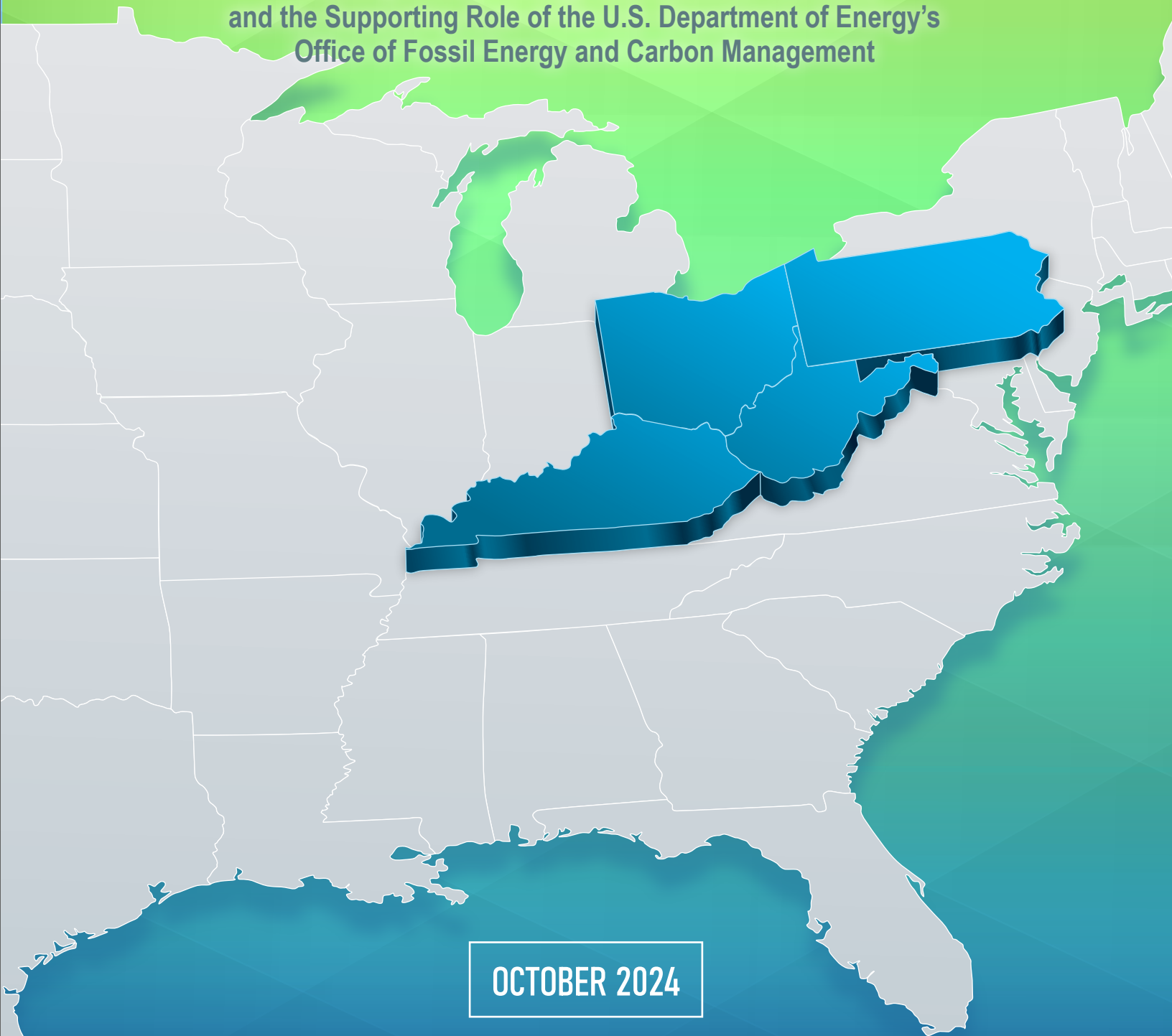
U.S. DEPARTMENT OF ENERGY | Fossil Energy and Carbon Management

# APPALACHIA REGIONAL REPORT

## Building A Clean Energy and Industrial Economy and the Supporting Role of the U.S. Department of Energy's Office of Fossil Energy and Carbon Management



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# Purpose of this Report

The "**Appalachia Regional Report: Building a Clean Energy Economy and the Supporting Role of the U.S. Department of Energy's Office of Fossil Energy and Carbon Management**" delves into decarbonization opportunities and challenges specific to Appalachia, supporting broader efforts to achieve a clean energy future. The Appalachia Region, as defined in this report, includes **West Virginia, Ohio, Kentucky, and Pennsylvania**. It draws on the region's extensive history in mining, energy, and industrial production to highlight opportunities for Appalachia's redevelopment. Additionally, by referencing the region's unique energy and industry mix, local energy resources, and current initiatives and priorities, this report identifies priority areas for Appalachia and aligns them with the research, development, and demonstration portfolio of the U.S. Department of Energy's (DOE's) Office of Fossil Energy and Carbon Management (FECM) to curate relevant solutions.

This report was developed by the Office of Fossil Energy and Carbon Management in collaboration with the National Energy and Technology Laboratory (NETL).

This report is being disseminated by the Department of Energy. As such, this document was prepared in compliance with Section 515 of the Treasury and General Government Appropriations Act for Fiscal Year 2001 (Public Law 106-554) and information quality guidelines issued by the Department of Energy.

# Introduction

The U.S. energy portfolio and economy currently depend heavily on fossil energy. However, it is crucial to advance clean energy solutions, such as carbon capture and storage, carbon dioxide removal, and other decarbonization pathways, to achieve a net-zero greenhouse gas emissions future. FECM is dedicated to minimizing the environmental and climate impacts of fossil fuels and industrial processes while working to achieve net-zero emissions across the U.S. economy. Its portfolio encompasses the research, development, demonstration, and deployment of technologies that include carbon capture, carbon conversion, carbon dioxide removal, carbon dioxide transport and storage, hydrogen production with carbon management, methane emissions reduction, and critical minerals production.

As part of successfully implementing this portfolio, FECM is engaging with communities and stakeholders across the country where significant project development is expected to occur to ensure community and stakeholder participation, understand and address concerns, and increase awareness regarding FECM funding and opportunities available. FECM focuses on two-way engagement, in which communities and stakeholders are not only informed, but they also have the opportunity provide input and shape the design and development of projects and infrastructure that affect them. This aligns with DOE's broader priority of placing s;akeholders and local communities at the center of project-development efforts, ensuring that DOE's investments result in tangible benefits for communities. The Community Benefits Plan framework is one example of a significant initiative that aims to institutionalize this priority. This framework aims to ensure that projects receiving federal funding, particularly from the Bipartisan Infrastructure Law and the Inflation Reduction Act, generate economic, environmental, and societal benefits for the communities and workers where the projects are located.

Through close collaboration between developers and local communities, Community Benefits Plans can evolve into Community Benefit Agreements, which are legally binding agreements between community groups and developers, stipulating the benefits a developer agrees to fund or furnish in exchange for community support of a project. DOE does not require Community Benefit Agreements but encourages them as an outcome of developing a Community Benefits Plan. Ideally, strong Community Benefit Plans result in formal agreements to create lasting benefits that will continue after DOE's involvement in a project ends.

As outlined throughout this report, FECM's focus areas and portfolio of technologies are well-aligned with Appalachia's energy and industrial mix, local infrastructure, and resources. These efforts will help the region engage communities, create new jobs, build new supply chains, and invest in supporting university research and development and innovation. Further, through DOE's Community Benefit Plans and Community Benefit Agreements, FECM illustrates how the design and scope of a project can maximize economic, environmental, and societal benefits for communities in the region, contributing to project success.

# Transforming Appalachia

## Retooling an Industrial Region Powered by Fossil Energy for a Net-zero Economy

"Just as the Appalachian Region produced the energy that powered our nation to win the two World Wars and deliver unprecedented prosperity in the 20th century, so too can it lead the way into a sustainable and secure energy future for the 21st century."

**(The Honorable Joe Manchin, Senator of West Virginia)**[1]

The Appalachia Region is defined in this report to include West Virginia, Ohio, Kentucky, and Pennsylvania. Although just 1% of the U.S. crude production comes from this region, Appalachia is one of the largest producers of natural gas and coal. Two of the largest shale gas formations in the United States, the Marcellus shale and the Utica shale, are in this region. Gas production from the Marcellus shale has made Pennsylvania (21.8% of U.S. production) the second largest gas producing state in the United States and West Virginia the fourth (7.4% of U.S. production)[2]. Ohio (5% of U.S. production) is also in the top ten U.S. natural gas producers, with production from the Utica shale formation. Two of the top five U.S. coal producers are also in Appalachia, with West Virginia accounting for 14% and Pennsylvania 7% of national output. Most of the coal produced in Appalachia is bituminous coal, with the second highest carbon content (45%-85%) and heating value of the four types of coal: anthracite (highest carbon content and heating value), bituminous, subbituminous coal, and lignite. The region represents roughly a quarter of U.S. coal production (in short tons).[3]

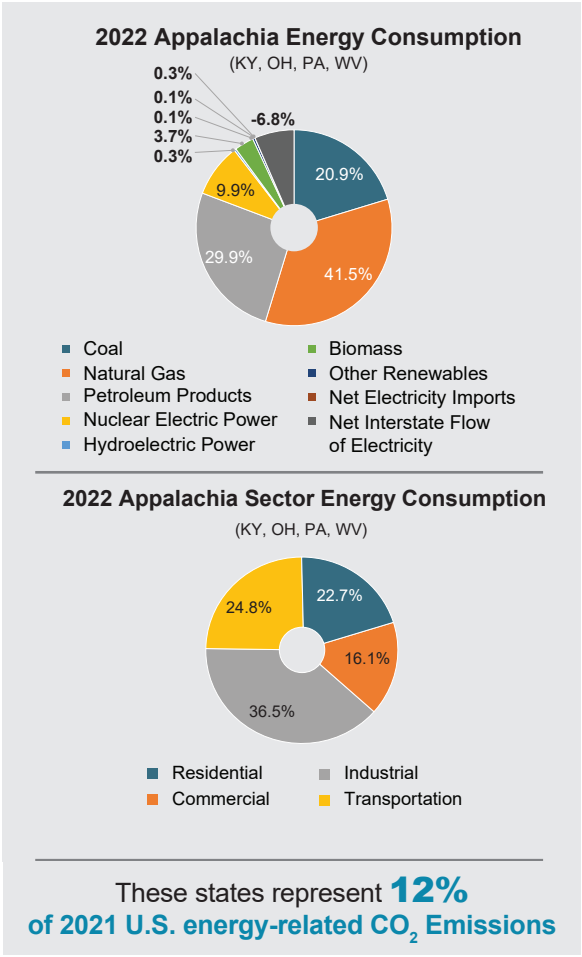
Coal mining is one of the largest industries in Appalachia, with over 70% of U.S. coal mines in the region. 62% of the mines in Appalachia are surface mines (where coal is less than 200 feet underground and large machines are used to remove the topsoil and layers of rock), and 38% of the mines are underground or deep mines (when the coal is more than 200 feet below the surface requiring tunnels and mine shafts). Industry historically located in this region to be near its rich coal resources. For example, the region has history of steel production with one-third of the U.S. pig iron (i.e., crude iron that is the direct product of the blast furnace and is refined to produce steel) producing capacity.

[1] Community Support | ARCH2 (arch2hub.com)

[2] Where our natural gas comes from - U.S. Energy Information Administration (EIA)

[3] Where our coal comes from - U.S. Energy Information Administration (EIA)

**Figure 1:** Energy in the Appalachia Region




**92%**
Of the energy mix in 2022 is fossil energy; nuclear (10%); biomass (almost 3.7%); wind, solar, and hydroelectric less than 1%. 6.8% energy exported as electricity.

**37%**
Of 2022 energy consumption is industrial from a diversity of industries steel, coal mining, glass, pulp and paper, chemicals.

**23%**
Of 2023 electricity mix was carbon neutral; nuclear (18.9%) and renewables (4.5%).

**70%**
Of total U.S. coal mines in 2022, including 145 underground mines and 235 surface mines

**26%**
Of coal production in 2022 (in short tons)

**34%**
Of total U.S. natural dry gas production in 2022

Source: EIA. Energy consumption (also referred to as energy mix) includes fuels consumed and electricity exported (negative net interstate flow). Electricity mix includes electricity generated from fossil, nuclear, and renewable plants. See EIA glossary. Glossary - U.S. Energy Information Administration (EIA)

Overall, industry makes up 37% of 2022 energy consumption compared to total U.S. industrial energy consumption of 33%. The high availability of local fossil resources combined with prominence of heavy industry has resulted in a total energy mix of more than 90% fossil energy for this region. Approximately 12% of total U.S. energy related greenhouse gas emissions come from the states in this region with industry as the largest energy consuming sector.

The significant mining activity and the clustering of energy-intensive industrial facilities has resulted in heath, air quality, and environmental challenges. For example, while surface mining is less labor intensive and considered safer for miners compared to underground mining, it can release more pollutants into the surrounding air and watersheds that can have worse health consequences. Although, unlike underground mining, surface mining avoids mine shafts and inhalation of coal mine dust, known to cause "black lung disease."[4] In both cases, the landscape needs to be remediated. Thus, communities in this region close to clusters of energy and industrial assets experience exposure to harmful criteria air pollutants such as nitrogen dioxide, sulfur dioxide,

[4] Surface coal mining and public health disparities: Evidence from Appalachia - ScienceDirect

and particulate matter (fine inhalable particles)[5]. Environmental degradation also occurs with both surface and underground mining, and the use of coal in steel production and other industries, results in adverse environmental and public health impacts.

The region is also characterized by its dependence on resources, underinvestment in public infrastructure and services, and persistent poverty. Communities in this region are rural and reliant on energy production as a source of employment and tax revenue. Therefore, the decline of coal production in the region has had significant impacts on employment and the ability for local governments to provide and maintain critical services and infrastructure such as schools, roads, health departments, and waste collection services. However, as the United States increases its efforts to deploy climate solutions, there is an opportunity to build a clean energy and industrial economy that harnesses the region's industrial base, local resources, work force and expertise, while also providing environmental and economic benefits to residents of these communities.

The portfolio of technologies being developed by FECM and other DOE offices are well-suited to the redevelopment and clean energy progress that has been occurring in the Appalachia Region over the last few decades. Companies in the region are increasing energy efficiency and energy productivity and reducing methane emissions. However, although nuclear has long provided electricity in Pennsylvania and Ohio and continues to represent almost 19% in the region, wind and solar are growing at a lower rate than the rest of the United States, representing just over 2% of electricity generation in the region. With the significant local availability of coal and natural gas and existing mining and traditional power generation infrastructure, carbon management will be critical to reducing power sector emissions. Furthermore, there is an opportunity to extract critical minerals from the coal ash impoundments and acid mine drainage left by the coal-fired power and mining, as well as to extract critical minerals from the produced water of the shale gas operations in the regiona, and to turn coal into critical materials.

The Bipartisan Infrastructure Law and the Inflation Reduction Act also established a historic policy framework that, through federal funding, financing, and tax credits, is helping to enable a robust market for clean energy and industrial projects. This framework includes tax credits that support the financing of projects in the carbon management and critical minerals industries, offering significant support to Appalachia's redevelopment.

As a part of the Bipartisan Infrastructure Law, DOE will deploy approximately $12 billion in new carbon management funding over five years, including $2.5 billion for six large commercial-scale carbon capture demonstrations and approximately $1.0 billion for large-scale pilot projects under the office of Office of Clean Energy Demonstrations (OCED); $2.1 billion for $CO_2$ transportation infrastructure; $2.5 billion for developing large-scale regional geologic storage sites; and $3.5 billion for regional direct air capture hubs. As part of the $2.1 billion in funding for $CO_2$ transport, FECM is working with the Loan Programs Office (LPO) to offer access to capital for large-capacity, common-carrier $CO_2$ transport projects (e.g., pipelines, rail, shipping, and other transport methods). Additionally, FECM is offering "Future Growth Grants" as part of the Carbon Dioxide Transportation Infrastructure Finance and Innovation Act (CIFIA) program program to extend or enlarge planned carbon transport infrastructure to connect additional $CO_2$ sources. The Bipartisan Infrastructure Law also allots $8 billion for the Clean Hydrogen Hubs, a program managed by the Office of Clean Energy Demonstrations. Of the seven hydrogen hubs selected for funding, at least five have carbon management projects.

[5] Air Pollution Monitoring | Air Quality Planning & Standards | US EPA

The federal 45Q tax credit provides up to $85 per metric ton of carbon dioxide ($CO_2$) captured from industry and power generation for dedicated storage in geologic formations, $60 per ton of $CO_2$ captured and geologically stored through the process of enhanced oil recovery, $60 per ton of $CO_2$ captured and converted into low carbon products or utilized (subject to the life cycle analysis and $CO_2$ reduction), and up to $180 per metric ton for direct air capture facilities with dedicated storage in geologic formations. Enhancements to the tax credit include: an authorization of the credit for a full ten years (i.e., all projects beginning construction by the end of 2032 are eligible); the ability to claim the credit for 12 years of operation, directly as a cash payment for the first five years of operation, and the option to transfer the credit to outside investors for the remaining seven years; and expanded eligibility for smaller industrial, power generation, and direct air capture facilities.

Since the Bipartisan Infrastructure Law and the Inflation Reduction Act, the number of U.S. carbon management projects announced annually by the private sector has more than doubled since 2019, with a cumulative total of 219 projects. Of the 219 projects, five are in the Appalachia region.[6] In 2023 alone, over $6.5 billion was invested in carbon management in the U.S., and about 17% went to the Appalachia region.[7] The application queue for Class VI wells is another indicator of activity. Currently, 149 well applications are under review by the EPA across the U.S., and several are located in the Appalachia region. Of those in the region, 3 applications are currently under review by EPA in Kentucky Pennsylvania, Ohio, West Virginia.[8]

There are a wide range of other tax credits as well. The 45X tax credit provides a 10% credit for the production of 50 different critical minerals that are essential to our clean energy economy and national security. The 45V tax credit creates a new 10-year incentive for clean hydrogen production of up to $3.00/kilogram. The level of the 45V credit provided is based on carbon intensity (i.e., the lower the carbon intensity, the higher the credit), with a maximum of four kilograms of $CO_2$-equivalent per kilogram of clean hydrogen eligible for the tax credit.

Appalachia is now entering its next chapter of evolution. Carbon management for its heavy industries and the recovery of critical minerals and materials from coal, coal byproducts, coal waste, and produced water are key opportunities to redevelop Appalachia and support the advancement of workforce development and training and create high-wage jobs for a net-zero emissions future.

[6] CRES illustration with data from IEA, https://www.iea.org/data-and-statistics/data-product/ccus-projectsdatabase. Used in GPI presentation at 2024 NETL Annual Review meeting; U.S. Carbon Capture Project Map – Clean Air Task Force (catf.us) August 28, 2024

[7] https://www.cleaninvestmentmonitor.org/database as of August 28th, 2024

[8] U.S. EPA Class VI Permit Tracker as of September 13, 2024. (Current Class VI Projects under Review at EPA | US EPA)

# Industry

## The concentration and proximity of industrial and energy facilities, coupled with regional projects that will deliver shared carbon management infrastructure, provides an exciting opportunity to redevelop Appalachia.

As shown in Map 1, the large concentration of integrated steel mills with blast furnaces/basic oxygen furnaces, pulp and paper, glass, and cement plants presents an opportunity to cost-effectively build out shared low carbon infrastructure that can contribute strategically to the ongoing redevelopment of Appalachia. Large-scale regional projects can create an ecosystem of regional $CO_2$ transport and storage coupled to carbon capture across a wide range of industries and power generation. For example, the Appalachia Regional Clean Hydrogen Hub (ARCH2), being funded by the DOE's Office of Clean Energy Demonstration (OCED), already has plans for shared hydrogen and carbon transport and storage. Similarly, the recently selected feasibility study by the University of Kentucky Research Foundation will examine a distributed direct air capture hub powered by solar and biomass with storage of $CO_2$ in a depleted natural gas field. For local emitters, shared $CO_2$ transport and storage infrastructure would reduce costs and accelerate project deployment and emissions reductions. A recent paper from Princeton University, "*Shared $CO_2$ capture, transport, and storage for decarbonizing industrial clusters*," found that when $CO_2$ pipelines are shared rather than dedicated to individual capture facilities, average transport costs can be reduced by two-thirds.[9]

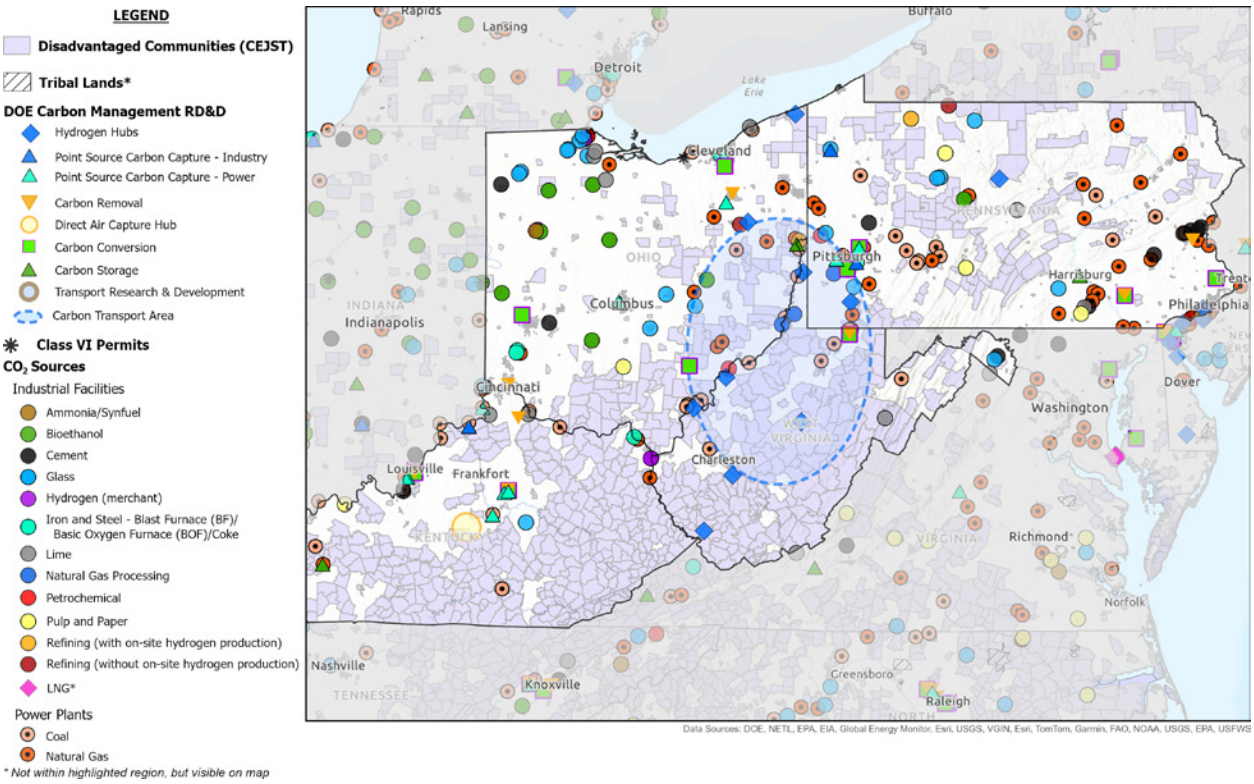
States in the region are also taking steps to put the policies in place to enable shared carbon management infrastructure to support emerging projects. For example, Tenaska has announced plans for a tri-state hub for carbon capture and storage from Ohio, Pennsylvania, and West Virginia and recently held a public informational meeting. The Princeton University paper (mentioned above) also analyzed how pooling emissions streams from facilities with different concentrations of $CO_2$ to a central capture site could significantly reduce capture costs.[10] Although technically complex and novel, shared capture could be considered for this region given the high concentration and proximity of emitters.

[9] Shared $CO_2$ capture, transport, and storage for decarbonizing industrial clusters - ScienceDirect

[10] Shared $CO_2$ capture, transport, and storage for decarbonizing industrial clusters - ScienceDirect

## **Map 1:** Industrial Activity in Appalachia

Clustered facilities spanning multiple industries, close to disadvantaged communities, could share carbon management infrastructure. This would create the opportunity for competitive lower carbon products and support high-wage jobs, communities, and regional supply chains.




Source: National Energy and Technology Lab (NETL) Research & Innovation Center (RIC). Developed using publicly available data sources (EPA, USGS, etc.).

Carbon capture will be important for industrial processes with high temperatures that cannot be electrified or decarbonized more economically through other carbon-free methods. Many industrial plants, in particular integrated steel mills, have decades of useful life remaining, and it would not be economically feasible to retire them early. Carbon capture can be applied to a wide variety of industries in the region including steel, pulp and paper, glass, and cement. In this region, DOE has already funded a carbon capture pilot to capture steel emissions and a front-end engineering and design study for capturing $CO_2$ at a petrochemical plant. The Inflation Reduction Act also boosted the 45Q tax credit, prompting a variety of proposed projects, including a natural gas power plant with carbon capture in West Virginia.

Research is also being conducted in this region on "flexible" capture solutions for natural gas power plants to enable natural gas power generation with carbon capture to ramp up and down to better support additional deployment of wind and solar and help ensure continued reliability of power on the grid. For example, DOE's Advanced Research Projects Agency-Energy has funded a University of Pittsburgh team that will develop a hybrid plant model. During peak demand hours (or when wind and solar production is low), the natural gas combined cycle plant produces power, and the two sequential carbon capture systems capture roughly 99% of the $CO_2$

produced by the combustion of natural gas. During off-peak hours, the natural gas combined cycle plant powers the two carbon capture systems to capture the $CO_2$ from the air and capture all the $CO_2$ produced by the plant.

Conversion of captured carbon emissions into fuels and products and carbon capture with biomass are also opportunities available in Appalachia. Chemical plants in the region can use captured $CO_2$ and carbon monoxide to produce valuable products such as fertilizer, fuels, building materials, plastics, and bioproducts. Additionally, carbon capture can be applied to local biomass resources (about 10% of forestry waste[11] is in West Virginia, Ohio, Pennsylvania, and Kentucky) to develop low carbon fuels and products such as sustainable aviation fuels and to reduce power sector emissions. For example, replacing a portion of coal with biomass by co-firing with locally available forestry waste and then capturing the $CO_2$ emissions presents a lower carbon pathway for plants that that cannot be economically retired in the near term. Depending on the amount of biomass used and the percentage of carbon capture and storage, the potential exists to achieve net-negative emissions for some facilities. Net-negative emissions refers to when the amount of emissions removed exceeds the amount emitted. In the best scenario, biomass without carbon capture and storage can achieve carbon neutrality because biomass, through photosynthesis, naturally remove emissions from the atmosphere which are then released when the biomass is combusted. Therefore, when combined with carbon capture and storage, biomass has the potential to achieve net-negative emissions. The "*Current state of industrial heating and opportunities for decarbonization*" paper[12] estimated that replacing coal with locally sourced waste biomass in an integrated steel mill could reduce emissions from the blast furnace by 25% and overall emissions by 60% if the production of coke was included. Under FECM's University Training and Research Program, two projects were awarded funding to perform technoeconomic analysis and life cycle assessment on net-zero or net-negative co-firing of waste coal and biomass with carbon capture and storage. The Ohio State University is evaluating co-firing of switchgrass and waste coal in a power plant.

DOE is also investing in bold industrial decarbonization technologies at each stage of the innovation pipeline to help manufacturers and businesses use clean energy, increase efficiency, and integrate new, innovative processes and technologies. These technologies will support the redevelopment of Appalachia, protect and create high-wage industry jobs, and enable industry to decarbonize more rapidly while creating additional pathways for existing industrial infrastructure to decarbonize in the near-term.

To realize the full potential of these opportunities in the Appalachia Region, engaging with communities and other impacted stakeholders is critically important. Two-way engagement focused on how project design and scope can maximize economic, environmental, and societal benefits for host communities can contribute to project success. For example, carbon capture technologies can also reduce pollution beyond $CO_2$ emissions, as they often require co-pollutants, such as sulfur oxides and nitrogen oxides, to be removed from the flue gas prior to capturing the $CO_2$. The potential of capture technologies to also capture co-pollutants is of particular importance to energy and industry-adjacent communities that have experienced significant environmental and health burdens due to their long-term exposure to these non-greenhouse gas emissions. Further, DOE recognizes the impact of amine solvents and their degradation on emissions and are developing novel

[11] BETO: Billion-Ton 2023 | Department of Energy (near-term, $70/ton; hardwood, mixed wood, and softwood)

[12] Current state of industrial heating and opportunities for decarbonization - ScienceDirect

monitoring approaches , as well as investing in a broad suite of capture technologies that do not require amines, such as solid sorbents, membranes, and cryogenic separation. Project developers should consider selecting a

carbon capture technology that addresses this environmental need and offer to be transparent in sharing air monitoring data with communities.

Developers should also consider, in consultation with communities, how to support local economic development—through jobs and reskilling opportunities and other means. For example, the OCED-funded Appalachia Regional Clean Hydrogen Hub (ARCH2) is anticipated to bring quality job opportunities to workers in coal communities and create more than 21,000 direct jobs in construction and operations. Designing projects that consider the needs and input of host communities will support the deployment pace and scale needed for industrial decarbonization and position this region to be a model of redevelopment.

# Energy and Resources

## Appalachia continues to drive down the emissions footprint of its local natural gas and coal resources, and the fiscal incentives for carbon management further support moving the energy mix toward a net-zero emissions economy while supporting regional development.

Appalachia has a long history of coal, oil, and natural gas production and use. There has been a focus on improving the environmental footprint of these operations and reducing emissions from natural gas production. FECM is working with the U.S. Environmental Protection Agency (EPA) to implement $1.36 billion in technical and financial assistance through the Methane Emissions Reduction Program that was established under the Inflation Reduction Act to target methane emissions across the oil and natural gas supply chain. The program will provide funding to measure emissions and to voluntarily plug high emitting marginal wells and provide financial assistance for installing equipment to reduce emissions from equipment such as valves, tanks, and compressors.

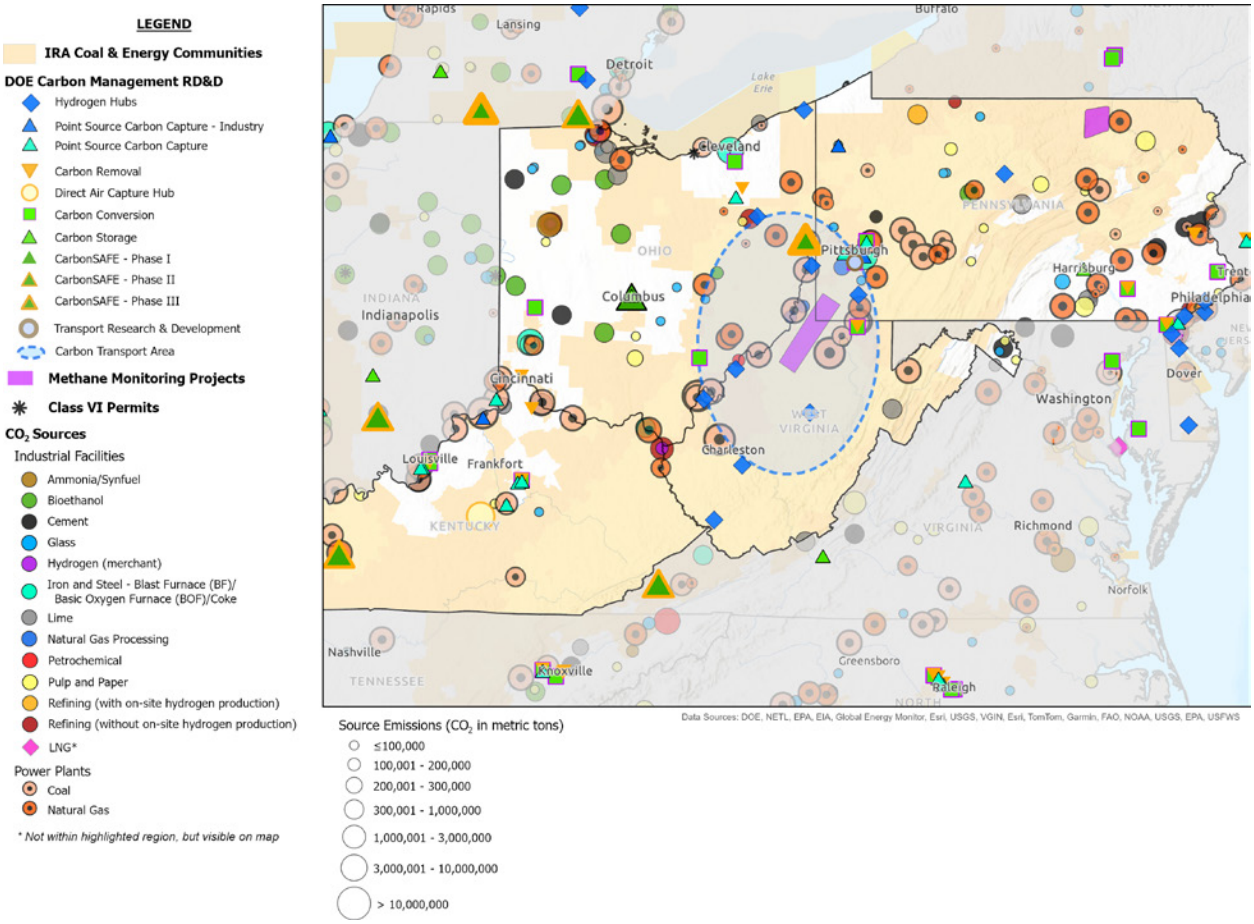
In December 2023, the Biden-Harris Administration announced the award of $350 million to 14 states, including West Virginia, Ohio, Pennsylvania, and Kentucky, to reduce methane emissions from the oil and gas sector. In Appalachia, FECM's Methane Mitigation Technologies Research and Development Program is also deploying the Marcellus Methane Monitoring Project focused on demonstrating a comprehensive, multi-scale methane measurement and reconciliation protocol of methane emissions in the Marcellus shale basin (see Map 2). Through extensive analysis and continuous monitoring field surveys, the M3 Project will provide an accurate representation of methane emissions, including resource characteristics and seasonal and temporal variability, from oil and gas facilities across the Appalachian region.

Additionally, in line with the Biden-Harris Administration's U.S. Methane Emissions Reduction Action Plan—which reflects an overall global goal to cut methane emissions by 30% from 2020 levels by 2030—FECM is leading a global effort to develop a measurement, monitoring, reporting, and verification (MMRV) framework. This framework aims to advance comparable and reliable information about greenhouse gas emissions across the natural gas supply chain to drive global emission reductions.

FECM, under the Under the Advanced Remediation Technologies Research and Development Program, has invested over $17 million in three Appalachia Field Test Sites that have helped explore and characterize the resource potential of shale, coalbed methane, and other unconventional formations grouped closely or overlapping one another (i.e., "stacked" plays) in the region. Valuable data from these projects including cores, logs, and novel core analysis can be used to assess the potential for geologic carbon and hydrogen storage in unconventional formations of Central Appalachia.

## **Map 2:** Energy Infrastructure and Resources in Appalachia

Sufficient geologic $CO_2$ storage potential close to large emitters (see CarbonSAFE projects), advanced remediation and methane mitigation and monitoring activities to reduce emissions of energy production, and an experienced energy workforce could make Appalachia a competitive region for $CO_2$ abatement for industry ($/metric ton of $CO_2$ abated).




Source: National Energy and Technology Lab (NETL) Research & Innovation Center (RIC). Developed using publicly available data sources (EPA, USGS, etc.).

As shown on Map 2, carbon storage for nearby emitting facilities is an opportunity in Appalachia, one of the largest producers of gas and home to robust gas-bearing geologic formations. More work needs to be done to characterize the geological formations in the Appalachia region, but there could be the potential to store $CO_2$ from power plants and industrial facilities, as well as $CO_2$ removed from the atmosphere via direct air capture and the $CO_2$ from the production of clean hydrogen hydrogen.

Additionally, the skilled energy workforce makes Appalachia an attractive region for deployment of geologic storage. DOE recently selected a Carbon Storage Assurance Facility Enterprise (CarbonSAFE) project that, if awarded, will conduct a site characterization study of four geologic carbon storage systems for the Tri-State Carbon Capture and Storage Hub supporting Ohio, Pennsylvania, and West Virginia. DOE previously funded

the Central Appalachian Basin CarbonSAFE Integrated Pre-Feasibility Project in Ohio. For background, in 2003, DOE launched regional research and development efforts in the Appalachia region focused on geologic storage of $CO_2$ and completed a series of successful projects.

In 2016, the CarbonSAFE Program was launched and provides crucial resources and information necessary for the development of large-scale geologic storage facilities and associated regional carbon management hubs.

The national network of CarbonSAFE projects is on track for targeted commercial injectivity on the scale of 100 million metric tons per year of $CO_2$ and to identify contingent storage resources[13] (i.e., potential storage subject to regulatory approvals, infrastructure development, or commercial viability) of 6 billion metric tons by 2035. These projects will support public engagement and dialogue, including providing technical assistance and resources to communities. Further, as mentioned previously, there are multiple additional incentives to take advantage of these storage opportunities.

Scaling carbon management in Appalachia requires broad local support, ensuring that project development equitably benefits the local communities, landowners, and other stakeholders. As shown on Map 2, there are a significant number of coal and energy communities in this region, many of whom have experienced environmental impacts from past mining and energy production. To help build community and stakeholder confidence and help ensure best practice project development, FECM intends to launch a "Responsible Carbon Management Initiative" to encourage project developers and industry to pursue the highest levels of safety, environmental stewardship, transparency, and community engagement and benefits for all projects, whether they are federally funded or not.

There is a significant opportunity to build on the oil and gas, coal, and heavy industry workforce in Appalachia to redevelop the region and create high-wage jobs for a net-zero emissions future. The Rhodium Group and Great Plains Institute estimates that carbon capture and storage in West Virginia, Pennsylvania, Ohio, and Kentucky could create over 47,000 annual jobs[15], spanning investment and operations, helping to ensure the Appalachian region benefits from the development and operation of the carbon management technologies and infrastructure. Further, a workforce development and training plan will be needed to transition the existing energy workforce to new technologies.

[13] Contingent storage resources are storage resources estimated to be accessible in known geologic formations, but the applied project(s) are not yet considered mature enough for commercial development, as a result of one or more contingencies. srms_sep2022_w_errata.pdf (spe.org)

[14] Increased credit values for storage in saline geologic formations

[15] Carbon Capture and Storage Workforce Development: State-by-State – Rhodium Group (rhg.com)

# Recovery of Critical Minerals

## Coal, coal byproducts, and coal wastes, as well as produced water from shale gas operations, in Appalachia have the critical minerals needed for clean energy technologies and our national defense..

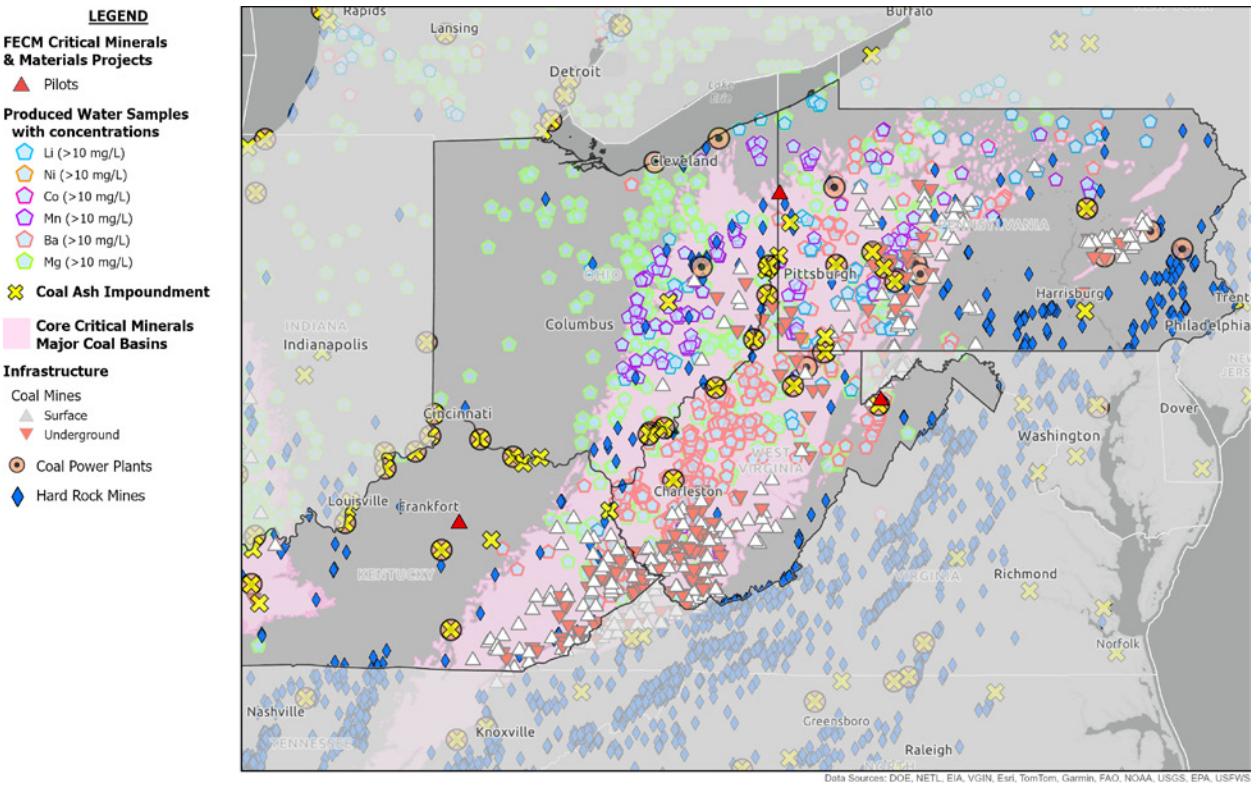
Appalachia is well positioned to have a key role in developing a domestic source of critical minerals and rare earth elements. Critical minerals and rare earth elements are key to manufacturing clean energy technologies—such as solar panels, wind turbines, electric vehicles, and hydrogen fuel cells—that will help the United States achieve a net-zero emissions economy. They are also essential to the manufacture of technologies and products vital to our country's national security. Demand for critical minerals and materials and rare earth elements is growing in the United States and globally, and the United States currently imports greater than 80 percent of its rare earth elements from non-domestic suppliers. There is significant opportunity in Appalachia to build a secure, sustainable domestic supply of critical minerals from a broad range of sources. For example, the long history of coal mining and hard rock mining in the past has left a legacy of hundreds of millions of tons of waste piles, ash impoundments, and mine drainage that often contain substantial amounts of rare earth elements and other critical minerals.

Even though these waste materials have relatively low concentrations of rare earth elements and critical minerals, leveraging previously mined materials presents an opportunity to meet our nation's growing demand for these minerals while helping to remediate these legacy wastes. While coal continues to be mined in the region, it also contains rare earth elements and other critical minerals. Furthermore, produced water generated during natural gas production often contains recoverable amounts of lithium and other critical minerals.

Together, these opportunities make Appalachia a strong potential resource to underpin the development of domestic supply chains to help reduce America's dependence on other countries for these critical minerals, create good-paying jobs, and support communities that historically have depended on mining and energy production.

## **Map 3:** Critical Elements and Rare Earth Elements Potential

Appalachia, with 70% of U.S. coal mines and 34% of U.S. natural gas production from its onshore fields, is well positioned to produce critical minerals and materials from coal and energy and mining waste streams (e.g., coal ash, acid mine drainage, and produced water) while remediating land and water.



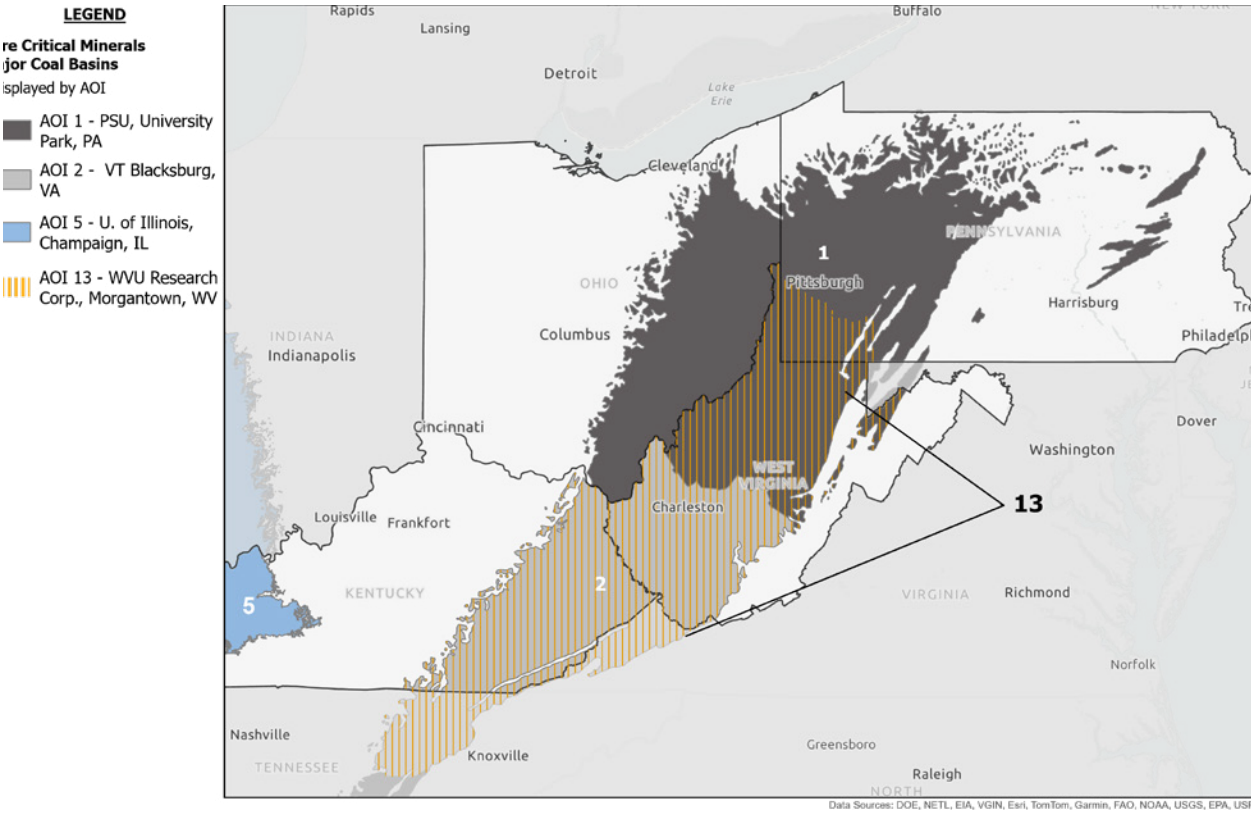

Source: National Energy and Technology Lab (NETL) Research & Innovation Center (RIC). Developed using publicly available data sources (EPA, USGS, etc.).

DOE is pursuing research to recover rare earth elements and critical minerals from coal, coal byproducts, coal wastes, produced water, and other energy and mining waste streams to develop a domestic supply chain for rare earth elements and other critical minerals and materials that will reduce U.S. dependence on insecure foreign sources. FECM and DOE's National Energy Technology Laboratory, with Pittsburgh, PA and Morgantown, WV sites in the Appalachian region, are already developing technologies to produce rare earth elements and critical minerals from unconventional feedstocks while remediating land and water from legacy fossil energy wastes (e.g., coal ash, acid mine drainage, and produced water).

Three first-of-a-kind pilot facilities have been built in Appalachia to test technologies and their ability to upgrade the rare earth element concentrations to individually separated, high-purity rare earth oxides and salts from acid mine drainage, coal ash, coal, and coal wastes. Through public-private partnerships, DOE has engaged with several companies to develop feasibility and/or front-end engineering and design studies for large scale demonstration facilities to produce rare earth metals and other critical minerals from similar feedstocks. Bipartisan Infrastructure Law funding will be used to build a large-scale demonstration facility to produce rare earth metals from acid mine drainage or coal waste within the next two to three years.

FECM's Carbon Ore Rare Earth and Critical Minerals (CORE-CM) Initiative brings together regional coalitions of universities, industry, state agencies, and others to provide assessments of these feedstocks in coal basins across the country. Three different coalitions are working in Appalachia (Figure 2) to evaluate the potential for coal, coal wastes, and other secondary and unconventional resources in the region to support domestic supply chains for electric vehicles, wind turbines, valuable carbon products, and other clean energy, defense, and high-tech technologies used in our everyday lives. This is an opportunity to clean up the legacy of two centuries of wastes left behind by coal mining and related activities while laying the foundation for a new value-added industry rooted in the new energy and high-tech economies. Initial estimates suggest that unconventional and secondary sources could provide significant amounts of the rare earth elements and other critical minerals needed to reach the Biden Administration's clean energy and industrial goals. Nation-wide, wastes and byproducts from known fossil fuel reserves and other industries currently contain more than 10 million tons of rare earth elements, which is equivalent to more than a 300-year supply at the current rate of U.S. consumption.

**Figure 2:** CORE-CM Coalitions in the Appalachian region




Source: National Energy and Technology Lab (NETL) Research & Innovation Center (RIC). Developed using publicly available data sources (EPA, USGS, etc.).

This is an opportunity to help bring a new industry of critical mineral recovery, processing, and refining to the region, finding new higher-value, non-combustion uses for coal, as well as for coal wastes and other energy and mining wastes and helping to remediate those wastes and their legacy environmental and community impacts in the process.

# Spotlight on FECM Investments and Support in Appalachia

Central to the Appalachia Region's technological strengths are FECM's cutting-edge facilities and initiatives. These facilities (Figure 3) symbolize the region's commitment to continued innovation and desire to attract researchers, scientists, and industry leaders.

**Figure 3:** FECM Research and Development Facilities and Initiatives

## Pittsburgh, Pennsylvania

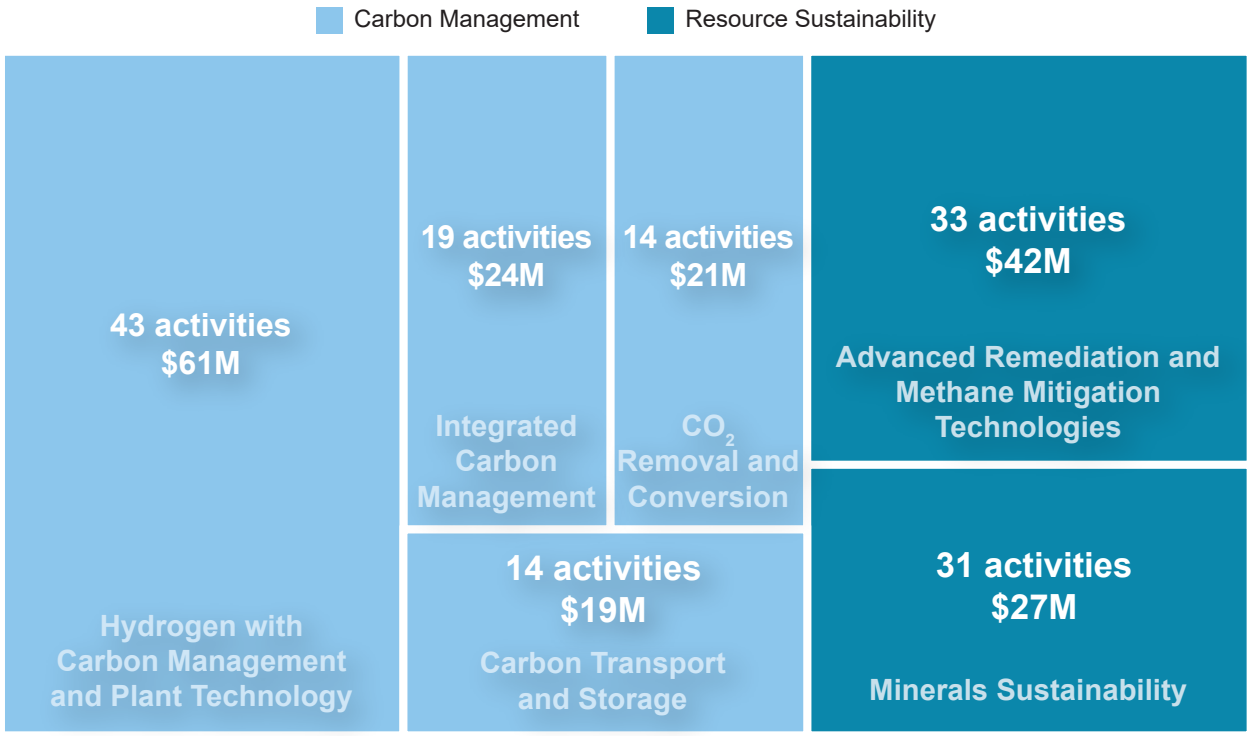
- **Direct Air Capture Center.** One-of-a-kind National Energy Technology Laboratory facility supporting private sector technology maturation to accelerate the commercialization direct air capture technologies.
- **Center for Artificial Intelligence and Machine Learning.** Center with a 37 petascale machine that allows researchers to explore problems using artificial intelligence, data mining, and analytics.
- **Carbon Dioxide Conversion.** Program focuses on research, development, and demonstration to convert $CO_2$ into environmentally value-added products to enable low-carbon supply chains in a decarbonized economy.
- **Coal to High-Value Carbon Nanomaterials.** Research to enable production of cost-competitive, high-value carbon fibers, and nanomaterials for use in non-traditional products.
- **Rare Earth Elements and Critical Minerals.** Program focused on extraction and processing technologies to support sustainable U.S. domestic critical minerals supply chain.

## Morgantown, West Virgina

- **Reaction Analysis and Chemical Transformation Facility.** Advancing research, leading to increased power production and reduced costs and emissions.
- **Center for Advanced Imaging and Characterization.** Utilizing technologies in tandem to provide characteristic geologic and geophysical information.
- **Joule 2.0. 3.6 PFLOP (one quadrillion floating-point operations per second)** supercomputer enables the numerical simulation of complex physical phenomena at various scales.
- **Hybrid Performance Project.** Test bed to research the combination of a high-temperature fuel cell and gas turbine with a gasifer or reformer as well as for new sensors and advanced control methods that could improve the performance of existing power plants.

FECM is investing federal funding to support academia, industry, and government entities to advance carbon management and resource sustainability in the region (Figure 4). At present, researchers and technology developers in the region are engaged in over 150 project activities, which represent a total investment ("award value") of nearly $200 million (Figure 4). Academia and industry each leads or support almost half of these activities with government entities leading less than 10%. These projects not only boost innovation but also lead to high-quality and long-term jobs, positioning the region as a hub for sustainable economic growth. The investment is detailed in Figure 3 Distribution of investment across FECM program areas.

**Figure 4:** Distribution of Investment Across FECM Program Areas
(includes value of awards to companies and organizations based in the region, both prime and sub-contracted)




Source: FECM and NETL database

The Appalachian Region, with its rich history of diverse collaboration and pioneering research initiatives, has established itself as center of excellence in the fields of energy technology, carbon management, and resource sustainability. By fostering collaboration across various sectors and driving transformative research, the region is not only shaping the future of energy but has also positioned itself as a model for successful collaboration between academia, industry, and government entities.

Selected projects shown in Figure 5 represent many opportunities discussed in this paper, including:

- Carbon capture in steel and petrochemical production,
- Improvements to turbine efficiencies,
- Appalachia Regional Clean Hydrogen Hub (ARCH2),
- Central Appalachian Basin CarbonSAFE Integrated Pre-Feasibility Project for geologic storage of $CO_2$,
- Small scale pilot facilities to produced mixed rare earth oxides (MREO) from coal and coal waste,
- Multiple projects to monitor and reduce methane emissions, and
- Multiple projects to reduce the land and water impacts of shale gas development.

The projects underway are not merely technological milestones; they represent the economic and intellectual vitality of the region and will contribute to sustainable and prosperous future for the region, nation, and the world at large. Importantly, although often in early stages, many of these projects have Community Benefits Plans to ensure that projects receiving public funding, particularly from the Bipartisan Infrastructure Law and the Inflation Reduction Act, create economic, environmental, and societal benefits for the communities and workers where projects are located. As Appalachia continues to evolve, the partnership between academia, industry, government entities, and communities will undoubtedly play a pivotal role in shaping a sustainable and technologically advanced future for the region.

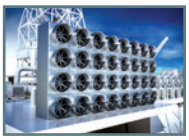
## **Figure 5:** Selection of Key Projects

**Point Source Carbon Capture** Industrial Sources | Power Sources

- $5M for University of Kentucky to lead small-pilot testing of carbon capture at the Nucor Steel Gallatin Plant
- $4M for Wood Environnent & Infrastructure Solutions to lead a FEED study for capturing $CO_2$ from a petrochemical plant
- $6M for a FEED study for capturing $CO_2$ from LG&E-KU's Cane Run Power Plant Unit 7

**Hydrogen with Carbon Management** Hydrogen Fuel | Gasification | Solid Oxide Fuel Cells & Gas Turbines

- $18M to CONSOL Energy, Inc. to Design Development and System Integration Design Study for an Advanced Pressurized Fluidized Bed Combustion Power Plant with Carbon Capture
- $11M to Pennsylvania State University (PSU) for Improving Turbine Efficiencies Through Heat Transfer and Aerodynamic Research in the Steady Thermal Aero Research Turbine (START)
- $9M to PSU for Advancing Turbine Technologies for Relevant Inlet Temperature Profiles in the Steady Thermal Aero Research Turbine (START) Lab
- Appalachia Regional Clean Hydrogen Hub (ARCH2)* * *OCED funded*



**Carbon Dioxide Removal** Direct Air Capture with Storage

- $3M to University of Kentucky to determine the feasibility of a distributed direct air capture hub that is powered by solar and biomass energy sources, and stores the carbon dioxide in a depleted natural gas field

**Carbon Transport and Storage** Monitoring, Verification, Accounting, & Assessment of Long-Term Storage | Storage Infrastructure Demonstration | Accelerating Regional Initiatives | CarbonSAFE

- $11M to Batelle, Carbon Storage Complex Feasibility for Commercial Development in Paradise, Kentucky – CarbonSAFE Phase II
- $23.7M, Batelle Memorial Institute, Regional Initiative to Accelerate CCUS Deployment in Midwestern and Northeastern USA

**Advanced Remediation** Environment Impacts of Development | Reducing Land and Water Impacts through Improved Recovery Efficiency | Abating Climate Risk from Oil and Gas Resources | Repurposing Existing Infrastructure

- $7.9M to West Virginia University, Marcellus Shale Energy and Environment Laboratory (MSEEL)
- $9.25M to Virginia Polytechnic Institute and State University, Field Laboratory for Emerging Stacked Unconventional Plays (ESUP) in Central Appalachia
- $650K to University of Kentucky Research Foundation, Conasauga Shale Research Consortium

**Methane Mitigation** Advanced Materials | Date Management Tools | Dynamic Compressor R&D | Direct & Remote Sensors | Data Analytics from Point Sources

- $5.5 Million to West Virginia University Research Corporation to assess oil and gas production storage tank emissions across the Marcellus region
- $1.5 Million to West Virginia Research Corporation to develop an advanced methane reduction technology for pipeline compressor systems
- $3 Million towards the Marcellus Methane Monitoring project
- $3 Million to West Virginia Research Corporation to develop a modular reactor capable of converting flared gas to high value carbons

**Critical Minerals** Efficient Rare Earth Element and Critical Mineral Recovery, Extraction, and Separation | Cost-Competitive Domestic Supply

- Small- Scale Pilot Facilities: Pilot-Scale Facilities Producing High Purity MREO/CM (Co, Mn, Ni, Ga, Gd) from Domestic Coal-Based Sources: WinnerWater Services, Lexington, KY; West Virginia University; and University of Kentucky

**University Training and Research** Education & Training | Novel, Early-stage R&D | Building R&D Capacity | Preparing the Future Workforce

- Nine active projects with a total award value of more than $3.7M and at least 18 students trained: Carnegie Mellon University; Kentucky State University; Ohio State University; Ohio University; Pennsylvania State University, and West Virginia University
- Five additional institutions involved in projects selected for negotiation in FY24: Lehigh University, University of Cincinnati, University of Pittsburgh, and University of Toledo

# Conclusion

Appalachia has a long history of mining, energy and industrial production, and its communities and workforce are rooted in those industries. In recent decades, the region has suffered from declining coal demand, power plant closures, and industrial decline. Yet, with the robust framework of federal funding, financing, and incentives for energy and industrial investment now available through the Bipartisan Infrastructure Law and Inflation Reduction Act, it is an exciting time for communities, workers, and businesses in the region.

FECM is committed to supporting the redevelopment of Appalachia, leveraging the region's existing industries to turn challenges into new economic opportunities, build clean energy and industrial supply chains, and sustain and create high-wage jobs. FECM's focus areas and portfolio of technologies are well-aligned with the region's energy and industrial mix, local infrastructure, and resources. These efforts will also help the region engage disadvantaged communities, create new jobs, build new supply chains and industry, and invest in supporting university research and development and innovation.

Together, these opportunities will support Appalachia, leveraging its strengths to advance a range of carbon management and resource sustainability solutions, moving the region forward as it emerges as a leader in the clean energy and industrial transition.

The Appalachia Regional Report is one of six regional reports that highlight resource sustainability and decarbonization solutions in fossil energy-producing and industrial regions. Given the rapidly evolving market, technology, and policy environment, the regional reports are intended to be "living documents" and will be updated as the outlook on each region evolves. Please note these reports and regional decarbonization workshops do not represent DOE policy or strategy, but rather are a representation of DOE's current understanding based on a synthesis of available facts.

FECM welcomes input and feedback on content for each of the reports. Please direct all inquiries and input to FECMRegionalReport@hq.doe.gov. Input and feedback should not include business-sensitive information, trade secrets, proprietary, or otherwise confidential information. Please note that input and feedback provided is subject to the Freedom of Information Act.

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