Hydrogen Combustion Systems for Gas Turbines.

In early 2022, the FOA was amended to accept applications for R&D on hydrogen generation from a variety of feedstocks via gasification approaches and front-end engineering design (FEED) projects that will advance clean hydrogen as a carbon-free fuel for transportation, industrial use and electricity production.

NETL's past project management experience with hydrogen R&D and FEED efforts as well as knowledge gained under this FOA will help build a foundation for next-generation demonstrations supported by the BIL, which provides funding to demonstrate clean hydrogen solutions and prove them at scale.

Additionally, the Lab has managed external projects with industry targeting co-gasification of coal, biomass and waste plastics.

Data Clearinghouse and Analyses

NETL is directed in the BIL to work with DOE's Idaho National Laboratory (INL) and the National Renewable Energy Laboratory (NREL) on regional clean hydrogen hubs and clean hydrogen manufacturing and recycling programs and act as a clearinghouse to collect information from, and distribute information to, national laboratories and other hydrogen stakeholders.

NETL's virtual data collaboration and curation platform, the Energy Data eXchange (EDX), will be used, with capability enhancements developed with INL and NREL, to fill this role because it supports secure, private, multi-institution collaborations for research projects. Creation of a national lab consortium to facilitate implementation and success of multiple sections of the BIL is also a possibility to address the task.

NETL will also use its world-renowned systems analysis expertise to help DOE bring down the costs and carbon intensity of hydrogen throughout the value chain to provide:

- Life cycle analysis to determine the greenhouse gas emissions and water impacts of hydrogen pathways.
- Modeling and techno-economic analyses of hydrogen production methods.
- Market assessments to determine the impact of energy and market forces on hydrogen hub growth and development.
- Assessments of regional hydrogen infrastructure buildouts and job impacts.
- Probabilistic risk assessments and process unit and hub-level optimizations through detailed system modeling.

The "to do" list to advance a job-creating and economy-altering hydrogen industry in the U.S. is long, but it is a list that NETL's researchers and program managers are poised to aggressively accomplish.

Renewing Our Future

By Gerry Griffith

NETL Senior Project Manager Gives an Insider's Look at Developing Technologies for Attaining Net-Zero Greenhouse Gas Emissions

"The work NETL does to increase the effectiveness and minimize the carbon footprint of producing electricity and advanced fuels such as hydrogen, will greatly assist EERE's mission and help us move towards a net-zero greenhouse gas emissions economy."

Neil Kirschner is a senior project manager in the Technology Development Center's Energy Efficiency Division at NETL who directly supports the DOE's Office of Energy Efficiency & Renewable Energy (EERE), including their Vehicle Technologies Office (VTO). He supports this group as an NETL team lead and a Clean Cities regional manager under VTO's Technology Integration program. The mission of Clean Cities is to "foster the economic, environmental, and energy security of the United States by working locally to advance affordable, domestic transportation fuels, energy efficient mobility systems, and other fuel-saving technologies and practices." He recently shared some of his insights with NETL Edge.

What led you to NETL and the pursuit of supporting energy efficiency and renewable energy?

Kirschner: I had been interested in employment at NETL since I graduated from the University of Pittsburgh with a mechanical engineering degree. I knew NETL as a prestigious DOE national lab located in the Pittsburgh area where I live. During my education, I realized there was much more to be done with vehicles to make them more efficient and to expand on the energy sources they rely on. I did not initially work with the EERE efforts at NETL. At first, I was a contractor helping with NETL's Department of Homeland Security efforts. I succeeded in getting a position as a federal employee under NETL's work for DOE's Office of Electricity Delivery and Energy Reliability, but soon found my way to the Vehicle Technologies team doing work for EERE. Already having a life-long interest in and prior experience with vehicles, this was an easy fit. During my experiences with this program, I quickly learned that there are many opportunities with renewable and alternative fuels.

What programs does NETL support for EERE's mission?

Kirschner: NETL provides support for several DOE offices, including ones under EERE. My division directly supports the VTO, from early-stage R&D to deployment activities. Technology areas under VTO include batteries, charging, and electric vehicles; advanced engines and fuels; lightweight materials; and technology integration. Our involvement includes executing funding opportunities, negotiating and managing resulting projects, coordinating interagency agreements, and managing supporting contracts. NETL also implements and manages projects for EERE's Building Technologies Office. On the laboratory side, NETL performs R&D for EERE-relevant work such as fuel cell development, which may have a key role in the future to provide electricity from fuels such as hydrogen. The work NETL does to increase the effectiveness and minimize the carbon footprint of producing electricity and advanced fuels such as hydrogen, will greatly assist EERE's mission and help us move towards a net-zero greenhouse gas emissions economy.

The team I lead and support under DOE's VTO Technology Integration program, has directly supported DOE Clean Cities since 2006. NETL houses the DOE Clean Cities Regional Managers which assist and guide a nationwide network of DOE-designated Clean Cities Coalitions. The Clean Cities network includes approximately 20,000 energetic stakeholders, who collaboratively work to advance new and energy efficient transportation fuels and technologies. Annually, this effort reduces and replaces the use of approximately 1 billion gasoline gallon equivalents of conventional fuels in the transportation sector. An added benefit of doing this is greatly reducing harmful emissions produced by the transportation sector.

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Does NETL have a specific expertise that helps it focus on the EERE mission?

Kirschner: We offer world-class project management services for the full project life cycle, technical expertise, and effective monitoring support. We have a unique ability to run funding opportunities for DOE, as well as negotiate, implement, and monitor federal awards, since NETL is DOE's only both government-owned and government-operated national laboratory. I have been impressed by the number and quality of projects our divisions have handled over the years. Our EERE supporting team has the knowledge and experience to make sound decisions to guide and manage technical projects for EERE. We also impressively handled many projects under the American Recovery and Reinvestment Act of 2009 (ARRA) for EERE, which demonstrates we are prepared to assist with the successful carryout of incoming work under the Bipartisan Infrastructure Law. This will be a rare chance to put some major funding behind and implement some very high-impact projects in support of EERE's mission.

What do you think the future of energy efficiency and renewable energy technologies will look like?

Kirschner: That's an interesting one. We have a lot of work to do to reduce greenhouse emissions, so renewables will continue to grow as energy sources. I see us utilizing the sun more, since it is always there for us, shining down and providing light, warmth and energy! Without the sun, we would not have hydro, wind, geothermal, or obviously solar power as energy options. Biofuels, renewable natural gas, and hydrogen will be part of the mix.

From a transportation standpoint (since it's more in my line of work), we will continue to electrify vehicle components and the vehicles themselves. What the future of the vehicles' on-board power source looks like may be a mix of batteries, various fuels, or something we haven't quite figured out just yet. I think no matter what the power source is, more vehicles will rely on electric motors to deliver power to the wheels and other components, especially since we can recover power during braking, and we will eliminate the need to idle a combustion engine. Electricity is going to be part of the future of transportation. Like most car enthusiasts though, I will sure miss driving around a manual naturally aspirated engine, but the new electric and even hybrid electric cars have more instant power, torque, control, and most importantly — they're more efficient.

There is much work to be done on the power generation and distribution side as well to support all of this. I hope we continue to see technologies that focus on efforts that reduce our impact on the environment and secure a clean path for future generations. ☰

EERE's mission is to:
Accelerate the research, development, demonstration, and deployment of technologies and solutions to equitably transition America to net-zero greenhouse gas emissions economy-wide by no later than 2050, and ensure the clean energy economy benefits all Americans, creating good paying jobs for the American people — especially workers and communities impacted by the energy transition and those historically underserved by the energy system and overburdened by pollution.

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