A Low Carbon Energy Transition in Southwest Pennsylvania

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Executive Summary

Southwest Pennsylvania has long fueled the US energy and manufacturing industries. For over a century it has powered the nation with coal and steel, and today it is one of the nation's top natural gas producers, thanks to the development of the Marcellus and Utica shales. Yet, as the nation and the world seek new, more efficient ways to use energy without emitting carbon dioxide (CO_2) and other greenhouse gases (GHGs), Southwest Pennsylvania faces an important transition. How can the region continue its economic development without leaving workers and communities behind?

This case shows the importance of taking an "all of the above" approach. The Commonwealth of Pennsylvania has enormous fossil fuel resources and related manufacturing and industrial sectors that are expected to grow under business-as-usual policies. Fossil fuel extraction, power generation, and manufacturing provide considerable income and relatively well-paying employment throughout the region, especially in rural areas. It is possible to lower carbon emissions in these industries while meeting growing global demand for energy and manufacturing. The Commonwealth also has considerable capacity to contribute to other energy sectors, including wind, solar, and nuclear power, and to capitalize on emerging manufacturing opportunities, such as additive manufacturing and clean steel.

Many of these opportunities will take time to cultivate, as they require substantial investment and infrastructure development. Meanwhile, the region's energy and manufacturing sectors are already under pressure, and some changes in the energy sector will be felt by workers and communities in the near term. For example, several coal mines and steel mills have been idled in recent years. A smooth transition of the energy and manufacturing sectors in this region will require investments and policies that address the needs of communities and workers. Doing so now will set the region on a course for future economic development.

1. In the near term, the Commonwealth of Pennsylvania should undertake a large-scale effort at remediation of methane leakage from wells and pipelines, of water contamination, and of brownfield sites. Plugging and capping the over 400,000 legacy wells in the area will provide immediate employment for workers, reduce greenhouse gas emissions, and improve public health.
2. In the medium and long term, development of carbon capture, utilization, and storage (CCUS) and hydrogen will allow the region to continue the use of existing fossil fuels in ways consistent with the rising demand for low greenhouse gas production. CCUS and hydrogen will require construction of pipelines and storage infrastructure and retrofitting of existing facilities. The Commonwealth of Pennsylvania will need to develop CCUS and hydrogen plans now to take advantage of these opportunities.
3. For the short to longer term, other aspects of energy production and manufacturing present substantial employment and growth opportunities for the region. Energy efficiency and the grid are and will continue to be the largest source of employment in the energy sector. Additional training programs are needed to meet the growing demand for these industries. Wind, solar, and nuclear energy have substantial potential, but are not predicted to grow significantly under business-as-usual policies, unless market or technology conditions change. Shifts in state laws, such as loosening restrictions on community solar, are needed to realize some of this potential. Clean technologies for

advanced manufacturing hold considerable promise for the development of modern manufacturing industries in this region.

4. Under all scenarios for the future, the region will need an effective workforce development strategy. Innovations in the energy sector will displace workers in traditional energy jobs, and emerging energy industries will require an appropriately trained workforce. Programs that engage local industry with area community colleges and local universities have proven very effective for helping workers adapt to the evolving job markets.

It must also be kept in mind that energy is just one of several key industries in the region today. Southwest Pennsylvania emerged from the decline of the steel industry in the 1990s with a much more diversified economy than it had in the past. In the 1990s the region's political, civic, and economic leaders identified health care as an opportunity for the future direction of the economy. Health care is now the largest industry in the region. In fact, health care is the largest employer and largest source of income in all but one of the thirteen counties in Southwest Pennsylvania. But, health care is not alone: the region has substantial finance, education, tech, and manufacturing sectors as well. The diversification of Southwest Pennsylvania's economy means that changes in the energy sector may not have as profound an effect on the region as in the past. The focus of this report is on energy, but the other sectors of the economy will also be important sources of employment for displaced fossil fuel energy workers and the creation of new economic opportunities.

The coming changes in the energy sector will require the Commonwealth of Pennsylvania and local political and economic leaders to identify successful models for adapting economic development and effectively deploying resources to impacted communities. Areas that have the highest dependence on fossil fuel extraction and power generation tend to be rural counties in this region. Economic development can be stimulated through regional infrastructure, especially transportation networks and broadband internet. There is a need to align the Commonwealth's policies with public and industry demands. The Commonwealth and the Southwestern Pennsylvania Commission should convene public-industry task forces and working groups that meet regularly to examine regional development in line with the needs of communities.

The coming transition in global energy production presents Southwest Pennsylvania with a unique opportunity to cultivate entirely new industries out of existing resources, such as carbon capture, hydrogen, and advanced manufacturing. Doing so will take time and investment. Fortunately, the region has a combination of assets that few other places in the world enjoy. It has the natural resources, the history, the know-how, and the people to help the world create a cleaner energy future.

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Chapter 1

Introduction

Southwest Pennsylvania has anchored energy production in the United States for almost two centuries. Fossil fuel extraction and related industries, such as steel and petrochemicals, are deeply rooted in the region's economy and culture. A global energy transition that will directly affect this region's energy-driven industries, however, is already underway. Over the past two decades, the US has seen significant growth in natural gas, wind, and solar energy and a massive drop in demand for coal. The US and other nations increasingly favor energy generation technologies, industrial development, and products that have lower carbon emissions than occur with traditional fossil fuels. Given the changes that are occurring in energy systems, how can Southwest Pennsylvania adapt to, or even take advantage of, these changes without leaving workers and communities behind?

The challenges and opportunities that the region faces will unfold over the course of decades. There are near-term effects of the low carbon energy transition that require immediate attention and solutions. Most notably, closures of coal mines, idling of steel facilities, and conversion of coal power plants to natural gas have displaced significant numbers of workers. There is an immediate need for new employment opportunities in the affected communities. These displacements, however, may just be the leading edge of deeper changes in the region's energy sector over the next 10 to 20 years. Consequently, the region has the opportunity now to develop strategies to manage the changes that will come over the medium and long term, and possibly to create entirely new energy and manufacturing industries. The coming energy transition will be eased further because the Southwest Pennsylvania economy is built around numerous industries, including health care, education, finance, and tech. This report focuses on just one of those core sectors of the economy – energy.

Today, energy is one of six key industries in Southwest Pennsylvania. Energy extraction, power generation, and related manufacturing account for up to 20 percent of the region's gross domestic product and roughly 10 percent of employment. Thanks to Southwest Pennsylvania's substantial energy industry, the commonwealth is the second largest energy producer in the US and an important source of energy for the nation. Notably, since 2005, the development of Marcellus Shale gas has driven a boom in energy extraction and is attracting related industries, such as petrochemicals.

The Commonwealth of Pennsylvania predicts continued expansion of natural gas extraction and related utilities and manufacturing industries over the next three decades. Southwest Pennsylvania will be central to that development. This assumes continued growth in national and global demand for natural gas. There is a growing likelihood that future demand for coal, natural gas, and oil, at least as we currently use them, will lessen. The region's political and industrial leadership should work together to develop strategies to anticipate this potential and take advantage of new opportunities.

Future demand for fossil fuel-generated energy and products from Southwest Pennsylvania face four pressures. First, other parts of the US are rapidly developing new energy sources, especially wind and solar power. These new energy resources will compete with natural gas and coal and will reduce demand for the region's energy resources. Second, public policies in other states (and possibly at the federal level), such as renewable portfolio standards and carbon taxes, will eventually lessen demand for fossil fuels from Southwest Pennsylvania. Third, other countries' carbon policies, such as the European Union's border carbon adjustment, will lower demand for metals, petrochemicals, and other products that are made with energy or materials from this region and that have high carbon emissions. Fourth, other regions of the country, notably Texas, are beginning to deploy technologies, such as carbon capture and hydrogen, to reduce the carbon content of fossil fuels. Southwest Pennsylvania risks falling behind in these sectors.

Because the region has a very diversified economy, the impact of a shift away from fossil fuels is predicted to have a mild, negative effect on the region's economy as a whole. The Roosevelt Project's REMI model predicts that, if there is a significant drop in demand for fossil fuels, the region can expect a two percent drop in employment, concentrated in energy extraction, utility, and manufacturing sectors. The effect is expected to occur in 10 to 15 years and will be a lasting shift in the region's output and employment. Importantly, these projections are driven, in part, by a projected increase in fossil fuel energy prices and costs, and they do not incorporate the possibility of development of carbon capture, hydrogen, utility-scale battery storage, or other new energy technologies. Such disruptive technologies can alter the region's trajectory.

The economic and social effects of decreased demand for the region's fossil fuels will be felt unevenly. The economic sectors and employment most closely tied to fossil fuel production tend to be concentrated in rural counties in Southwest Pennsylvania, such as Greene County, Fayette County, and Indiana County. Many of the fossil fuel industry jobs pay well, currently providing people without college educations with solid middle-class incomes. Loss of these jobs will place a burden on these counties in Southwest Pennsylvania and increase the income gap in the area.

We are confident in the ability of this region to navigate the coming energy transitions. The critical questions for Southwest Pennsylvania are how can energy production and related manufacturing industries put themselves in a position to head off possible contraction in the future? How can the Commonwealth of Pennsylvania and regional planning organizations help workers and communities already being affected adapt to change? How can industry and research organizations take advantage of new economic opportunities that will arise with the energy transition?

The region has a history of navigating successful, if painful, industrial transitions. Pittsburgh and the surrounding counties emerged from the decline of the steel industry in the 1990s with a much more diversified economy. Today, healthcare is the largest industry in terms of employment and gross product in the region, but the area also has substantial finance, higher education, tech, and manufacturing industries. Embracing healthcare was a conscious decision by local civic, economic, and political leaders who took stock of the region's assets in this industry, especially Pittsburgh's medical centers and universities. In urban and rural counties alike, healthcare is now the region's largest industry. More importantly, every county has several significant industries, rather than just one big employer or a single-sector economy.

The region has maintained and even strengthened its deep community of civic, economic, and government organizations. Local non-governmental organizations, such as community development corporations, industrial development authorities, universities, and foundations, are already focused on the challenges that the transition from traditional fossil fuel industries presents.

Unlike the transition following the decline of the steel industry, the region is in front of some of the changes that are occurring and are to come in the energy and manufacturing sectors. We are impressed by the large number of organizations that are focused on the region's future and the ability of the region to navigate changes in its economy successfully.

This report presents a case study of the energy transition in Southwest Pennsylvania: what is happening now, and how the region can capitalize on key opportunities. It is not an exhaustive study of the region's economy. Rather, it focuses on energy and closely-related industries, and is organized around five topics: the organizational ecosystem, remediation, fossil fuels, diversification of energy and manufacturing, and workforce development. Each of the chapters of this report can be read as stand-alone analyses, as well as part of the whole.

One specific near-term recommendation recurs throughout this report. We recommend that stakeholders in the region, working through existing organizations such as the Allegheny Conference on Community Development, the Southwestern Pennsylvania Commission, or the Appalachian Regional Commission, establish a set of Task Forces, each focusing on a particular theme, such as remediation or workforce development. These Task Forces should develop a region-wide plan for the particular topic under examination. The Task Forces should include a wide range of stakeholders, and they should conduct public meetings to listen to people in the region about how to address coming changes in the energy, industrial, and manufacturing sectors.

We see four organizational and political needs. First, there is a need for building organizational capacity in smaller communities. Many small towns lack the permanent governmental and civic organizations that continually invest in revitalizing downtowns and other essential economic development activities. Second, there is a need for streamlining planning processes. Third, there is a need for more region-wide planning and for coordination among the regional commissions, such as county planning commissions, the Appalachian Regional Commission and the Southwestern Pennsylvania Commission. Finally, there is the need for political leadership to champion economic development programs in regions that will be hardest hit by a transition away from fossil fuel extraction and manufacturing.

In the near term (over the next 5 to 10 years), there is the need for investments that can stimulate commercial activity and provide well-paying jobs for those already experiencing dislocations due to decreasing demand for coal. Remediation of well leakage and soil and water contamination in Southwest Pennsylvania can provide a substantial and immediate economic stimulus in precisely the areas that have been hardest hit. Well-capping and other forms of remediation, such as leak detection and repair, will also greatly reduce greenhouse gas emissions and other forms of pollution in the area.

The region's long history of fossil fuel production through coal mining and conventional well drilling has in many places left a deeply problematic environmental landscape. There are at least 400,000 wells in the region that require capping and maintenance to prevent leakage of methane and other pollutants. There are substantial employment, environmental, and public health benefits to remediation at natural gas and coal sites. There are also substantial challenges. Large numbers of these wells – perhaps most – were operated by firms that no longer exist and long preceded the current unconventional gas extraction brought about with hydraulic fracturing.

Ample, reasonable opportunities exist to change and enhance the incentives of active fossil fuel operations to help correct past harms and prevent future ones. These include modifications to bonding requirements on wells and third party leakage minimization certification programs for active extraction and transport operations. The Commonwealth should expand databases of problematic sites and operations, and create a "low-emission natural gas" certification for Pennsylvania natural gas that can be sold at a small premium, with revenue going back into remediation work.

Research investments by area universities and industries in technologies for detecting and quantifying specific harms, like methane leakage, will help create new tools to direct remediation investments.

Brownfield sites, such as former coal powered power plants, are opportunities for future development. However, potential investors face substantial uncertainties. Investing in site specific "playbooks"—and actively promoting and distributing them--can help reduce these uncertainties and unlock opportunities.

In the medium to long term, carbon capture, utilization, and storage (CCUS) can provide a way to continue the region's fossil fuel industries in line with rising demand for low carbon energy. There are significant opportunities for substantial economic growth in fossil fuel energy and related manufacturing with the deployment of technologies to capture carbon from power generation or manufacturing processes, and to store the waste carbon or use it in other applications. Ramping up a CCUS system in the region at scale may take 10 to 15 years, because of the time horizons needed for planning, siting, permitting and building infrastructure. There is also a need for technological improvements to reduce further the costs of carbon capture and utilization. Hence, if the region is to become a hub for CCUS, it is important to take the first steps now.

The region is ideally suited for the creation of an innovation hub to meet global demand for new technologies for carbon management. Southwest Pennsylvania has the natural resources, existing industry, trained workforce, and research and development capacity--with the National Energy Technology Laboratory, Carnegie Mellon University, the University of Pittsburgh, and Penn State University--to develop, demonstrate, and deploy carbon capture, storage, and utilization technologies. An innovation hub in Southwest Pennsylvania focused on carbon management would help maintain US leadership in the emerging industry and would stimulate growth locally.

Development of CCUS in the region may eventually support other industrial development. CCUS can be instrumental in reducing carbon emissions in the production of cement, steel and other metals, and petrochemicals. Perhaps most intriguing, CCUS can also be used to produce hydrogen using natural gas (blue hydrogen) and support the development of hydrogen to transform transportation, industrials, and petrochemicals.

If the Commonwealth chooses to develop CCUS to extend its fossil fuel industries, now is the time to plan for its deployment and to invest in core infrastructure. The Commonwealth lacks a comprehensive plan for carbon capture and sequestration and has not laid the foundation for development of hydrogen. Texas has jumped out to a lead in developing CCUS and hydrogen infrastructure, with the construction of CO_2 and hydrogen pipelines and storage facilities. ExxonMobil has announced the investment of $100 billion in the Gulf Coast for the development of carbon capture and sequestration. Development of the requisite infrastructure will take time, but to be competitive or even lead in this industry will require investment in the near term.

Deployment of CCUS at scale in this region will require the construction of a backbone or trunk CO2 pipeline as well as branch pipelines that connect energy and industrial facilities to storage sites. It will also require construction and maintenance of underground CO2 storage facilities. We estimate that the core infrastructure will cost in the neighborhood of $10 billion. If the region is to capitalize on this opportunity, industry and government will need to plan and invest in such infrastructure development in the near term.

Energy efficiency and grid development hold substantial promise for economic development and expanding employment. The development of wind and solar energy within the state is not expected to reach the same level as existing fossil fuel power generation, or to replace existing fossil fuel jobs, but under the right circumstances wind and solar energy sources have the potential to make significant contributions to Pennsylvania's energy mix.

Energy efficiency (especially heating, ventilation, and air conditioning) and grid already account for the largest number of energy jobs and most of the growth in energy employment in Pennsylvania. Some of these jobs, especially construction of grid infrastructure, require skills similar to those in energy extraction and manufacturing. Energy efficiency and grid jobs are expected to grow considerably over the coming decades. Appropriate training programs are needed to meet growing labor demand for these sectors.

Forecasts by the Pennsylvania Department of Environmental Projection predict no substantial production of energy from wind and solar power in the state over the next 30 years, under business-as-usual assumptions. However, some projections do foresee substantial development of these resources. The region has some potential for wind development along the Appalachian ridges, and open farmland may be used for solar development. Our sense is that there is considerable room for growth of wind, solar, biogas, geothermal, hydropower and other energy sources, but development of these sources has so far not received the same attention that fossil fuels have.

Development of solar and wind power on a large-scale in Pennsylvania will require regulatory and policy changes, such as enabling legislation for community solar, and may depend on breakthroughs in utility-scale storage, including large battery storage.

The Pittsburgh area is experiencing a surge in the development of new industries, especially in tech around robotics and artificial intelligence, and in biomedical science around the university medical centers. These emerging industries will absorb some of the dislocation due to a transition away from energy, and their emergence will further diversify and strengthen the region's economy.

Carnegie Mellon University and the University of Pittsburgh have been important engines for generating innovation in the Pittsburgh area. Innovations in robotics at CMU, for example, have led to the development of the university's National Robotics Engineering Center and the Advanced Robotics for Manufacturing Institute. These, in turn, have created employment and new companies in the region. The area has excellent existing infrastructure for new manufacturing and innovation centers. Hazelwood Green in Pittsburgh is one such example.

An important challenge is to leverage the region's assets to attract more investment capital for manufacturing ventures in Southwest Pennsylvania. There is ample venture capital for ideas in the region, but there is less venture capital for development of new manufacturing, especially firms related to the region's innovation and technology centers.

Strategic decisions by political leaders locally and across the state can accelerate these new industries. Expanding the Industrial Development Authorities, which provide tax incentives for new industrial development, is one possible strategy. At the very least there is the need for more aggressive political leadership regionally to attract investment in new manufacturing.

A central challenge for the region over the coming decades is to create good-paying jobs for people whose livelihoods currently depend on fossil fuel industries. The effects of decreasing demand for coal and, eventually, for natural gas will be felt most acutely in rural areas where fossil fuel extraction and utilities are among the most important industries, especially for workers who do not have college degrees.

Loss of fossil fuel jobs will likely exacerbate wage gaps. The typical fossil fuel related job in this region pays approximately the median income in the area and requires a high school education. Currently, the typical job in any sector in the region's economy that requires a high school degree or less pays substantially less than a fossil fuel job. The loss of such jobs will likely add to inequities in wages and income.

Institutions, such as local community colleges, county governments, and planning commissions, like the ARC, are bracing for this transition. The most common strategy involves training programs to narrow the wage gap and improve the transition for coal field workers to other sectors. Such programs are difficult to do successfully, because typically they do not track workers into a specific job or industry that will definitely provide long-term employment at the end of the program. That said, we have encountered several promising successful models in the region. The most successful models are those that work with industry and that offer people skill training that goes beyond just one specific job.

We recommend that industry, educational institutions, governments, and NGOs develop a regional strategy to improve workforce training. The Southwestern Pennsylvania Commission should convene a joint task force to improve physical infrastructure and broadband access to assist these training efforts.

Pittsburgh and Southwest Pennsylvania emerged from the decline of steel with a diversified economy and a resilient civil society. These are the core strengths of the region as it will face future transitions in its energy and manufacturing sectors. Some areas of the region, especially traditional coal producing communities, are already experiencing dislocations. Immediate action is needed to help these communities. Now is also the time to develop strategies to adapt to changes in the energy industry that will come in the next decade. It can take years to implement a successful economic development strategy or to build the infrastructure needed to sustain emerging industries. Fortunately, Southwest Pennsylvania has the opportunity now to participate actively in the energy transition.

Chapter 2

Challenges and Opportunities for a Diversified Southwest Pennsylvania Society

Elizabeth Thom

Introduction

Southwest Pennsylvania is no stranger to major economic transitions. The region has engaged in coordinated planning efforts to tackle industrial, environmental, and infrastructure challenges for over 75 years. During the 1940s, concerns over air pollution and the need for economic diversification drove development plans; in the 1970s and 80s, declining demand for steel and coal resulted in strategies to invest in new industries and revitalized communities. Today, climate change and the forthcoming energy transition pose a new set of challenges to economic growth and prosperity in the region.

However, the current moment also presents Southwest Pennsylvania with an opportunity to capitalize on previous regional development successes. The area is well positioned to leverage its natural resources, dedicated workforce, world-class colleges and universities, and diverse institutional landscape to become a leader in the transition to a low carbon future. As the Allegheny Conference on Community Development put it, "reinvention is our pedigree."[1]

Indeed, the planning organizations and blueprints that steered Southwest Pennsylvania through previous transitions can be credited for the region's economic diversification relative to other former industrial or "rust belt" areas. This is especially true for the city of Pittsburgh, whose transformation from an industrial manufacturing center to a health care and technology hub has been well documented.[2] Insights from these previous periods of change and adaptation provide important lessons for the upcoming energy transition.

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[1] "The Vision: Regional Vitality," Long Range Plan: 2020-2030, accessed June 29, 2021, https://www.alleghenyconference.org/long-range-plan/.

[2] Scott Andes et al., "Capturing the next Economy: Pittsburgh's Rise as a Global Innovation City," Brookings (Brookings, October 24, 2018), https://www.brookings.edu/research/capturing-the-next-economy-pittsburghs-rise-as-a-global-innovation-city/.

To start, successful outcomes are possible when stakeholders align and engage in regional planning with shared goals. During the steel industry collapse, political leaders, county commissioners, universities, and economic development groups, such as the Allegheny Conference, came together to assess the region's assets and craft a forward-looking plan. Among the region's primary resources were its many colleges and universities, including the University of Pittsburgh (Pitt) and Carnegie Mellon University (CMU). They formed a core part of the region's redevelopment plan, known as Strategy 21. The plan focused on investments in infrastructure, real estate, and a joint partnership between CMU and Pitt to establish technology centers.[3] Billions in private investments and $400 million from the state facilitated the reimagination of the city into an engine for technology-driven innovation.[4]

Stakeholders also identified healthcare as another industry to invest in given the area's network of universities, hospitals, and research centers. Today, the lifeblood of post-steel Pittsburgh consists of university affiliated technology centers and medical services. Healthcare predominates outside of Pittsburgh and Allegheny County, too. Among the thirteen counties in our study, the healthcare industry is the largest job creator in all but Greene County, employing about one in five workers.[5]

The success of tech and health care in Southwest Pennsylvania is a direct result of the region's coordinated planning efforts and shared strategic vision. Similar processes ought to be put in motion now in order for the region to get out in front of the energy transition and take advantage of its diversified assets. This time around, however, regional planning will have to contend with two new issues.

The first is that it will be critically important for regional planning to incorporate stakeholders from both within Pittsburgh *and* its surrounding counties. The economic benefits of Pittsburgh's transformation were not evenly distributed throughout the Southwest region. Absent from the regional planning model were clear strategies for assisting displaced workers from rural counties with roots in coal and steel industries. Blue collar workers were largely left out of the city's reimagined medical and tech future, exacerbating the effects of steel-related income and revenue losses.

Southwest Pennsylvania's more rural counties will again face the immediate consequences of the next transition, perhaps even more so this time given the region's recent natural gas boom. While technology firms took hold in Pittsburgh, natural gas boosted rural economies. The industry offered opportunities for workers without college degrees and put money in the pockets of land owners to build wells on their properties. Local businesses benefited from increased traffic to the region, and gas companies invested heavily in local communities, sponsoring agricultural fairs and infrastructure projects. Both the state and local governments have profited from gas-related

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[3] Armstrong, Ben. 2019. "Brass Cities: Innovation Policy and Local Economic Transformation." PhD diss. Massachusetts Institute of Technology.

[4] Peluso, Nina and Michael Kearney, Richard Lester. "Assessing the Role of Public Policy in Industrial Transitions: How Distinct Regional Contexts Inform Comprehensive Planning," The Roosevelt Project Working Paper Series (September, 2020).

[5] PA Department of Labor and Industry, Center for Workforce Information & Analysis. April 2021. https://www.workstats.dli.pa.gov/

taxes and impact fees. In order to ensure inclusive prosperity during the energy transition, an even more diverse set of Southwest Pennsylvania stakeholders must come together to coordinate a new vision that takes into account the needs of all residents in the area.

Second, the region will have to contend with an institutional ecosystem that looks a lot different than previous transitions. Historically, the Southwest Pennsylvania region has tended to rely on one big industry or employer for jobs and revenue. Energy and energy-adjacent industries have often filled this role. However, thanks to the success of the region's transition away from steel, the institutional environment today is much more diffuse. Put simply, there are many more players with stakes in the region's continued economic development. Previous transition formulas will be mostly obsolete given this new institutional environment, which presents both challenges and opportunities for coordinated regional planning.

This chapter surveys the current institutional ecosystem in Southwest Pennsylvania, examining the interconnectedness of various groups and industries, while revealing gaps to be filled in regional planning processes. Then, it discusses how the ecosystem is currently addressing regional development issues by highlighting a few illuminating examples. With these insights in mind, the chapter considers how the ecosystem could be leveraged to address five main proposals in our report: CCUS pipeline development, environmental remediation, sustainable diversification, and workforce retraining. We conclude with some additional recommendations for how the region can build upon its proven track record of innovation and reinvention.

Today's Institutional Ecosystem in Southwest Pennsylvania

Southwest Pennsylvania consists of a dense network of regional assets that sets it apart from neighboring states and other parts of Central Appalachia. Many of these are legacy institutions that have formed a critical part of the region's social fabric for decades, while others are new organizations that have been born out of dedicated investment in the area. To summarize, these assets fall into four broad categories: (1) diversified economic activity; (2) planning and development capacity at various levels; (3) financial resources; and (4) good hardware. We discuss each in turn, examining how they might be able to coordinate effectively to address the energy transition.

Asset 1. Diversified economic activity

For much of the twentieth century, the Southwest Pennsylvania economy relied on a handful of industries. Today it is home to an increasingly diverse set of companies, entrepreneurs, nonprofit organizations, manufacturing facilities, and educational institutions. Major industries include healthcare, tech, finance, insurance, robotics, artificial intelligence, autonomous vehicles, arts and entertainment, energy, utilities, universities and research institutions, advanced manufacturing, philanthropies, tourism and a growing small business ecosystem. We highlight a few of these in order to call attention to ways they could be utilized to offset the anticipated effects of the energy transition.

(1) Educational institutions for research and training

A key feature of Southwest Pennsylvania's institutional ecosystem is its dense network of public and private colleges and universities. There are fourteen community colleges in the Commonwealth of Pennsylvania and five of them are located in the southwest region. The

Community College of Allegheny County is the largest among them, with a total of 40,000 students enrolling annually across all programs.[6] There are also community colleges in Beaver, Butler, and Westmoreland counties, and the Pennsylvania Highlands Community College has satellite campuses throughout the southwest. Private and for-profit technical schools in the area offer additional opportunities for associates degrees and training.

Several of Pennsylvania's public universities also have a strong presence here. Penn State University, the commonwealth's land grant university, has five satellite campuses in the region, including one in New Kensington that we highlight later on in this chapter. The University of Pittsburgh is a major part of the city's institutional ecosystem, with a 132-acre campus and roughly 33,000 students.[7] It is the top employer in Allegheny County, thanks to its affiliated hospitals and research centers. Historically, the university has played a key role in guiding the region through economic changes, and we expect it will continue to do so. In addition to Pitt and PSU, California University of Pennsylvania, Indiana University of Pennsylvania, and Slippery Rock University enroll thousands of students in the counties surrounding Allegheny.

Dozens of private colleges and universities are based in the region as well. Carnegie Mellon University is well-known globally for its programs in science and technology, especially robotics and artificial intelligence. It consistently ranks as one of the top schools in the country for computer science and engineering, and its focus on innovation has helped it attract companies such as Google, Uber, GE, and Intel to Pittsburgh.[8] CMU students themselves have also created their own companies, contributing to the region's growing start-up culture. The university has been a major driver of the city's transformation into a technology hub, and it will certainly be a leader in the region's response to the technological and social challenges of the energy transition.

Other prominent private institutions in the area include Robert Morris University, Chatham University, Duquesne University, Waynesburg University, and Washington and Jefferson University, to name a few. All serve critical roles in their respective communities, attracting tens of thousands of talented students to the region and educating twenty-first century workforces.

(2) Healthcare networks

A pillar of Southwest Pennsylvania's diversified economy is its healthcare infrastructure. As we have already noted, healthcare is the leading industry in nearly all of the counties in the southwest region. Hospitals, doctors' offices, and out-patient facilities serve important functions in these communities, providing opportunities for employment, as well as much needed medical care to an aging population. The largest provider in the region is the University of Pittsburgh Medical Center (UPMC), a $23 billion institution that operates 40 academic, community, and

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[6] "CCAC At a Glance," CCAC at a Glance (Community College of Allegheny County), accessed June 29, 2021, https://www.ccac.edu/about/at-a-glance.php.

[7] "About University of Pittsburgh," University of Pittsburgh (University of Pittsburgh), accessed June 29, 2021, https://www.pitt.edu/about.

[8] "Carnegie Mellon University Fact Sheet," Carnegie Mellon University (Carnegie Mellon University, March 2020), https://www.cmu.edu/assets/pdfs/cmu-fact-sheet.pdf.

specialty hospitals in the area.[9] It is the largest non-governmental employer in the Commonwealth of Pennsylvania, with more than 90,000 employees. UPMC contributes hundreds of millions in state and local taxes and gives about $1 billion each year to the Southwest Pennsylvania community through investments in charity, health programs, and medical research.[10]

Smaller regional facilities form another important piece of the healthcare network. Many of them are located in more rural communities that otherwise would face barriers to accessing care. The southwest region is also home to dozens of community-based Federally Qualified Health Centers (FQHC), that provide primary and preventative care to individuals regardless of their ability to pay. There are twenty-seven such centers in Pittsburgh alone.[11] Their deep community ties make them invaluable assets for both the economic and physical well being of Southwest Pennsylvanians.

(3) Technology and innovation

Thanks in part to the region's rich ecosystem of research universities, Southwest Pennsylvania is a national and global leader in technology and innovation across a range of fields. Carnegie Mellon University leads the way in artificial intelligence, machine learning, and robotics, with the number one AI program in the nation. Advancements by CMU faculty and students in supercomputing, AI, autonomous vehicles, cybersecurity, biotech, and medical devices have attracted $141 million in computer and information science R&D funds.[12] In 2017, CMU received $250 million to launch the Advanced Robotics and Manufacturing Institute (ARM). The institute is part of the Department of Defense's efforts to invest in advanced manufacturing and collaborative robotics research.[13] Today, the facility is headquartered in Mill 19 of Pittsburgh's Hazelwood Green site, a former abandoned steel mill that is being redeveloped as a hub for the

[9] "UPMC FAST FACTS," University of Pittsburgh Medical Center (University of Pittsburgh Medical Center), accessed June 29, 2021, https://cdn.upmc.com/-/media/upmc/about/facts/documents/fast-facts.pdf?la=en&rev=ed0dcacbb2b547aeada15cac2d140f5d&hash=7CC8ED83B0341FD3A012FE4F0952E38A&_ga=2.166760637.2099047737.1622199051-915173518.1622199051.

[10] Ibid.

[11] "Federally Qualified Health Center (FQHC) - Pennsylvania: Page 1," NPIdb.org (National Provider Identifier Database), accessed June 29, 2021, https://npidb.org/organizations/ambulatory_health_care/federally-qualified-health-center-fqhc_261qf0400x/pa/?page=1.

[12] "Cybersecurity," Pittsburgh Region (Pittsburgh Region, April 6, 2021), https://pittsburghregion.org/key-industries/cybersecurity/.

[13] "DoD Announces Award of New Advanced Robotics Manufacturing (ARM) Innovation Hub in Pittsbu," U.S. Department of Defense (U.S. Department of Defense, January 23, 2017), https://www.defense.gov/Newsroom/Releases/Release/Article/1049127/dod-announces-award-of-new-advanced-robotics-manufacturing-arm-innovation-hub-i/.

area's next chapter in manufacturing.[14] We discuss Hazelwood Green in more detail later on in this chapter.

CMU has also teamed up with Pitt on several joint technology research ventures, most prominently the Pittsburgh Supercomputing Center (PSC). The center receives federal, state and private funds to support high-performance computing, communications and data analytics for scientists and engineers.[15] With the help of a $5 million grant from the National Science Foundation, PSC recently launched Neocortex, a supercomputer designed to "revolutionize scientific AI research" in fields such as medical imaging, genomics, climate research and computational fluid dynamics.[16]

Attracted by these growing research centers and a large pool of talented graduates, private tech companies and start ups have also found a home in Southwest Pennsylvania. Google, Amazon and Facebook are capitalizing on the region's AI technology, while Uber is taking advantage of advancements in sensors for autonomous vehicles. A stream of homegrown start ups have also been very successful. Duolingo, the language-learning platform, is Pittsburgh's first "unicorn" start-up, reaching a valuation of $1.5 billion in 2019.[17] Pitt graduate Bryan Salesky founded the self-driving technology company Argo AI, which has partnered with Volkswagen and Ford to use its lidar sensors to get commercial autonomous vehicles on the road in the coming years.[18] Together, these companies form a new section of Pittsburgh's business district, affectionately dubbed "Robotics Row."

The region is also home to the National Energy Technology Laboratory (NETL), which is part of the Department of Energy's national laboratory system. With offices in Pittsburgh and Morgantown, West Virginia, the government owned and operated lab specializes in energy and environmental research, especially in the areas of coal, natural gas and oil technologies.[19] Established partnerships between the lab and other research institutions in the Southwest Pennsylvania ecosystem make the region an ideal center for developing new technologies for carbon management in the energy transition.

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[14] "Future of Manufacturing To Rise Within Abandoned Steel Mill," News (Carnegie Mellon University, October 25, 2017), https://www.cmu.edu/news/stories/archives/2017/october/hazelwood-green.html.

[15] "About PSC," Pittsburgh Supercomputing Center (Pittsburgh Supercomputing Center), accessed June 29, 2021, https://www.psc.edu/about/.

[16] Ken Chiacchia "Neocortex, a Groundbreaking AI Supercomputer, Begins Early User Access at PSC" Pittsburgh Supercomputing Center (Pittsburgh Supercomputing Center, March 29, 2021), https://www.psc.edu/neocortex-a-groundbreaking-ai-supercomputer-starts-user-access-at-psc/.

[17] Sophia Kunthara, "Duolingo Lands $30M, Reaches Unicorn Status" Crunchbase News (Crunchbase, December 4, 2019), accessed June 29, 2021, https://news.crunchbase.com/news/duolingo-lands-30m-reaches-unicorn-status/.

[18] Kirsten Korosec, "Argo's new lidar sensor could help Ford, VW deploy self-driving vehicles at scale" TechCrunch (TechCrunch, May 4, 2021), accessed June 29, 2021, https://techcrunch.com/2021/05/04/argos-new-lidar-sensor-could-help-ford-vw-deploy-self-driving-vehicles-at-scale/.

[19] "About," National Energy Technology Laboratory, accessed June 29, 2021, https://www.netl.doe.gov/about.

(4) Finance and venture capital

Access to capital for these innovative and entrepreneurial activities comes from a diverse set of financial institutions and venture capitalists with deep roots in the region. PNC Bank was founded in Pittsburgh in the 1850s and its corporate headquarters has been located at the same city intersection for more than 160 years.[20] The former Mellon Financial Corporation, now the Bank of New York Mellon, maintains an important presence in the region's financial sector, too.

Other sources of investment include groups such as Innovation Works and the Pittsburgh Technology Council. Both focus on helping tech entrepreneurs gain access to capital and resources for business growth. Innovation Works is the largest seed stage investor in Southwest Pennsylvania, contributing $113 million to more than 700 companies. Meanwhile, the Pittsburgh Technology Council focuses on growing technology clusters in the area by connecting companies with the region's workforce and advocating for public policies that foster business development.

With so much entrepreneurial activity taking place in the region, it comes as no surprise that venture capital is now a major component of the institutional ecosystem. The Pittsburgh Venture Capital Association is the primary membership organization for over 200 firms and investors in western Pennsylvania.[21] The group sponsors investor events such as the 3 Rivers Venture Fair and helps coordinate funds toward promising deals. With a mix of both large corporations and small entrepreneurs, there is a steady flow of capital investment in Southwest Pennsylvania.

(5) Foundations and nonprofits

The economic activity of the region is anchored by a dense network of foundations and nonprofits with deep histories and commitments to Southwest Pennsylvania. In the greater Pittsburgh metro area, there are an astounding 3,955 foundations and grantmaking organizations, totaling $20 billion in assets.[22] The most prominent among them are private foundations such as Heinz Endowments, the Richard King Mellon Foundation, the Claude Worthington Benedum Foundation, PNC Foundation, the Pittsburgh Foundation, and the Hillman Family Foundations, to name a few.[23] Each has its own mission and favored causes, spanning public health, education, workforce readiness, environmental conservation, economic development, the arts and more.

[20] "Corporate History," PNC, accessed June 29, 2021, https://www.pnc.com/en/about-pnc/company-profile/legacy-project/corporate-history.html.

[21] "About the PVCA," Pittsburgh Venture Capital Association, accessed June 29, 2021, https://thepvca.org/about.

[22] "Pittsburgh foundations," Cause IQ (Nonprofit Metrics LLC, 2021), accessed June 29, 2021, https://www.causeiq.com/directory/foundations-list/pittsburgh-pa-metro/.

[23] Joyce Gannon, "Pittsburgh's top foundations by grant money: Hillman rises in the ranks," Post-Gazette (Pittsburgh Post-Gazette, May 30, 2018), https://www.post-gazette.com/business/pittsburghhttps://www.rkmf.org/news_posts/richard-king-mellon-foundation-unveils-10-year-strategic-planh-company-news/2018/05/30/top-foundations-pittsburgh-Henry-Hillman-family-foundations-grants-heinz-endowments/stories/201805300120.

The RK Mellon Foundation is the largest in the region and among the biggest in the world, with an endowment of $3.1 billion.[24] In January of 2021, the foundation revealed its new strategic plan with a commitment to invest $1.2 billion in the area by 2030. Signaling its commitment to this mission, in May 2021 the foundation approved $150 million-- the largest grant in its history-- for CMU to build a revolutionary science facility on its Oakland campus and two new centers in Hazelwood Green--one a robotics innovation center and the other focused on advanced materials and manufacturing.[25] And in April of 2021, Heinz Endowments committed a historic $30 million to CMU in order to create The Center for Shared Prosperity, which will focus on establishing community-university partnerships to address socioeconomic inequality in the area.[26] Both examples illustrate how various institutions in Southwest Pennsylvania's ecosystem can come together to tackle important issues in the community.

There are thousands of smaller nonprofits in the region, including unions, community health organizations, educational groups, religious institutions, community development organizations, and recreational clubs that provide critical resources to the community, too. Together with the foundations they are essential components of Southwest Pennsylvania's social fabric and a key feature of the region's ecosystem that sets it apart from other areas in Central Appalachia.

(6) Manufacturing

Southwest Pennsylvania has a rich history of using its natural resources to manufacture the materials that have built and powered cities around the world. This is how Pittsburgh earned its reputation as an industrial capital and its nickname, "Steel City." Manufacturing remains a dominant industry, ranking among the top employers in eleven of the thirteen counties in our study. There are over 2,800 manufacturing establishments in the area producing materials ranging from heavy metals, lighting and bottling, to computer systems, cryogenic pumps and ethane cracking.[27]

The region's manufacturing history and infrastructure, along with its many universities and research centers, position it well to take advantage of continued innovation in advanced manufacturing capabilities. CMU's National Robotics Engineering Center and its Advanced Robotics for Manufacturing Center in Hazelwood Green focus closely on how to incorporate robotics systems into manufacturing. Meanwhile, Pitt's Ansys Additive Manufacturing Lab focuses on additive manufacturing processes of metal, polymer and composite materials.[28] The concentration of these innovative manufacturing techniques and approaches has, in turn,

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[24] "Richard King Mellon Foundation Unveils 10-Year Strategic Plan" News (Richard King Mellon Foundation, January 27, 2021), https://www.rkmf.org/news_posts/richard-king-mellon-foundation-unveils-10-year-strategic-plan.

[25] "CMU, R.K. Mellon Foundation Announce Historic Partnership," News (Carnegie Mellon University, May 20, 2021), https://www.cmu.edu/news/stories/archives/2021/may/rkm-grant.html.

[26] "Carnegie Mellon, Heinz Endowments Launch Initiative to Promote Economic Empowerment, Address Inequities in Pittsburgh Region," News (Carnegie Mellon University, April 28, 2021), http://cmu.edu/news/stories/archives/2021/april/center-for-shared-prosperity.html.

[27] "The creators, innovators & inventors make here," Pittsburgh Region, accessed June 29, 2021, https://pittsburghregion.org/wp-content/uploads/2021/04/AdvMfg_FINAL.pdf.

[28] Ibid.

attracted new investment and companies to the region eager to take advantage of these assets. There is perhaps no better example of the kind of advanced manufacturing clusters that could grow in Southwest Pennsylvania given its existing infrastructure than Neighborhood 91 at the Pittsburgh International Airport campus. We discuss how the ecosystem mobilized for that project in the next section of the chapter.

(7) Energy and utilities

Lastly, a key part of the region's diversified economic activity is the utilization of its natural resources, today most prominently the Marcellus Shale. While a handful of coal mines remain open in the southwest corner of the state, natural gas has taken over as the primary driver of the region's energy economy. This is especially true in the more rural counties surrounding Pittsburgh, where the region's gas supply powers much of the east coast. Virtually all major fossil energy companies are present in the region, although most are headquartered elsewhere. A major, multi-billion-dollar new ethane cracker plant is currently being built by Shell in Beaver County on property that was once a steel mill.[29] The company plans to take advantage of its proximity to the shale resource in order to streamline plastics manufacturing processes.

There are solar and wind companies in the region, although they operate on a much smaller scale than the fossil energy firms and are less visible in the regional ecosystem. Nevertheless, the region's diverse natural resources, landscape and inland location are all important assets to take into account when trying to find ways to get out in front of the next energy transition.

Asset 2: Planning and development capacity

In addition to a diversified economy, Southwest Pennsylvania's institutional ecosystem also features a dense network of regional, state, and local planning and economic development organizations. They range from major federal agencies, such as the Appalachian Regional Commission, to local level community development corporations and industrial development authorities. In the greater Pittsburgh area, there are 144 local community development corporations with combined assets of $81 million.[30]

Throughout the region as a whole, these sorts of planning organizations are responsible for devising economic development strategies, finding ways to finance new projects, and attracting regular investments. We view them as vital assets for the forthcoming energy transition because of their ability to identify local needs, engage with their communities, and find innovative solutions to pressing challenges. In the table below, we highlight several of these organizations at the regional, state and local levels. This is not an exhaustive list, but rather a way to illustrate the kinds of planning activities already happening in the region.[31]

Table: Planning and Economic Development Groups

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[29] Thomas Francis "A Community Ripe for Revival," Shell Global (Shell, September 10, 2018), https://www.shell.com/inside-energy/pittsburgh-pennsylvania-beaver-county.html.

[30] "Pittsburgh community development corporations," Cause IQ (Nonprofit Metrics LLC, 2021), accessed June 29, 2021, https://www.causeiq.com/directory/community-improvement-organizations-list/pittsburgh-pa-metro/.

[31] Industry, trade, and professional associations are a part of these conversations, too, however they are not the primary focus of our analysis here.

Multi-State or Federal	**Pennsylvania**	**Regional**	**Local**
Appalachian Regional Commision Great Plains Institute Midwest Regional Carbon Initiative Marcellus Shale Coalition US Economic Development Administration Reimagine Appalachia Great Lakes Metro Chambers Coalition The Progress Fund TriState Energy and Advanced Manufacturing (TEAM) Consortium BlueGreen Alliance	Southwestern Pennsylvania Commission Southern Alleghenies Planning and Development Commission Dept of Community and Economic Development (DCED) Keystone Innovation Zones (DCED) Pennsylvania Industrial Development Authority Regional Industrial Development Corporation Team Pennsylvania Keystone Economic Development and Workforce Command Center Pennsylvania Economic Development Association	Allegheny Conference on Community Development County-level economic development commissions Sustainable Pittsburgh Foundations	Industrial Development Authorities (IDAs) and Industrial Development Corporations (IDCs) Community Development Corporations (CDCs) Mon Valley Alliance Fay-Penn Economic Development Council Pittsburgh Economic & Industrial Development Corporation Economic Growth Connection of Westmoreland Pittsburgh Technology Council

Asset 3: Financial resources

There is a wealth of financial capital across the many economic activities and planning groups in the Southwest Pennsylvania ecosystem. Potential access to investments from well-endowed universities, research centers, venture capitalists, foundations, nonprofits, and economic development groups sets the region apart from other former industrial centers. As strategies and plans for the energy transition come together, these financial assets will be critical for funding new industries and investing in workforce development.

Asset 4: Good hardware

Lastly, thanks to its industrial roots, Southwest Pennsylvania has a well-organized infrastructure system to support a diverse set of economic activities. Four interstate highways intersect the region, along with over 1,000 miles of freight railway.[32] An extensive inland port and international airport connect the region to the rest of the country and world. The Southwestern Pennsylvania Commission also recently launched a new regional transit plan called "SmartMoves" that takes into account the technological, environmental, and economic changes already taking place in the region. The plan is designed as a chance to connect communities in the southwest corner of the state by increasing physical mobility via public transit and virtual connectivity through expanded broadband access. It outlines investments in highways, roads, and trails that would form a more integrated transportation system.[33] Following through with this plan would present new possibilities for regional development.

Connections and gaps in the regional ecosystem

Overall, Southwest Pennsylvania's diversified ecosystem is a valuable asset and offers many opportunities for planning around the energy transition. First, the involvement of multiple stakeholders suggests there will likely be several pathways for workers and industries to move beyond traditional fossil fuel approaches. The diverse industry landscape in the region can help attract future investments and provide the foundation for building out existing capabilities. In addition, current stakeholders are committed to the region's success and share a deep commitment to the area, providing a basis upon which to overcome differences and build out relationships. Having numerous players also means there will be possibilities for new collaborations to emerge, as was the case with CMU and Pitt in the 1980s. Today, these partnerships represent some of the strongest connections between institutions in the ecosystem.

Nevertheless, there are some challenges that come with a more diverse and diffuse institutional landscape. To start, it will be difficult to ensure that everyone who wants to be at the table has an invitation. Previous transition processes were very Pittsburgh-centric and did not effectively incorporate voices from the surrounding rural counties. Leaders involved in the planning process will have to engage in outreach efforts and build partnerships with a diverse set of stakeholders.

This will be especially important given that the rural counties in Southwest Pennsylvania are the ones closest to the energy and manufacturing industries that will be hardest hit by a transition away from fossil fuels. On top of that, their economies are generally not as diversified as the Pittsburgh metro area's and are further removed from rising tech and venture capital investments. Of particular note when it comes to industry support is the fact that while there is plenty of venture capital for ideas in the region, there is less for the development of new manufacturing,

[32] "Market Access," Pittsburgh Region, accessed June 29, 2021, https://pittsburghregion.org/doing-business-in-pittsburgh/market-access/.

[33] "Smart Moves for a Changing Region Summary Report," Southwestern Pennsylvania Commission, accessed June 29, 2021, https://www.spcregion.org/wp-content/uploads/2020/02/SM_Plan.pdf.

which would benefit blue collar workers. Attracting more diverse investments to the area--and especially to rural counties most impacted by a transition away from fossil fuels--should be a high priority for regional planning.

The commonwealth already appears to be working towards this end. In 2020, the Department of Community and Economic Development launched a venture capital program to, "invest primarily in lower middle-market manufacturing and business service companies," in communities that do not traditionally attract those kinds of investments.[34] This represents an important step forward toward filling the gap in capital flows across communities and accelerating new industry development.

Tackling the distribution of capital flows would also help address the broader challenge of how to diversify rural economic development. The Appalachian Regional Commission often invests in small businesses, nonprofits, and workforce training in rural communities in the region, along with foundations such as Benedum. However, it remains difficult to attract continuous investments for new ventures and redevelopment in smaller communities. One of the limitations is scale--it is challenging to develop projects on a small scale without appropriate resources. Regional planning organizations at the local level are often committed to solving this issue, however they also face their own capacity limitations.

While Southwest Pennsylvania has a rich network of planning organizations at various governmental levels, it is not obvious to what extent they coordinate amongst themselves to achieve region-wide goals. For example, how engaged are the regional planning commissions, such as county planning commissions, the Southwestern Pennsylvania Commission and the Appalachian Regional Commission with one another on planning for the energy transition? There appears to be a degree of fragmentation across these groups. When it comes to crafting a new blueprint for the region's future in a low carbon energy environment, it will be beneficial to increase coordination among various economic development organizations, align on a shared vision, and streamline planning processes. This would also help, in part, with the need to build organizational capacity in smaller towns and engage more with rural communities in the energy transition.

Lastly, it is notable how disconnected renewable energy firms are from other major players in the institutional ecosystem, especially compared with fossil energy and utility companies. This may be due partly to the fact that many of the wind and solar companies are based outside of the U.S. However, if they are to play a key role in the energy transition in Southwest Pennsylvania, they will need to get more involved in the economic, political, and community fabric of the region.

In sum, the region overall is rich in the kinds of resources and infrastructure needed to weather and thrive in yet another major economic transition. However, it will have to contend with ensuring a more even distribution of resources and development across Pittsburgh and rural communities, and more effective coordination across planning organizations.

[34] "New State Funding Will Support Venture Capital Investments in Pennsylvania Businesses," PA DCEP (Pennsylvania Department of Community and Economic Development, January 22, 2020), https://dced.pa.gov/newsroom/new-state-funding-will-support-venture-capital-investments-in-pennsylvania-businesses/.

Insights from three innovative regional developments

We turn next to a brief discussion of three projects that demonstrate how the regional ecosystem can be activated to incentivize new developments.

Penn State New Kensington

Situated to the northeast of Pittsburgh in Westmoreland County is the city of New Kensington, a prototypical rust belt town that was the birthplace of the Alcoa Corporation. The city is like many others that surround Pittsburgh and Allegheny County-- it has experienced population loss and shrinking investments in local infrastructure and economic activity. However, it happens to be home to one of Penn State University’s twenty-one branch campuses, and New Kensington’s Chancellor Dr. Kevin Snider saw this as an opportunity to transition the city from the rust belt to the digital belt. He believed fostering innovation could be a way to help prepare students for a twenty-first century workforce, while also revitalizing the city’s downtown.

In order to do so, Snider spent several years building relationships with a diverse set of actors in the local community, including political leaders, chambers of commerce, community groups, school districts, foundations, corporations, and other local colleges. He listened to their needs and interests, while sharing with them his vision to build a coworking space and “corridor of innovation” to foster entrepreneurship in New Kensington. The goal was to establish, “a living, learning laboratory for developing innovative solutions to the challenges faced by small rust belt towns.”[35] The plan attracted investments to renovate parts of the city’s downtown to build the coworking space and revitalized corridor. Today, the coworking space, called “The Corner” is a multifunctional work space and construction is underway for “The Digital Foundry,” a state-of-the-art innovation and manufacturing lab. The recent redevelopments have attracted new companies and small businesses to the area. The Penn State New Kensington experience highlights how educational institutions, business groups, foundations, and community leaders can come together to diversify and revitalize economic development outside of major cities.

Hazelwood Green

The redevelopment of Pittsburgh’s Hazelwood section along the Monongahela River is an excellent example of the way former industrial brownfield sites can be remediated and repurposed for public parks, renewable energy sites, and advanced manufacturing facilities. The Hazelwood site was once home to the Jones & Laughlin Steel Company and became a major industrial hub during World War II.[36] The plants closed in the late 1990s as a result of the steel industry collapse. In 1999, a nonprofit organization called Riverlife created a redevelopment plan for Pittsburgh’s waterfronts. Named “Three Rivers Park,” the plan envisioned a 15-mile stretch of industrial redevelopment and green space.[37] Since the strategic plan’s launch in 2000, there has been $4.2 billion in investment in the downtown riverfront area.

Hazelwood Green constitutes a fraction of these investments. A group of foundations got together to purchase the property with a commitment to using the site for sustainable community

[35] Thom, Elizabeth, and Stephen Ansolabehere. Interview with Kevin Snider. April 26, 2021.

[36] “The site’s history,” Hazelwood Green, accessed June 29, 2021, https://www.hazelwoodgreen.com/thehistory.

[37] About Riverlife,” Riverlife, accessed June 29, 2021, https://riverlifepgh.org/about-us/.

development. After environmental remediation and several rounds of neighborhood plans, the site began attracting investments from CMU and Uber, who used part of the land as a test track for self-driving cars. Today, the 178-acre site is divided into three districts, each with its own development purpose. In the Mill District, continued funding from RK Mellon has encouraged additional investments to build CMU's Advanced Robotics for Manufacturing Institute and Manufacturing Futures Initiative, which are housed in the former steel company's historic Mill 19 building. The River District features residential and business developments, while a good portion of the Flats District is dedicated to open public space. Together, these riverfront developments demonstrate how a community vision can come to life with sustained investments and stakeholder buy-in.

Neighborhood 91

The third example is Pittsburgh International Airport's Innovation Campus, called Neighborhood 91. The 200-acre campus, which is situated adjacent to the airport's airfields, is home to a growing additive manufacturing hub. At the hub's core is a group of 3D printing supply chain businesses who aim to take advantage of proximity to the airport for seamless transport, research and grads from Pitt, easy access to AM components, onsite production of new and recycled Argon, and a microgrid powered by local natural gas resources.[38] The development provides an excellent blueprint for how the region can leverage its natural resources, manufacturing legacy, skilled workforce, affordable land for development, and connections to research universities to foster innovative approaches to manufacturing and economic development.

How the ecosystem could engage our proposed developments

With these insights in mind, we now turn to how the Southwest Pennsylvania ecosystem may coordinate to advance the proposed energy-related developments we put forward in this report.

Development of CCUS pipeline infrastructure

Southwest Pennsylvania is ideally suited for the creation of a carbon capture innovation hub. The region has the natural resources, existing industry, workforce, and research capacity--with NETL, CMU, Pitt, and PSU--to develop and deploy carbon capture, storage, and utilization technologies. An innovation hub in Southwest Pennsylvania focused on carbon management would help maintain U.S. leadership in the emerging CCUS industry and would stimulate growth locally. If Pennsylvania chooses to develop CCUS, now is the time to devise a systematic plan to invest in the core infrastructure it requires. Deployment of CCUS will necessitate the construction of major pipelines to connect energy and industrial facilities with storage sites. It will also require construction and maintenance of underground CO2 storage facilities. Such plans will need to be set in motion by local, state, regional, and federal planning agencies.

Remediation

Several federal, state and local groups will need to coordinate strategies to address issues associated with environmental remediation. To start, federal support will be essential for

[38] "The Neighborhood: Neighborhood 91's Pittsburgh Innovation Campus," Neighborhood 91 (Neighborhood 91, May 26, 2021), https://neighborhood91.com/the-neighborhood-concept/.

guaranteeing reliable funding sources. The PA DEP should maintain a state approved list of contractors and a database of remediation sites, among other related initiatives. The PA DCED could be utilized to expand remediation playbooks, along with the help of other organizations in the state, such as the BlueGreen Alliance. The Marcellus Shale Coalition and the Pennsylvania Public Utility Commission could unite to sponsor a certified gas program. Meanwhile, leaders in remediation technologies, such as PSU and NETL, should work toward improved technologies to seal wells with advanced monitoring sensors. Lastly, unions should mobilize to ensure that wages and benefits in remediation remain high enough to support workers and their families.

Sustainable development

A cohesive regional strategy is also needed to support more sustainable development in the region. The Allegheny Conference and Southwestern Pennsylvania Commission could work together to mobilize targeted, direct investments; workforce programs with more hands-on training opportunities and programming for certification in NABCEP, EPA, and electrician licensing; and alignment in industry-educational efforts to build out traditional manufacturing with clean or carbon management, such as with CCUS and combined heat and power.

Workforce development

Local community colleges, county governments, and planning commissions are bracing for the effects the energy transition will have on workers. Educational institutions, governments, and NGOs will need to develop comprehensive regional strategies to improve workforce training. The most successful models are those that work with industry and offer people skills training that goes beyond just a specific job, such as general communication and teamwork skills. The Tristate Energy Consortium (TEAM) offers a good example for building workforce development programs and partnerships.

Recommendations summary

In summary, we see four ways to engage in successful regional and economic development in order to get out in front of the energy transition:

First, Capacity Building

There is a lot of human energy and social capital for economic development, however smaller communities need assistance and a continuous flow of resources to more fully take advantage of these assets. Targeted efforts to encourage broad engagement in the continued health of local communities is essential to maintaining vital towns and cities in the region, especially as the industrial base transitions from traditional fossil fuel activities.

Second, Resource Deployment

The region has access to an enormous amount of capital, but it needs to be more evenly distributed across Pittsburgh and surrounding communities. Reducing the physical and virtual distance between these communities with improved transit and broadband would help bridge this gap.

Additionally, local communities need support in realizing their economic development plans. The Commonwealth of Pennsylvania provides resources through industrial development authorities and economic development tax credits. However, the PA DECD should also consider ways to supplement those funds in communities that will be hardest hit if there is a continued transition away from coal and, eventually, from natural gas.

Third, Coordination

There are hundreds of planning groups and organized interests in the region, but they need to be able to align and streamline their strategies to address the pressing demands of the energy transition. We see a much larger role for organizations such as the Southwestern Pennsylvania Commission and the Allegheny Conference as venues for coordinating groups and devising shared goals.

Fourth, Champions

All proposed developments and strategies require champions who can engage in activities to build partnerships and attract investments to the region. Political and community leaders need to take on more direct roles to ensure that Southwest Pennsylvania is able to take advantage of the opportunities the energy transition presents. Doing so would ensure the region maintains its position as a national and global leader in energy, technology, and manufacturing.

Chapter 3

Regional Remediation Opportunities for a Job Driven Cleaner Environment

Alison Hu, Dustin Tingley

Introduction

Pennsylvania, home to a recent boom in natural gas production as well as a largely legacy coal and oil industry, faces a range of environmental problems. Chief among them are contaminated soil and water in part due to years of fossil fuel extraction that was unregulated or under-regulated. Recently, more attention has been paid to another problem: leakage of methane from wells. As a result, Pennsylvania and other states in the region such as West Virginia, routinely score very poorly compared to other states on a variety of environmental metrics.

Fortunately, this does not have to be the case. Pennsylvania has made regulatory progress in the past, there is a substantial desire among many currently operating in the fossil fuel sector to improve the situation (Pennsylvania is the second-largest producer of gas in the nation),[39]ample opportunities for market based approaches to the problem, and there exists a combination of

[39] "Frequently Asked Questions (FAQs) - U.S. Energy Information Administration (EIA)," U.S. Environmental Information Agency (Environmental Information Agency), accessed June 29, 2021, https://www.eia.gov/tools/faqs/faq.php?id=46&t=8.

ingenuity and a hard working ethic that could turn this situation around. In this chapter, we focus on the methane and abandoned or orphaned well problem, as well as the myriad challenges associated with soil and water contamination. While at times related, each poses unique challenges requiring different solutions.

Over 150 years of oil and gas production has resulted in wells littered across the landscape, many of which release methane and other chemicals into the region's air, soil, and water.[40] Methane is of particular concern. It comprises 10% of greenhouse gas emissions, but it is much more potent than carbon dioxide.[41] Methane absorbs eighty-six times more heat than carbon dioxide in the span of two decades and over twenty-five times more in the span of a century.[42] Methane release is a major contributor to global warming. Human activities account for over 25% of atmospheric releases of methane,[43] and energy-related activities are the second-largest contributor to methane emissions in the United States.[44] The rate of methane emissions is accelerating.[45]

Actively utilized wells have methane leakage problems, especially from older operations.[46] These emissions can be dealt with using appropriate approaches, including standards and regulations and tax incentives. These practices do generate costs for companies, but the benefits can be sufficient to make remediation cost-effective. The broader benefits to society of responsible extraction are even more substantial, given the greenhouse potential of methane and health effects of other pollutants.[47]

Abandoned and orphaned natural gas wells pose a larger and more difficult problem. Abandoned wells are wells that have not been in active production for a certain period of time and may be plugged, unplugged, or improperly plugged. Orphaned wells are a subset of abandoned wells whose legal owner cannot be found. Wells become orphaned for a variety of reasons – most

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[40] Peter Moskowitz, "The Hidden Leaks of Pennsylvania's Abandoned Oil and Gas Wells," *Guardian News and Media*, September 18, 2014), https://www.theguardian.com/environment/2014/sep/18/pennsylvania-abandoned-fracking-wells-methane-leaks-hidden.

[41] "Overview of Greenhouse Gases," EPA (Environmental Protection Agency, April 14, 2021), https://www.epa.gov/ghgemissions/overview-greenhouse-gases.

[42] "Gas Companies Are Abandoning Their Wells, Leaving Them to Leak Methane Forever," *Bloomberg*, accessed June 29, 2021, https://www.bloomberg.com/news/features/2020-09-17/abandoned-gas-wells-are-left-to-spew-methane-for-eternity.

[43] J. K. Shoemaker et al., "What Role for Short-Lived Climate Pollutants in Mitigation Policy?," *Science* 342, no. 6164 (December 2013): pp. 1323-1324, https://doi.org/10.1126/science.1240162. Importantly, work on reducing methane should not come at the expense of efforts to reduce C02.

[44] "Overview of Greenhouse Gases," EPA (Environmental Protection Agency, April 14, 2021), https://www.epa.gov/ghgemissions/overview-greenhouse-gases#methane.

[45] Adam Vaughan, "Earth's Methane Emissions Are Rising and We Don't Know Why ," *NewScientist*, May 24, 2019, https://www.newscientist.com/article/2204466-earths-methane-emissions-are-rising-and-we-dont-know-why/.

[46] Hiroko Tabuchi, "Here Are America's Top Methane Emitters. Some Will Surprise You," *The New York Times*, June 2, 2021, https://www.nytimes.com/2021/06/02/climate/biggest-methane-emitters.html.

[47] Leakage can also happen during extraction and shipment of natural gas in these cases.

often when the owners of a well go out of business.[48] Neglect typically results in leakage of pollutants into the atmosphere and groundwater. With no one liable for an abandoned well, responsibility for remediation to prevent further pollution becomes difficult to establish.

In addition to methane leakage, fossil fuel activities can pollute land and water. Coal mining practices, abandoned coal mines, some of which date to colonial times, coal-related industries, such as iron and steel production, and coal-fired power plants have all led to soil and water contamination in the region.

Of particular concern are abandoned mine lands (AML). These lands were once used for coal mining but were not properly reclaimed. Water that flows through AMLs picks up chemicals found in coal that when mixed with water creates toxic solutions and can lead to clogged streams and polluted runoff.[49] In turn, this increases the chance of flooding in regions with AMLs. Rising acidity levels in waterways from acid mine drainage (AMD) also leads to imbalances in, or completely destroys, biodiversity in aquatic ecosystems and their surrounding communities.[50] Abandoned coal mines also create other safety and environmental issues. For example, underground mine fires, formed from coal and waste remains lit either naturally or by human activity, are a major source of greenhouse gas emissions and air pollution.

Addressing these problems is not only an environmental necessity but also an economic opportunity for a region that has relied heavily on extractive fossil fuel industries. Reclaimed lands can be used for agriculture, other industrial uses, or to attract tourism. Brownfield sites, such as Washington's Landing, can become promising locations for new industrial developments or urban redevelopment.

Scope of the problem

Abandoned or orphaned wells account for an estimated 7 to 10% of Pennsylvania's methane emissions.[51] The amount each well emits is not uniform but varies greatly based on a number of factors, including well depth, age, and proximity to other wells.[52] Although plugged wells may

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[48] Ted Boettner, "Repairing the Damage from Hazardous Abandoned Oil & Gas Wells" Ohio River Valley Institute (Ohio River Valley Institute, April 2021), https://ohiorivervalleyinstitute.org/wp-content/uploads/2021/04/Repairing-the-Damage-from-Hazardous-AOG-Wells-Report.pdf.

[49] Eric Dixon, "Repairing the Damages" Ohio River Valley Institute (Ohio River Valley Institute, April 2021), https://ohiorivervalleyinstitute.org/wp-content/uploads/2021/04/Dixon-AML-paper-4.11.21-1.pdf.

[50] Ad Crable and Will Parson, "Orange Water, Dirty Air: What Will It Take to Clean up Abandoned Mine Land in the Chesapeake Watershed?," *Bay Journal Media*, March 8, 2021, https://www.bayjournal.com/news/energy/orange-water-dirty-air/article_dd947c74-7b66-11eb-81e3-232de92f42f3.html.

[51] Mary Kang et al., "Direct Measurements of Methane Emissions from Abandoned Oil and Gas Wells in Pennsylvania," *Proceedings of the National Academy of Sciences* 111, no. 51 (August 2014): pp. 18173-18177, https://doi.org/10.1073/pnas.1408315111. "The Hidden Leaks of Pennsylvania's Abandoned Oil and Gas Wells," *Guardian News and Media*, September 18, 2014, https://www.theguardian.com/environment/2014/sep/18/pennsylvania-abandoned-fracking-wells-methane-leaks-hidden.

[52] Mary Kang et al., "Direct Measurements of Methane Emissions from Abandoned Oil and Gas Wells in Pennsylvania," *Proceedings of the National Academy of Sciences* 111, no. 51 (August 2014): pp. 18173-18177, https://doi.org/10.1073/pnas.1408315111.

still emit methane, unplugged wells in general are much higher emitters and are the main contributors to associated environmental problems. In fact, as little as 10% of all wells, deemed "super emitters", contribute over three-quarters of total greenhouse gas emissions from extractive activities.[53]

Methane can also contaminate water. Wells may penetrate aquifers, underground layers of rock that contain groundwater, or oil and gas reservoirs, and carry contaminants throughout the surrounding area.[54] Leakages from unplugged wells may seep into groundwater sources.[55] Processes involved in hydraulic fracturing, when carried out in close proximity to abandoned wells, may only exacerbate the groundwater pollution problem.[56]

The scope of the problem is at once immense and uncertain. There are around 8,700 documented orphan wells, but several estimates suggest that there are over 500,000 abandoned or orphaned wells in Pennsylvania.[57] Well drilling in Pennsylvania commenced over 100 years prior to the establishment of permit requirements in 1955.[58] Records for wells drilled in the 19th century are long lost, and many wells were drilled in the 20th century under minimal regulatory oversight. The total cost of plugging 500,000 wells could exceed $18 billion. [59] Typical estimates for the

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[53] Caulton, Dana R., Jessica M. Lu, Haley M. Lane, Bernhard Buchholz, Jeffrey P. Fitts, Levi M. Golston, Xuehui Guo et al. "Importance of superemitter natural gas well pads in the Marcellus shale." Environmental science & technology 53, no. 9 (2019): 4747-4754.

[54]R. Kubichek et al., "Identifying Groundwater Threats from Improperly Abandoned Wells "(University of Wyoming), accessed June 30, 2021, https://engg.ksu.edu/hsrc/97Proceed/General2/identifying.html.

[55]Kate Galbraith, "Abandoned Oil Wells Raise Fears of Pollution," *The New York Times*, June 8, 2013, https://www.nytimes.com/2013/06/09/us/abandoned-oil-wells-raise-fears-of-pollution.html.

Nicholas Kusnetz, "Deteriorating Oil and Gas Wells Threaten Drinking Water Across the Country," *Scientific American*, April 4, 2011, https://www.scientificamerican.com/article/deteriorating-oil-gas-wells-threatening-americas-drinking-water/.

[56] One person we interviewed argued that unplugged wells pose a greater liability to groundwater contamination than modern hydraulic fracturing.

[57] "Defining the Scope of the Legacy Well Problem in Pennsylvania and Developing Collaborative Solutions" Pennsylvania Department of Environmental Protection (DEP, May 16, 2018), http://www.marcellus.psu.edu/news-events/docs-pdfs/workshop-2018-05-16/spelepko-psu-o-and-a-workshop-share-2018-05-16.pdf. Mike Lee, "Millions of abandoned wells spark climate, safety fears," *E&E News*, May 20, 2019, https://www.eenews.net/stories/1060364121. "Idle and Orphan Oil and Gas Wells: State and Provincial Regulatory Strategies" Interstate Oil & Gas Compact Commission (IOGCC, 2019), https://iogcc.ok.gov/sites/g/files/gmc836/f/2020_03_04_updated_idle_and_orphan_oil_and_gas_wells_report_0.pdf.

[58]"Defining the Scope of the Legacy Well Problem in Pennsylvania and Developing Collaborative Solutions" Pennsylvania Department of Environmental Protection (DEP, May 16, 2018), http://www.marcellus.psu.edu/news-events/docs-pdfs/workshop-2018-05-16/spelepko-psu-o-and-a-workshop-share-2018-05-16.pdf. Scott Detrow, "Across Pa., Abandoned Wells Litter The Land," *NPR*, November 13, 2012, https://www.npr.org/2012/11/13/164139865/across-pa-abandoned-wells-litter-the-land.

[59]The national average cost for plugging a well is estimated to range from $24,000 to $48,000. An average of $36,000 per well times 500,000 equals $18 billion. Pennsylvania wells have historically cost closer to $80,000 to plug. Daniel Raimi, Neelesh Nerurkar, and Jason Bordoff, "Green Stimulus for Oil and Gas Workers: Considering a Major Federal Effort to Plug Orphaned and Abandoned Wells," *Resources for the Future*, July 20, 2020,

effectiveness of a plugging job range from 50 to 100 years, but neither states nor the federal government have regulations in place to enforce methane emission monitoring.[60]

These challenges are not unique to southwest Pennsylvania. There are an estimated two to three million abandoned wells around the country,[61] emitting over 280 kilotons of methane annually. [62] That is the equivalent of the emissions from 16 million barrels of oil, in 2018. Many states face environmental challenges similar to Pennsylvania due to methane leaks from abandoned wells.[63]

Methane releases from abandoned wells are not the only environmental issue facing the region. Earlier eras of coal extraction have created a range of land- and water-based environmental problems. Like oil and gas drilling, most coal mining occurred in eras with no environmental regulation. In 1977, Congress passed the Surface Mining Control and Reclamation Act (SMCRA), the first formal legislation to address the environmental effects of mining.[64]

Mine reclamation is particularly important for Pennsylvania. Today, one-third of the nation's abandoned mine lands are located in Pennsylvania.[65] In the past, many coal mining operations would simply move on after exhausting a coal seam. Soil that had been removed was not put back in place. Runoff from these areas pollutes one in three of Pennsylvania's streams. Over 5,500 miles of waterways are contaminated by acid mine drainage, which negatively affects

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https://www.rff.org/publications/reports/green-stimulus-oil-and-gas-workers-considering-major-federal-effort-plug-orphaned-and-abandoned-wells/.

[60] "Gas Companies Are Abandoning Their Wells, Leaving Them to Leak Methane Forever," *Bloomberg*, accessed June 29, 2021, https://www.bloomberg.com/news/features/2020-09-17/abandoned-gas-wells-are-left-to-spew-methane-for-eternity.

[61] Naveena Sadasivam, "Dying oil companies' parting gift: millions in cleanup costs," *Grist,* March 2, 2021, https://grist.org/energy/abandoned-oil-wells-texas-railroad-commission/. Nichola Groom, "Special Report: Millions of abandoned oil wells are leaking methane, a climate menace," *Reuters,* February 28, 2020, https://www.reuters.com/article/us-usa-drilling-abandoned-specialreport/special-report-millions-of-abandoned-oil-wells-are-leaking-methane-a-climate-menace-idUSKBN23N1NL.

[62] Nichola Groom, "Special Report: Millions of abandoned oil wells are leaking methane, a climate menace," *Reuters,* February 28, 2020, https://www.reuters.com/article/us-usa-drilling-abandoned-specialreport/special-report-millions-of-abandoned-oil-wells-are-leaking-methane-a-climate-menace-idUSKBN23N1NL.

[63] "Gas Companies Are Abandoning Their Wells, Leaving Them to Leak Methane Forever," *Bloomberg*, accessed June 29, 2021, https://www.bloomberg.com/news/features/2020-09-17/abandoned-gas-wells-are-left-to-spew-methane-for-eternity.

[64] Eric Dixon, "Repairing the Damages" Ohio River Valley Institute (Ohio River Valley Institute, April 2021), https://ohiorivervalleyinstitute.org/wp-content/uploads/2021/04/Dixon-AML-paper-4.11.21-1.pdf.

[65] "PA's Mining Legacy and AML," Department of Environmental Protection (DEP), accessed June 30, 2021, https://www.dep.pa.gov/Business/Land/Mining/AbandonedMineReclamation/AMLProgramInformation/Pages/PA's-Mining-Legacy-and-AML.aspx. Kara Holsopple, "'Downstream' documentary looks at pollution in Pennsylvania's water," *State Impact Pennsyvlania,* October 16, 2018, https://stateimpact.npr.org/pennsylvania/2018/10/16/downstream-documentary-looks-at-pollution-in-pennsylvanias-water/.

agriculture, recreation, wildlife, and human health.[66] One source estimates that Pennsylvania has forty active mine fires which are polluting the air and beyond.[67]

Across the nation, an estimated $11 to 21 billion is needed to clean up AMLs, with an additional $5 billion more to be added before 2050. At current fee levels set in place by the SMCRA, only $0.7b will be collected in the same time period, leaving a funding shortfall of over $25 billion. Pennsylvania is home to an estimated 41% of AMLs to be reclaimed.[68] As with abandoned oil and gas wells, these numbers are based on known sites and, thus, likely underestimate the true extent of the problem.

Finally, Pennsylvania's rich industrial history has left a legacy of contaminated sites. Examples range from former steel factories to tanneries. These "Brownfields" require extensive (and job-supporting) remediation. For example, a recent EPA grant of $3.7 million covers eight sites.[69]

Remediation Landscape

The landscape of remediation opportunities and approaches is vast. The activities include engineering, construction, and monitoring.

When a well goes out of production, it needs to be sealed in order to prevent liquid or gas leakages. Permanently sealing a well involves a series of steps, including removal of debris (e.g., collapsed walls), removal of well casing, and plugging with cement to separate geological layers. Properly plugging a well is key. A faulty job can lead to contamination of ground water as well as continued methane leakage. This process typically involves some heavy equipment, which can make access difficult in wooded and hilly regions. Water used in this process needs to be captured and remediated. In cases where there also exist coal seams, a vent (with flaring) is required to prevent explosions.

Many methods and technologies for water and soil remediation have been developed. They include removal, where contaminants are treated at the contamination site (in situ); separation,

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[66] "Abandoned Mine Lands," Western Pennsylvania Conservancy, October 4, 2019, https://waterlandlife.org/how-we-work/public-policy/abandoned-mine-lands/. Ad Crable, "Report: Third of PA waterways impaired?," *Bay Journal Media*, July 29, 2020, https://www.bayjournal.com/news/pollution/report-third-of-pa-waterways-impaired/article_e49334c2-d1cd-11ea-a9da-abf33a98e4d8.html#:~:text=One%20of%20every%203%20miles,detailing%20the%20state's%20latest%20assessment.&text=That's%2030%25%20of%20all%20stream,are%20considered%20unsafe%20for%20recreation "Pennsylvania's Surface Mining Control and Reclamation Act Funded Abandoned Mine Lands Program: Past, Present, and Future" Pennsylvania Department of Environmental Protection, accessed June 30, 2021, https://files.dep.state.pa.us/Mining/Abandoned%20Mine%20Reclamation/AbandonedMinePortalFiles/AML_Fact_Sheet_Final_2019_03_11.pdf.

[67] Ad Crable and Will Parson, "Orange Water, Dirty Air: What Will It Take to Clean up Abandoned Mine Land in the Chesapeake Watershed?," *Bay Journal Media*, March 8, 2021, https://www.bayjournal.com/news/energy/orange-water-dirty-air/article_dd947c74-7b66-11eb-81e3-232de92f42f3.html.

[68] Eric Dixon, "Repairing the Damages" Ohio River Valley Institute (Ohio River Valley Institute, April 2021), https://ohiorivervalleyinstitute.org/wp-content/uploads/2021/04/Dixon-AML-paper-4.11.21-1.pdf.

[69] "EPA Selects Eight Pennsylvania Projects to Receive $3.7 Million for Brownfields Cleanup and Assessment" *U.S. Environmental Protection Agency,* May 6, 2020, https://www.epa.gov/newsreleases/epa-selects-eight-pennsylvania-projects-receive-37-million-brownfields-cleanup-and.

where contaminants are physically removed from the soil or water and treated off site (ex situ); destruction, whereby contaminants are treated via chemical or biological processes (in or ex situ); and containment, where contaminants are immobilized and controlled (in situ).[70]

For water sources affected by acid mine drainage, alkaline materials are often inserted into the environment in an attempt to neutralize the contaminated land. Contaminated water may also be treated with treatment plants or artificial wetlands.[71]

In order to determine which strategy to use, sites are evaluated along a number of criteria such as feasibility, effectiveness, cost, extent of contamination, and physical properties.[72] The methods for cleaning up soil tend to be more straightforward than those addressing groundwater, in part because sources of groundwater pollution are much harder to trace.[73]

Causes of problems

Historical legacy

For most of its history, fossil fuel extraction in the region was largely unregulated. Wells date back all the way to the late 1800s. Few, if any, records exist on where older wells were located and what types of wells they were. This makes identification of wells that need to be plugged extremely difficult. And even if a well is identified, the lack of records on the type of well and other information helpful to successful capping are nonexistent.

Similarly, coal mining in the region was historically under-regulated with some operators having minimal environmental safeguards in place. On top of this, as mines became less productive or as coal became less competitive, mines were simply abandoned. This has generated the need for programs like the Abandoned Mine Reclamation Program in Pennsylvania.

Incentives

A reasonable principle is that "the polluter pays". Unfortunately, this has not always been the case. There are a range of incentive problems that create a situation where those profiting from extraction do not pay the costs of pollution.

One challenge starts at the very beginning of the extraction process. When a new well is to be drilled, companies are required to put down a bond. This bond is designed in part to cover the

[70] Florentina Anca Caliman et al., "Soil and Groundwater Cleanup: Benefits and Limits of Emerging Technologies," *Clean Technologies and Environmental Policy* 13, no. 2 (2010): pp. 241-268, https://doi.org/10.1007/s10098-010-0319-z.

[71] "What Can Be Done to Prevent or Clean up Acid Mine Drainage?," American Geosciences Institute, September 3, 2020, https://www.americangeosciences.org/critical-issues/faq/what-can-be-done-prevent-or-clean-acid-mine-drainage.

[72] For more information on the criteria: http://www.depgreenport.state.pa.us/elibrary/PDFProvider.ashx?action=PDFStream&docID=1420617&chksum=&revision=0&docName=03+SECTION+II%3A++ACT+2+REMEDIATION+PROCESS&nativeExt=pdf&PromptToSave=False&Size=3885410&ViewerMode=2&overlay=0

[73] Urban regions also face a range of challenges including subsurface spills and heavy metal contamination.

costs of properly closing down the well once production ends. However, for this incentive scheme to work, the bonds need to be appropriately priced. Current bonding requirements are not appropriately priced, with actual cost of plugging more than ten times the bond price.[74] This is not just a state problem. The bonding requirements set by the Bureau of Land Management for federal lands have not been adjusted since the 1950s and 1960s to account for inflation.[75] Addressing this concern is important, especially if federal funding for well capping is seen as a bailout for fossil fuel producers.[76]

The Pennsylvania government has resisted efforts to reprice bonds, and some described this as a non-starter for the industry. Some argue that opposition to higher bonding requirements has traditionally been driven by conventional well owners and operators that do not require hydraulic fracturing stimulus funds, especially firms that have been buying older, less productive wells. Others are slightly more optimistic, suggesting that as more capitalized firms are established there will be more willingness to change requirements. While some firms have made settlements to change the bonding requirements,[77] many indicate this is insufficient given the scope of the problem.[78]

Non-conventional operators are required (under the 2012 Act 13) to pay impact fees.[79] Counties can then apply to use these funds for a variety of purposes. One way these funds are distributed is through the Marcellus Legacy Fund (MLF). However, applications are rarely made to the MLF for the purposes of well capping. One estimate indicates that only 1% of these funds have gone towards plugging wells.

Another challenge is that individual property owners do not have incentives to report abandoned wells due to property value implications. If reporting an abandoned well is seen as a liability, then this can adversely impact property values. If there were a financial motivation (e.g., qualifying for offsets) property owners might be differently incentivized.

Related issues have also confounded water and soil remediation. In the coal industry, for example, low bonding requirements give companies little incentive to put in place environmental

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[74]Sophie Quinton, "Why 'Orphan' Oil and Gas Wells Are a Growing Problem for States" *The Pew Charitable Trusts,* July 9, 2018, https://www.pewtrusts.org/en/research-and-analysis/blogs/stateline/2018/07/09/why-orphan-oil-and-gas-wells-are-a-growing-problem-for-states.

[75]*Bureau of Land Management Should Address Risks from Insufficient Bonds to Reclaim Wells*, (Government Accountability Office, September 2019), https://www.gao.gov/assets/gao-19-615.pdf.

[76]Myles McCormick "Joe Biden's oil clean-up plan slammed as bailout for fossil fuels," *Financial Times,* April 13, 2021, https://www.ft.com/content/6d1707d0-7a35-4caa-861a-4c77cc9348e9.

[77]Laura Legere and Anya Litvak, "Pa. strikes well-plugging deal with largest conventional oil and gas operator in Appalachia," *Pittsburgh Post-Gazette*, March 11, 2019, https://www.post-gazette.com/business/powersource/2019/03/11/Diversified-Gas-and-Oil-abandoned-wells-plugging-settlement-Pennsylvania-DEP/stories/201903080130. Reid Frazier, "DEP, CNX reach $1.48 M settlement on abandoned wells," *State Impact Pennsylvania,* October 11, 2019, https://stateimpact.npr.org/pennsylvania/2019/10/11/dep-cnx-reach-1-48-m-settlement-on-abandoned-wells/.

[78] In addition, it appears that plugging costs are on the rise, especially as wells are being drilled to even further depths.

[79] Impact fees are calculated based on the age of the well and the price of natural gas. They are not calculated based on the actual extraction, a format that is common in other states.

guards for when their operations cease.[80] The current system of "self-bonding" allows companies to appease regulators while bypassing payments. Some may simply sell off their permits to other companies.[81] In West Virginia, a coal company with one hundred holdings filed for bankruptcy, leaving behind abandoned mines which the state estimates will cost more than $230 million to clean up.[82] Across the Appalachian region is an estimated 490,000 acres of mined land that have yet to be restored with substantial bonding shortfalls.[83]

Private sector driven development of brownfield sites, such as shuttered coal power plants, represents a substantial opportunity. Power of 32, an initiative led by the Allegheny Conference on Community Development, highlights the impact that such private investment can have on the revitalization of brownfield sites and creating future investment opportunities.[84] However, such investment faces uncertainties about the suitability of a site and any liabilities that might come with it. Putting this discovery work entirely on the shoulders of potential investors can be a major deterrent. As discussed below, developing site specific "playbooks" can help.

Limited government investments

Efforts to deal with this problem to date are limited compared to the size of the challenge. While the Pennsylvania Department of Environmental Protection (DEP) has put in place some programs,[85] legislative engagement has not led to an overhaul or any substantial progress, and funding allocated to well plugging has diminished. Currently, the DEP is capping ten to twelve wells per year with a budget of about $400,000 annually.[86] This contrasts with neighboring Ohio, which plugged 131 wells in 2020 and is budgeting $25 million annually.[87]

As a result, there is not a deep bench of established firms in the plugging and abatement business. One company, noting they are one of the largest in the region, has approximately 50 employees and plugging and abatement is only part of their business. Other existing or future

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[80] Peter Morgan, "The Coal Mining Industry Is Collapsing, and Communities Are at Risk from Abandoned Mines," *Sierra Club,* November 23, 2020, https://www.sierraclub.org/articles/2020/11/coal-mining-industry-collapsing-and-communities-are-risk-abandoned-mines.

[81] "Restoration and Renewal" *Appalachian Voices,* accessed June 30, 2021, https://appvoices.org/resources/AML-RAC/AML_RAC_report-2020-b-low-res.pdf.

[82] Mike Tony, "Appalachian coal mine reclamation bonding issues highlighted in new report," *Charleston Gazette-Mail,* January 14, 2021, https://www.wvgazettemail.com/news/energy_and_environment/appalachian-coal-mine-reclamation-bonding-issues-highlighted-in-new-report/article_8c4e607f-ccbc-5788-8b85-3769b116c1cb.html.

[83] "Restoration and Renewal" *Appalachian Voices,* accessed June 30, 2021, https://appvoices.org/resources/AML-RAC/AML_RAC_report-2020-b-low-res.pdf.

[84] Power of 32 – Site Development Fund, accessed July 1, 2021, https://p32sitefund.com/.

[85] "Well Plugging Program," Department of Environmental Protection (Department of Environmental Protection), accessed July 1, 2021, https://www.dep.pa.gov/Business/Energy/OilandGasPrograms/OilandGasMgmt/LegacyWells/Pages/Well-Plugging-Program.aspx.

[86] https://www.eenews.net/stories/1060364121; https://www.eenews.net/stories/1063430105

[87] "Odnr Seeking New Contractors To Plug Orphan Oil And Gas Wells," *Ohio Department of Natural Resources,* February 8, 2021, https://ohiodnr.gov/wps/portal/gov/odnr/discover-and-learn/safety-conservation/about-odnr/news/orphan-well-program-contractors-2021.

operators may be smaller and quality assurances will be a challenge given the distributed nature of the problem.[88]

Soil and water remediation face similar challenges. Like the scope of abandoned wells, the scale of brownfields and contaminated properties is difficult to quantify, but current estimates put Pennsylvania's land in need of remediation at over 287,000 acres.[89] Remediating a site, from the site assessment through the cleanup process and later monitoring, can be extremely costly. According to the Bureau of Abandoned Mine Reclamation, which oversees the Abandoned Mine Reclamation Program under the Pennsylvania DEP, it would take $15 billion and over a century of work to clean up the state's AMLs at existing levels of support.[90] Additionally, the current structure of fee collection is set to expire this year; if federal support is not renewed, the state will potentially lose $750 million of funding and over $28 million in economic benefits to communities that are impacted by AMLs.[91]

Even at current levels of funding, Pennsylvania has historically been a leader in this space, with the Pennsylvania DEP being one of the first state agencies in the US to establish funds directly targeted at brownfield remediation in 1995. The state's Land Recycling Program sets regulatory standards and provides liability protection and funding to private individuals, groups, or companies who would like to remediate a site.[92] Other incentives also spur voluntary cleanup, such as the Key Sites Initiative which employs state-funded contractors to assess remediation sites and associated costs, and encourage the reuse process.[93] Pennsylvania has been able to garner funding from federal sources as well.[94]

Nevertheless, sufficient economic resources for brownfield cleanup remains a challenge, as the current structure for tax incentives may not cover enough of the cleanup costs to properly

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[88] "Workshop: Analyzing the Challenges of Improperly Abandoned and Orphaned Wells," American Association for the Advancement of Science (American Association for the Advancement of Science), accessed July 1, 2021, https://www.aaas.org/events/workshop-analyzing-challenges-improperly-abandoned-and-orphaned-wells.

[89] Malaska, Greg, and Brian Wagner. Letter to Members of the Pennsylvania Delegation. "Re: Reauthorization of the Abandoned Mine Land Reclamation Program." PA Environment Digest, June 21, 2019. http://www.paenvironmentdigest.com/newsletter/default.asp?NewsletterArticleID=47028&SubjectID=.

[90] Ad Crable and Will Parson, "Orange Water, Dirty Air: What Will It Take to Clean up Abandoned Mine Land in the Chesapeake Watershed?," *Bay Journal Media*, March 8, 2021, https://www.bayjournal.com/news/energy/orange-water-dirty-air/article_dd947c74-7b66-11eb-81e3-232de92f42f3.html.

[91] "Pennsylvania's Surface Mining Control and Reclamation Act Funded Abandoned Mine Lands Program: Past, Present, and Future" Pennsylvania Department of Environmental Protection (Pennsylvania Department of Environmental Protection), accessed June 30, 2021, https://files.dep.state.pa.us/Mining/Abandoned%20Mine%20Reclamation/AbandonedMinePortalFiles/AML_Fact_Sheet_Final_2019_03_11.pdf.

[92] "Land Recycling Program," Pennsylvania Department of Environmental Protection (Pennsylvania Department of Environmental Protection), accessed July 1, 2021, https://www.dep.pa.gov/Business/Land/LandRecycling/pages/default.aspx.

[93] Charles Bartsch, *Analysis Of Pennsylvania's Brownfields Program,* (Brookings Institution Center on Urban and Metropolitan Policy, December 2003), https://www.brookings.edu/wp-content/uploads/2016/07/Bartsch.pdf.

[94] "EPA Selects Eight Pennsylvania Projects to Receive $3.7 Million for Brownfields Cleanup and Assessment" *U.S. Environmental Protection Agency,* May 6, 2020, https://www.epa.gov/newsreleases/epa-selects-eight-pennsylvania-projects-receive-37-million-brownfields-cleanup-and.

incentivize such efforts. In addition, as the state faces growing problems in other areas such as abandoned wells, more resources and staffing will be needed to sustain progress in this space.[95]

Limited discovery, monitoring and enforcement capacity relative to scope of problem

The location of many abandoned wells is not known due to the historical legacy. Furthermore, drilling over the past 120 years has taken place over broad swaths of land that in this region has a highly variable landscape. Finding and documenting these wells is challenging.

Even when a well is known (and even in use), estimating the extent of methane leakage and potential soil and groundwater contamination can be challenging. Solutions for detecting atmospheric release being explored in some regions[96] might not work as well in others. As discussed below, research on leak detection and repair (LDAR) technologies is an opportunity.

Unfortunately, the monitoring challenge can be even more vexing. Even if a well is plugged, it needs to be done correctly. Especially with older wells with little documentation, plugging can be challenging and requires deep background knowledge and even custom equipment to deal with well technologies multiple decades old. As such, even with well-intentioned plugging operations, the job can be difficult to complete and require resources for quality implementation.

If there were sufficient monitoring and enforcement capacity to evaluate the quality of well capping, poor quality well capping jobs could be reduced. However, at present there are around three inspectors in the Pennsylvania DEP that do this type of work. This number is greater than what exists in West Virginia. Given this, even if there was a large investment in well capping, there is at present insufficient state capacity to take advantage of such an investment fully and effectively. This is problematic because incorrectly capped wells could not only be ineffective at curtailing emissions, but they could exacerbate groundwater contamination.

Similarly, accurate assessments of the locations and extent of AMLs are nonexistent. As a result of inadequate funding, the initial federal inventory of AMLs was incomplete and remains incomprehensive, especially as more lands become abandoned every year.[97] Since the 1980s, resources in Pennsylvania have since shifted from discovery to reclamation.

As with plugged wells, ensuring remediated soil or water sites remain clean is challenging at current state capacities. Regulatory agencies have been slow to implement more automated, remote-sensing systems that would help to fill the need for manpower due to their still high costs.[98] As more mines become abandoned, sites are at greater risk of becoming contaminated again, leading back to the initial challenge of identifying the source of contamination.

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[95] Charles Bartsch, *Analysis Of Pennsylvania's Brownfields Program,* (Brookings Institution Center on Urban and Metropolitan Policy, December 2003), https://www.brookings.edu/wp-content/uploads/2016/07/Bartsch.pdf.

[96] "WTMS Description," West Texas Methane Showdown (West Texas Methane Showdown), accessed July 1, 2021, https://dept.ceer.utexas.edu/ceer/astra/showdown/description.cfm.

[97] Eric Dixon, "Repairing the Damages," Ohio River Valley Institute (Ohio River Valley Institute, April 2021), https://ohiorivervalleyinstitute.org/wp-content/uploads/2021/04/Dixon-AML-paper-4.11.21-1.pdf.

[98] "Challenges of Ground Water and Soil Cleanup," in *Innovations in Ground Water and Soil Cleanup from Concept to Commercialization* (Washington, D.C.: National Academy Press, 1997), pp. 18-41.

Economic Opportunities

Activities aimed at well discovery, capping, and monitoring would have a near term impact on job opportunities, especially for individuals with experience in the oil and gas industry. Estimates here range from 14,000 to as many as 120,000 jobs per 500,000 wells for capping, plus thousands more for discovery and monitoring.[99] A study conducted in Pennsylvania specifically estimates that with $1.2 billion in federal investment, over 9,000 jobs will be created annually in remediation, with over one-third of those coming from well capping.[100] Employment in the leak detection and repair space may be relatively high-paying as well.[101] Workers in the conventional well drilling space likely have many of the required skills--but also expertise and institutional knowledge--to work in this space, a point emphasized by a number of individuals interviewed.

Effective remediation is important for ensuring a positive public and political evaluation of the natural gas industry as a whole. Opposition to natural gas production based on environmental considerations has already led to bans on drilling in some regions.

Some firms seem to recognize that minimizing methane leakage makes good business sense. Indeed, a burgeoning industry involves firms going through certification processes that examine operations from extraction to shipment. Given a set of standards, third party assessors can evaluate operations which can often identify cost savings above and beyond environmental savings.[102] Recently, Chesapeake Energy, a major gas operator in the region, partnered with one such organization.[103] And a major utility company, Xcel, announced plans to purchase natural gas from a certified party.[104] As discussed below, these market based approaches can be coupled

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[99] Kelly and Jenny Rowland-Shea, "How Congress Can Help Energy States Weather the Oil Bust During the Coronavirus Pandemic," *Center for American Progress,* April 29, 2020, https://www.americanprogress.org/issues/green/reports/2020/04/29/484158/congress-can-help-energy-states-weather-oil-bust-coronavirus-pandemic/. Daniel Raimi, Neelesh Nerurkar, And Jason Bordoff, "The Potential for Plugging Abandoned Wells as Green Economic Stimulus," *Resources,* July 23, 2020, https://www.resources.org/common-resources/potential-plugging-abandoned-wells-green-economic-stimulus/.

[100] "ReImagine Appalachia blueprint creates 243,000 jobs in Pennsylvania," (ReImagine Appalachia, January 2021), https://reimagineappalachia.org/wp-content/uploads/2021/03/ReImagine-Appalachia_PeriBrief_PA_Jan2021.pdf.

[101] "It's a Win: Good Jobs and Cleaner Air," (Local Majority, August 26, 2020), https://www.localmajority.org/wp-content/uploads/2020/08/PA.OilandGas-Methane-Jobs.20200828.LAJ_.pdf.

[102] Examples of standards include the Equitable Origins (https://energystandards.org/), MiQ (https://miq.org/), Project Canary (https://www.projectcanary.com/responsibly-sourced-gas/) and the Natural Gas Sustainability Initiative (https://www.aga.org/about/investor-relations/natural-gas-sustainability-initiative-ngsi/).

[103] "Using real-time, continuous emissions monitoring at well pads, the pilot project aims to validate the high environmental standards by which natural gas is produced and that a *market exists for differentiated RSG products*." Project Canary, "Chesapeake Energy and Project Canary Announce Multi-Basin Responsibly Sourced Gas Partnership," *PR Newswire*, April 23, 2021, https://www.prnewswire.com/news-releases/chesapeake-energy-and-project-canary-announce-multi-basin-responsibly-sourced-gas-partnership-301267619.html.

[104] Iulia Gheorghiu, "Xcel opts for gas suppliers with lower methane emissions in Colorado," *Utility Drive*, May 13, 2021, https://www.utilitydive.com/news/xcel-looks-to-gas-suppliers-with-lower-methane-emissions-in-colorado/600108/

with a small surcharge system such that consumers can pay slightly more for natural gas that is produced in ways that minimize environmental damage due to extraction and shipment processes. These funds can then be distributed by the state for remediation of abandoned wells as well as other remediation opportunities that will provide quality jobs. Several stakeholders we spoke to were excited about these market driven opportunities.

Responsibly sourced gas is not just pertinent for US domestic markets. In 2020 France barred liquified natural gas exports from the US firm NextDecade due to concerns about methane emissions from extraction, processing, and shipment stages. This effectively blocked a multiyear deal with French gas distribution firm Engie.[105] Such considerations will become even more binding as the European Union considers targeting methane release as part of its broader climate goals.[106] Economic consequences like this are helping to animate various industry groups focusing on methane emissions, such as OneFuture.[107] This all becomes more pertinent for the broader region if LNG export terminals, such as the Gibbstown, NJ facility, move forward.[108]

Land based remediation is of substantial value as well.[109] The broader restoration economy is estimated to generate nearly $25 billion and over 220,000 jobs, and many of these employment opportunities are in rural or low-income communities.[110] For restoration of oil and gas extraction lands, estimated environmental benefits of $21 billion far outweigh costs of $7 billion.[111] Reclamation of known and existing AML lands is estimated to generate up to 170,000

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105 Alan Krupnick, "Europe Moves toward Requiring Low-Methane Natural Gas," *Resources,* October 28, 2020, https://www.resources.org/common-resources/europe-moves-toward-requiring-low-methane-natural-gas/.

106 *Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions* (Brussels: European Commission, 2020), https://ec.europa.eu/energy/sites/ener/files/eu_methane_strategy.pdf.

107 "Our Members," One Future (One Future, July 28, 2020), https://onefuture.us/our-members/.

108 Will Englund, "Proposal to build LNG terminal on Delaware River could pose early test for the Biden administration," *The Washington Post,* January 5, 2021, https://www.washingtonpost.com/business/2021/01/05/lng-terminal-delaware-river/.

109 Todd K. BenDor et al., *Exploring and Understanding the Restoration Economy* (Chapel Hill, NC: University of North Carolina at Chapel Hill, 2014), https://curs.unc.edu/wp-content/uploads/sites/400/2013/05/BenDor-and-Lester-Exploring-and-Understanding-the-Restoration-Economy.pdf.

110 Sophie Kelmenson, Todd BenDor, and T William Lester, "The Economic Impacts of the US Ecological Restoration Sector" *Federal Reserve Bank of Boston*, June 2, 2016, https://www.bostonfed.org/publications/communities-and-banking/2016/summer/the-economic-impacts-of-the-us-ecological-restoration-sector.aspx.

111 Chomphosy, W. H., Varriano, S., Lefler, L. H., Nallur, V., McClung, M. R., & Moran, M. D. (2021). Ecosystem services benefits from the restoration of non-producing US oil and gas lands. *Nature Sustainability*, 1-8.

employment opportunities. These jobs would in turn stimulate supporting industries and surrounding communities.[112] Ultimately, remediation will improve area property values.[113]

Beyond direct job creation, activities in the restoration sector can help increase biodiversity and agricultural productivity, slow land degradation, tackle greenhouse gas emissions, and improve overall quality of life. If all AML lands were reforested, they would have the potential to sequester over 232,000 metric tons of carbon dioxide annually; reforestation would also help to address many of the environmental issues associated with AMLs mentioned previously by reducing acidic water runoff and decreasing flood risk.[114] Mine lands and surrounding areas have also been repurposed for a number of different uses (e.g., solar plants and wind farms, recreational use, and commercial developments).[115] One example of a coal site reclamation in Pennsylvania, funded by the U.S. Economic Development Association, is estimated to generate nearly 200 jobs and over $120 million in private investment.[116] Another brownfield remediation example is Mill 19 in Pittsburgh, a former steel mill undergoing renovations to become a community center and site for robotics and artificial intelligence innovations.[117] Other projects like Power32 provide additional examples that leverage a broader regional ecosystem.[118]

Recycling waste from coal mining operations may also generate income, particularly through the extraction of rare earth elements. According to the National Energy Technology Laboratory (NETL), global demand for rare earth elements was 149,000 metric tons in 2015, of which the U.S. comprised 11%.[119] Currently, the U.S. imports most of its supply from China, which raises national security concerns. In collaboration with NETL and the U.S. Department of Energy, the

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[112] Eric Dixon, "Repairing the Damages" Ohio River Valley Institute (Ohio River Valley Institute, April 2021), https://ohiorivervalleyinstitute.org/wp-content/uploads/2021/04/Dixon-AML-paper-4.11.21-1.pdf.

[113] Haninger, K., Ma, L., & Timmins, C. (2017). The value of brownfield remediation. Journal of the Association of Environmental and Resource Economists, 4(1), 197-241.

[114] Eric Dixon, "Repairing the Damages" Ohio River Valley Institute (Ohio River Valley Institute, April 2021), https://ohiorivervalleyinstitute.org/wp-content/uploads/2021/04/Dixon-AML-paper-4.11.21-1.pdf.

[115] Examples of solar plants: https://www.dw.com/en/germany-opens-worlds-biggest-solar-plant/a-1321857, https://semspub.epa.gov/work/HQ/190025.pdf; wind farms: https://semspub.epa.gov/work/HQ/176038.pdf; recreation: http://www.downstreamstrategies.com/documents/reports_publication/amd-remediation-nbp_downstreamstrategies.pdf

[116] "Fiscal Year 2019 Annual Report," Economic Development Administration, (U.S. Department of Commerce, 2019), https://www.eda.gov/files/annual-reports/fy2019/FY2019-Approved-EDA-Annual-Report.pdf.

[117] "Mill 19: A Pittsburgh Industrial Hallmark - RIDC: Regional Industrial Development Corporation of Southwestern Pennsylvania," RIDC (Regional Industrial Development Corporation), accessed July 1, 2021, https://ridc.org/impact/case-studies/cultivating-community-assets/mill-19-a-pittsburgh-industrial-hallmark/.

[118] Power of 32 – Site Development Fund, accessed July 1, 2021, https://p32sitefund.com/.

[119] Daniel Moore, "Energy secretary lays out need for funding for clean energy, fossil fuel research near Pittsburgh," *Pittsburgh Post-Gazette,* May 6, 2021, https://www.post-gazette.com/news/politics-nation/2021/05/06/Energy-department-budget-Granholm-fossil-fuel-research-wind-solar-batteries/stories/202105060057.

West Virginia Water Research Institute is researching efficient rare earth element extraction from acid mine drainage. Previous research found that acid mine drainage from treatment sites in West Virginia, Pennsylvania, Maryland, and Ohio combined could produce up to 2,200 tons of rare earth elements annually.[120] Similar efforts around the use of coal refuse are also promising (e.g., the West Virginia University's Mid-Appalachian Carbon Ore, Rare Earth and Critical Minerals Initiative).

Some economic opportunities may create tensions between emission reductions and land or soil remediation. For example, this region is the world's epicenter for using coal refuse to create energy by using circulating fluidized bed boilers. Coal refuse is a major source of water and land pollution, but it can still be leveraged to produce energy. The world's largest coal refuse burning plant in the world is a facility in New Florence, PA. Refuse coal plants are said to generate upwards of 10% of power in the region, with a variety of employment and revenue upshots.[121] Unfortunately, a variety of emissions related consequences are created by this opportunity. Finding appropriate ways to take advantage of coal refuse--and thereby helping clean up soil and water pollution problems--in an emissions friendly manner will be a challenge and opportunity.

In summary, these economic opportunities can tap into the substantial knowledge base and skills of individuals currently employed in fossil fuel extraction. Experience with well drilling can in some contexts prove beneficial for well capping efforts. Experience with operating a mine may help with various land remediation and reclamation efforts. Such skill adjacent opportunities, even if they are not perfect, could help transition some workers into new economic opportunities.

Policy Options for the Region

This region faces a range of possible approaches to enhance environmental quality and reduce emissions of methane and other gases. We discuss these approaches in terms of Incentives, Processes, Research Investments, and Stakeholder Engagement. Some can be pursued at the state and local level and complement federal initiatives. Some do not directly require government and can be led by industry. For clarity, we discuss methane release separately from soil and water contamination. In some cases, it makes sense to think about both problems together.

Methane Release

<u>Incentives</u>

- Increase bonding requirements for wells while aiming to reduce inadvertent economic consequences that would put smaller, often conventional well operators, out of business. These changes in bonding requirements would apply to existing wells as well as future wells. In order to minimize economic impact, especially on older wells run by smaller operators, different strategies might be used. For example, a process of phased increases

[120] Rachel Pell, "From pollutant to resource: WVU scientists push rare earth element technologies closer to production," *West Virginia Water Research Institute*, April 23, 2021, https://wvwri.wvu.edu/news/2021/04/23/from-pollutant-to-resource-wvu-scientists-push-rare-earth-element-technologies-closer-to-production.

[121] These plants also qualify for special state tax credits, https://dced.pa.gov/programs/coal-refuse-energy-reclamation-tax-credit/.

could be used. As discussed above, there exists precedent for increasing bonding requirements on existing bonds.

- Establish third-party certification for Responsibly Sourced Gas (RSG) for natural gas produced by minimizing methane leakage from in-production operations. These certifications will complement existing regulations and existing efforts by firms to minimize methane release. Establish a gas premium charge, approved by the Public Utility Commission, for gas produced and shipped in a way that has been certified. This surcharge will raise funds for plugging abandoned wells, for other remediation activities, or for research on preventing methane leakage. Use the RSG certification to brand Pennsylvania gas exported to other states or overseas.
- Establish a voluntary additional charge on current extractive, shipment, and storage operations. These funds then go to cleanup operations in the regions the company works in. Voluntary contributions by companies will be publicly reported as a percentage of economic activity. Firms not contributing will appear in these public records. While voluntary programs historically have found it difficult to raise substantial funds, such a program would enable firms committed to environmental quality to be better recognized for these contributions. These contributions would be above and beyond money raised through existing levies.
- Maintain a list of companies vetted and approved for doing remediation work in Pennsylvania. These companies are then eligible to bid on remediation projects. Assess projects for quality and make membership on the list dependent on effective quality. This decreases the tendency to underbid and do poor quality remediation work.
- Establish consistent streams of funding for remediation projects.[122] In addition to increasing efficiencies, this will also help to incentivize individuals to switch into this industry.
- Explore incentives for property owners to report abandoned wells. For example, carbon offset funds could be used to properly compensate landowners once remediation occurs.
- Make permanent calculations of the social cost of methane that recognize the higher potency of methane compared to carbon dioxide as a greenhouse gas. Current measures are interim. Build in a social cost of methane as part of an integrated cost of greenhouse gases policy.[123]

Processes

- Invest in improving existing data and data processes for keeping track of wells by funding an expansion of the Exploration and Development Well Information Network

[122] *Pennsylvania Abandoned Mine Land Campaign* (Western Pennsylvania Coalition for Abandoned Mine Reclamation, July 2019), http://amlcampaign.wpcamr.org/files/PA%20AML%20Campaign%20General%20Fact%20Sheet%20DRAFT%20July2019.pdf. Ad Crable and Will Parson, "Orange Water, Dirty Air: What Will It Take to Clean up Abandoned Mine Land in the Chesapeake Watershed?," *Bay Journal Media*, March 8, 2021, https://www.bayjournal.com/news/energy/orange-water-dirty-air/article_dd947c74-7b66-11eb-81e3-232de92f42f3.html.

[123] *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990*, (Interagency Working Group on Social Cost of Greenhouse Gases, United States Government, February 2021), https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf.

(EDWIN) program. This would enable more detailed access to information about wells and their location which will enhance remediation efforts but also prevent unintended harms from new drilling operations.
- Identify ways to improve the predictability of various permitting processes spanning a range of operations, including remediation. Work with industry, regulatory, and community stakeholders to ensure commonly held values around protecting the environment and economic livelihoods.
- Expand the PA DEP's monitoring and inspection capabilities around all forms of remediation. This will include, for example, a focus on quality of well capping so as to avoid groundwater contamination and atmospheric release due to poorly executed jobs.

<u>Research Investments</u>

- Invest in detection and quantification research. Methane leakage detection is a fast-moving area in the development of sensors and also in strategies of deploying sensors (drones, continuous time sensing). Quantification is one of the biggest investment opportunities, because the scale of emissions in a site is critically important. Quantification will help identify super-emitter sites and the scale of capping needed. Industry, federal, and state funds should be used for research on remote methane leak detection that recognizes that different producing regions will have different challenges. Similarly, sustained research in other techniques for identifying abandoned wells, such as aeromagnetic techniques, warrant continued exploration.[124]
- Encourage industry led investments in the creation of a common database where firms can report problems that lead to inadvertent leakage from in production facilities. This enables identification of potentially common problems so any firms using similar equipment and practices can be proactive. This enables focus on prevention given the relatively low percentage of places where there is accidental release. By "engineering out" solutions to common challenges, industry can take the lead in prevention.

<u>Stakeholder/Public engagement</u>

- Encourage the formation and flourishing of industry groups and nurture their existence and effectiveness in the remediation space. While industry groups like the Marcellus Shale Coalition exist on the active extraction side, these relationships are less established around remediation. This can be facilitated by regional foundations. Encourage the involvement of local and regional companies and workers. This will help build up a community that can advocate for itself.
- Promote the importance of well capping efforts as part of the broader remediation and environmental quality effort. This will help well capping projects achieve greater public awareness and make community driven proposals for funds to the Marcellus Legacy Fund more likely. Currently other, more visible, projects get prioritized by applicants. For example, Act 13 (Impact Fee) Funds for Greenways/Trails totaled $87 million in 2019/2020 whereas plugging abandoned wells totaled $1.7 million from a handful of applicants.

[124] Patricia M. Saint-Vincent et al., "Identifying Abandoned Well Sites Using Database Records and Aeromagnetic Surveys," *Environmental Science & Technology* 54, no. 13 (2020): pp. 8300-8309, https://doi.org/10.1021/acs.est.0c00044. For industry efforts, see https://methanecollaboratory.com/

Soil and Water Remediation

Incentives

- Establish a *predictable* stream of funding for soil and water remediation. This will help the private sector and civil society make longer term investments in workers and equipment. A major source of this funding can come from existing programs. Release funds from the existing federal Abandoned Mine Lands fund to jump start high priority cleanup jobs. As laid out in the Revitalizing the Economy of Coal Communities by Leveraging Local Activities and Investing More (RECLAIM) Act, this money could be allocated immediately. Renewing Abandoned Mine Land Act (set to expire in 2021) will improve predictability of financing.
- Identify and prioritize areas located in former mining regions that can be repurposed for renewable energy locations. This includes locating solar and wind installations at former open air mining locations that are less likely to have other productive economic opportunities. This also includes strategic repurposing of facilities like coal powered plants that take advantage of their access to rail, energy grids, and contiguous land.
- Increase bonding requirements on active fossil fuel extraction operations. This includes coal mines. If possible, this should be part of a federal program so as to ensure that no particular region, like the Appalachian region, is disadvantaged due to policies in other states.
- Expand the set of "brownfield" sites that have state commissioned "playbooks."[125] These sites can be great investment opportunities, but investors might be intimidated by the due diligence process and potential liabilities that come with these sites. By producing "playbooks" ahead of time, these uncertainties can be reduced and site-specific opportunities highlighted. Ensure these playbooks are promoted and utilized.
- Power plants that use coal refuse should be incentivized to be first in class when it comes to emissions mitigation. Using coal refuse to produce energy reduces water and soil pollution, but these power plants emit a range of airborne pollutants and greenhouse gases.[126] The relevant industry association, ARIPPA, notes that coal refuse fires, which are scattered across the region, are even more pernicious. Existing tax credits that these plants receive could be adjusted to incentivize further emissions mitigation.[127] Large, more recently built facilities might be used as carbon sequestration pilots if appropriate.

Processes

- Invest in data collection and oversight resources needed to accurately document AML lands. In particular, the existing federal AML inventory can be used as a baseline but should be updated and expanded upon. Thorough assessments of sites can then be used to tackle highest-priority areas and yield more accurate cost estimates.

[125] Jeff Brady, "Finding New Opportunity For Old Coal-Fired Power Plant Sites," *WBUR News,* May 23, 2019, https://www.wbur.org/npr/724454774/finding-new-opportunity-for-old-coal-fired-power-plant-sites.

[126] "The Coal Refuse Dilemma: Burning Coal for Environmental Benefits," *Power Magazine,* July 1, 2016, https://www.powermag.com/coal-refuse-dilemma-burning-coal-environmental-benefits/.

[127] "Coal Refuse Energy and Reclamation Tax Credit," PA Department of Community & Economic Development (PA Department of Community & Economic Development, March 30, 2020), https://dced.pa.gov/programs/coal-refuse-energy-reclamation-tax-credit/

- Highlight and support the bipartisan Congressional efforts around abandoned mines and reclamation coming from legislators in this region. This includes reauthorizing the Abandoned Mine Land act, but also other initiatives such as the RECLAIM Act. With bipartisanship rare in the US Congress, job producing efforts that clean up the environment for all is a win-win for America and the region. This support extends beyond Congressional leaders to a variety of civic associations, such as Trout Unlimited and related organizations.[128]

Research Investments

- Fund research on groundwater contamination due to underground gas leakage.[129] This has been a challenge in part due to the complexity of measurement and source identification. Research is needed in methods to properly identify sources of soil or groundwater contamination.[130] More research is needed to make remediation methods for groundwater and soil more cost efficient and scalable.[131] This could entail investments in remote sensing and even robotics technologies.[132]
- Research on reclamation of trace metals from coal tailings and coal ash could help unlock value from otherwise hazardous waste from years of coal mining. Emerging needs around rare earth and trace metals for various industrial applications require research and development support to achieve proof of concept demonstrations all the way up to processes that can achieve required scale economies. This work can be done in conjunction with industry partners.[133]

Stakeholder Engagement

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128 *Legislative Hearing on HR 1734, HR 1733, HR 1146- "Restoring Abandoned Mine Lands, Local Economies, and the Environment" before the Subcommittee on Energy and Mineral Resources,* (Ashley, PA: Eastern PA Coalition for Abandoned Mine Reclamation, March 12, 2021). https://naturalresources.house.gov/imo/media/doc/Testimony%20-%20Mr.%20Bobby%20Hughes,%20EPCAMR%20-%20EMR%20Leg%20Hrg%2003.18.21.pdf.

129 Annie Manning, "$1.1 million to fund CSU research on detecting dangerous underground gas leaks," *Colorado State University,* March 16, 2020, https://engr.source.colostate.edu/1-1-million-to-fund-csu-research-on-detecting-dangerous-underground-gas-leaks/.

130 *Safeguards Are Not Preventing Contamination From Injected Oil and Gas Wastes,* (Washington, D.C.: United States Government Accountability Office, July 1989), https://www.gao.gov/assets/rced-89-97.pdf.

131 Caliman, F. A., Robu, B. M., Smaranda, C., Pavel, V. L., & Gavrilescu, M. (2011). Soil and groundwater cleanup: benefits and limits of emerging technologies. *Clean Technologies and Environmental Policy*, *13*(2), 241-268.

132 Benjamin Boettner, "Laying the ground for robotic strategies in environmental protection," *Wyss Institute*, April 8, 2019, https://wyss.harvard.edu/news/laying-the-ground-for-robotic-strategies-in-environmental-protection/.

133 Austyn Gaffney, "Can Harvesting Rare Earth Elements Solve the Coal Ash Crisis?," *The Magazine of Sierra Club,* Februrary 23, 2021, https://www.sierraclub.org/sierra/2021-2-march-april/feature/can-harvesting-rare-earth-elements-solve-coal-ash-crisis. "Phoenix Tailings," Phoenix Tailings, accessed July 2, 2021, https://www.phoenixtailings.com/.

- Given the labor-intensive nature of much soil and water remediation work, it will be important to ensure that jobs created by investing in this area pay a respectable wage. In part this can be facilitated by involving unions, including those representing existing coal workers. For instance, although AML workers' wages are generally above the poverty line, they are often below a livable wage; tying wage regulations to AML jobs can help to raise workers' pay.[134]
- Private sector leadership--ranging from the energy sector to industrial sectors to other organizations including local Chambers of Commerce--will be key given the expansive set of challenges. Making sure these groups are aware of various funding streams and real business opportunities, including from land developers, will be important. To facilitate this engagement, the state should invest in more "playbooks" for additional sites (see discussion in Chapter 5).
- Prioritize training, hiring, and funding of workers from historically marginalized groups. Many of the areas experiencing economic hardship from declining coal activity face issues related to race- or gender-based disparities.[135]

[134] Eric Dixon, "Repairing the Damages" Ohio River Valley Institute (Ohio River Valley Institute, April 2021), https://ohiorivervalleyinstitute.org/wp-content/uploads/2021/04/Dixon-AML-paper-4.11.21-1.pdf.
[135] Ibid.

Chapter 4

Carbon Management and the Future Development of Fossil Fuel Resources in Southwest Pennsylvania

Stephen Ansolabehere, Heidi Li

Coal, oil, and natural gas from southwest Pennsylvania have been critical energy resources for the United States for the better part of two centuries. With the rise of the Marcellus and Utica shale gas industries since 2005, fossil energy production in the region has witnessed a renaissance. The Pennsylvania Department of Environmental Protection forecasts a doubling of gas production between 2020 and 2050, and, with that, the promise of attracting other industries, such as petrochemicals, to the region.

The global transition of energy industries to lower carbon emissions, however, will alter the region's energy, manufacturing, and industrial sectors. The expansion of natural gas production in the near term will help reduce greenhouse gas emissions, as natural gas has much lower carbon density than coal. Eventually, however, the use of natural gas will itself be in tension with increased consumer demand for cleaner energy and with public policies and goals.[136] The projections of the Roosevelt Project's REMI model indicate that a shift in demand toward lower carbon energy will result in a permanent contraction in energy extraction, industrials and manufacturing in the region, unless new ways of using fossil fuels are deployed.

Carbon management is a logical strategy for southwest Pennsylvania. The suite of technologies and processes for carbon management is called carbon capture, utilization, and storage, or CCUS. Carbon dioxide and other greenhouse gases (GHGs) can be captured during power generation or other industrial and manufacturing activities. Waste carbon may, then, be stored underground or used as an input for other products, such as cement or steel, in ways that prevent it from escaping into the atmosphere. In its *2020 Flagship Report*, the International Energy Agency identifies CCUS as the "only group of technologies that contributes both to reducing emissions in key sectors directly and to removing CO2 to balance emissions that are challenging to avoid—a critical part of 'net' zero goals."[137]

Carbon management offers southwest Pennsylvania a plausible way to reduce its greenhouse gas emissions from fossil fuels. The region has excellent geology for storage of waste carbon, natural gas, and hydrogen. The region has the requisite industry, expertise, and workforce to build and operate CCUS infrastructure, as well as extensive existing infrastructure, some of which may be used as part of a carbon management system.

Potentially larger opportunities for southwest Pennsylvania can emerge with the development of a CCUS innovation hub. Such a hub would connect the region's fossil fuel energy facilities to

[136] "REPORT towards a WTO-Compatible EU Carbon Border Adjustment Mechanism," European Parliament, 2021, https://www.europarl.europa.eu/doceo/document/A-9-2021-0019_EN.html.

[137] International Energy Agency, "CCUS in Clean Energy Transitions – Analysis," IEA, September 2020, https://www.iea.org/reports/ccus-in-clean-energy-transitions.

carbon storage facilities. It would also serve as an incubator for research and development of commercially viable technologies for CCUS. There is growing global demand for cost-effective technologies that can be deployed on a large-scale to reduce carbon emissions from existing and new fossil fuel power plants, agricultural processing facilities, industrial production, and manufacturing processes. There will also be demand for new technologies to store waste carbon underground or to use carbon as an input to other industrial processes.[138]

Carbon capture is not a matter of "if" but "where." The US is currently the global leader in CCUS technology. Half of all large-scale carbon capture and storage projects in the world are in the United States.[139] US development of CCUS is also beginning to attract very large investments.[140] CCUS technologies are the subject of intense investigation worldwide and this technology is beginning to attract significant investments from leading energy companies.

Southwest Pennsylvania can become a global leader in CCUS technology. The region has the research and development capacity to become an innovation hub for CCUS. The US Department of Energy's fossil fuel research lab – the National Energy Technology Laboratory (NETL) – is anchored in Pittsburgh, with a second office nearby in Morgantown, West Virginia. The region also has world-class research universities, including Carnegie Mellon, the University of Pittsburgh, Penn State University, and, nearby, universities in West Virginia and Ohio. With its natural resources, industry and workforce, and research capabilities, southwest Pennsylvania is extremely well-positioned to create an innovation hub for the development of CCUS.

Carbon capture and sequestration infrastructure in the region can eventually support the production of hydrogen, which can be used as a fuel or as a feedstock to produce fertilizers, ammonia, and other petrochemicals. When coupled with CCUS, hydrogen produced using natural gas, called blue hydrogen, can have minimal GHG emissions, bringing it in line with environmental goals and policies. Commercial development of blue hydrogen will require further technological innovations and infrastructure, but the technology offers an option for the region to develop its natural gas industry over the long run.

Large-scale commercial deployment of CCUS requires a clear plan for regional deployment, championed by political leaders in the region and in the Commonwealth. We recommend the following.

(1) Establish a Carbon Management Task Force. The Task Force should develop a regional plan for carbon transportation and storage, and should represent views of the community, industry,

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[138] In 2020 alone, China brought online 38.4 gigawatts of new coal-fired power into operation. Michael Standaert, "Despite Pledges to Cut Emissions, China Goes on a Coal Spree," *Yale Environment 360*, March 24, 2021, https://e360.yale.edu/features/despite-pledges-to-cut-emissions-china-goes-on-a-coal-spree

[139] Lee Beck, "Carbon capture and storage in the USA: the role of US innovation leadership in climate-technology commercialization" Clean Energy 4(2020): 2-11. https://doi.org/10.1093/ce/zkz031

[140] Most notably, ExxonMobil announced that it will invest $100 billion in CCUS in the State of Texas. David Blackmon, "Exxon's $100 Billion Carbon Capture Plan: Big, Challenging And Needed," Forbes, April 22, 2021, https://www.forbes.com/sites/davidblackmon/2021/04/22/exxons-100-billion-carbon-capture-plan-big-challenging-and-needed/?sh=6265236f417b

government, and research institutions. It should meet regularly to discuss public concerns, regulatory issues, and industrial development strategies.

(2) Expand the region's research and development capacity for carbon capture, utilization, and storage. The federal government should authorize the National Energy Technology Lab to establish a new program devoted to carbon management and should increase funding for research on CCUS and hydrogen.

(3) Double down on demonstration projects for underground carbon storage and for carbon capture at industrial scale. Demonstration projects should be designed and operated by NETL and affiliated US research universities as part of the initiative on innovation in and optimization of carbon management.

(4) Assess the potential for hydrogen. The Department of Environmental Protection and the Department of Conservation and Natural Resources, working with industry, should produce its plan for development of hydrogen infrastructure, especially pipeline and storage facilities.

(5) Develop a region-wide planning process for the management of underground assets. The relevant state agencies of Ohio, Pennsylvania, and West Virginia should conduct a joint study of the below surface assets of the region, such as deep saline formations, and how they can be managed efficiently and equitably.

(6) Develop environmental and safety standards for CCUS and hydrogen. The Commonwealth of Pennsylvania should develop clear environmental and safety standards for CO2 and hydrogen sources, pipelines, and storage facilities. The Commonwealth should increase the capacity of state and federal agencies for monitoring pipelines and storage facilities and enforcing standards.

Context

Energy production is one of five key industries in the highly diversified economy of southwest Pennsylvania.[141] Energy extraction and power generation account for 9 percent of the gross domestic product of the region. Manufacturing, which depends heavily on energy, adds another 10 percent. Although they contribute greatly to the domestic product, energy extraction and utilities account for only about 2 percent of employment.[142] The reason for the discrepancy between gross product and employment is that much of the value of energy extraction is from export of fuels, especially natural gas, to other states.

Coal remains the primary fuel for electricity generation. Approximately 7 gigawatts of generating capacity from coal compared with 3.5 from natural gas and 1.8 from nuclear power. Another 7.5 gigawatts of power are generated using coal in a handful of power plants in areas of

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[141] The City of Pittsburgh identifies five key industries to be Advanced Manufacturing, Health Care and Life Sciences, Energy, Financial Services, and Information Technology. "Key Industries & Corporations," Visit Pittsburgh, accessed May 31, 2021, https://www.visitpittsburgh.com/pcma2019/industries-and-corporations/. Energy has the highest CapEx (capital expenditure) of these industries in the area. "Deal & Dealmakers 2018," Scorecard 2018 (Pittsburgh Regional Alliance), accessed May 31, 2021, https://scorecard2018.pittsburghregion.org/.

[142] See Chapter 6 of this report.

Ohio and West Virginia that border Southwest Pennsylvania. That said, coal mining in southwest Pennsylvania is in decline, with the only significant presence in Greene County, PA.

The development of natural gas in the Marcellus shale in the early 2000s transformed energy production and related industries in the region. Almost all energy extraction in the region is now natural gas. In 2019, Pennsylvania produced nearly 7 trillion cubic feet of gas, making the state the second largest energy producer in the nation[143] and one of the top three energy exporters in the US.[144] Most of the gas from this area goes to New York, New Jersey, Maryland, Ohio, and West Virginia.[145] The Pennsylvania Department of Community and Economic Development views Marcellus natural gas resource as central to future economic development of the state, including power generation and downstream manufacturing.[146]

Fossil energy has long attracted other industries to the region, such as steel. Pennsylvania's Marcellus shale gas is beginning to attract development of petrochemicals and other manufacturing.[147] Shell is constructing an ethane cracker plant in Beaver, County, PA, to produce ethylene. This plant is projected to employ 600 to 800 people when operational. Three other plants are under consideration in Ohio and West Virginia, though those facilities are still uncertain.[148] In Clinton County, PA, Key State Agri is raising capital to build a chemical facility to produce, among other things, ammonia and fertilizer, from natural gas.[149]

The economic impact of energy extraction and utilities varies within the region. In Greene County, Mining, Quarrying and Oil & Gas accounted for 18 percent of employment in 2018; in Armstrong, Fayette, Indiana, and Washington Counties energy extraction activities accounted for approximately 5 percent of employment; in Allegheny, Beaver, Butler, Cambria, Lawrence, and

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143 "Pennsylvania Profile State Profile and Energy Estimates," Pennsylvania State Energy Profile, U.S. Energy Information Agency, Accessed June 1, 2021. https://www.eia.gov/state/?sid=PA.

144 Allen McFarland, "Wyoming, Texas, and Pennsylvania Rank as the Top Net Energy Suppliers among States," Today in Energy (U.S. Energy Information Agency, July 31, 2017), https://www.eia.gov/todayinenergy/detail.php?id=32272.

145 "Pennsylvania State Energy Profile," Pennsylvania Profile (U.S. Energy Information Agency, September 17, 2020), https://www.eia.gov/state/print.php?sid=PA#19.

146 "Key Industries Natural Gas," PA Department of Community & Economic Development, January 22, 2020, https://dced.pa.gov/key-industries/naturalgas/.

147 Nationwide shale gas is fueling development of petrochemicals. American Chemistry Council, "Shale Gas, Competitiveness, and New US Chemical Industry Investment: An analysis Based on Announced Projects," May 2013 https://www.americanchemistry.com/First-Shale-Study/.

148 Beth Burger, "Petrochemical Hub along Ohio River in Belmont County Faces Indefinite Delay," The Columbus Dispatch (The Columbus Dispatch, February 4, 2021), https://www.dispatch.com/story/business/2021/02/04/petrochemical-hub-faces-indefinite-delay-market-forces-dont-support-buildout-in-appalachia/4386072001/.

149 Chase Bottorf, "Innovative Natural Gas Project Gaining Investors," (Lock Haven, January 20, 2021), https://www.lockhaven.com/news/local-news/2021/01/innovative-natural-gas-project-gaining-investors/.

Westmoreland Counties energy extraction was less than 1 percent of employment.[150] The development of Marcellus shale gas has generated the equivalent of 25,000 additional jobs annually in the region.[151] Gas operations have resulted in substantial increases in income and employment and in county government revenues especially in outlying parts of the region, notably in Fayette, Greene, and Washington Counties to the southwest of Pittsburgh, in Armstrong and Indiana counties to the northeast of Pittsburgh.[152]

Income from the natural gas industry has been a windfall for state and local governments. The Commonwealth of Pennsylvania imposed a Gas Impact Tax in 2012. That fee has generated approximately $200 million per year for the Commonwealth. Over half of that revenue goes directly to the county and local governments in areas where there is gas extraction. Those revenues have helped improve schools and roads in these counties. Approximately 20 percent of the revenues from the gas impact tax go to counties for parks and bridges; 15 percent goes to statewide environmental funds; and 9 percent of the revenue funds state agency oversight.[153] These funds are a particularly important source of revenue for local governments in the counties where the Marcellus development has occurred.[154]

The rise of Marcellus gas has also had two negative impacts on the region. First, there has been an increase in air and water pollution. An extensive study, conducted by researchers at Princeton and Carnegie Mellon Universities, of the economic benefits and health costs of the first decade of shale gas development to the Appalachian region concluded that the benefits net the costs have been a wash. The health effects associated with air pollution, when monetized, have cost $23 billion and produced $21 billion in direct economic benefits to Ohio, Pennsylvania, and

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[150] "County Profiles," Center for Workforce Information & Analysis, accessed June 1, 2021, https://www.workstats.dli.pa.gov/Products/CountyProfiles/Pages/default.aspx.

[151] In 2010, a PSU study predicted Jobs from Marcellus Shale in PA: 212,000 by 2020. https://marcelluscoalition.org/wp-content/uploads/2010/05/PA-Marcellus-Updated-Economic-Impacts-5.24.10.3.pdf. Subsequent PSU research found that only about the Marcellus shale development generated approximately 25,000 jobs annually, and half of those jobs were filled by workers from outside of Pennsylvania. Wrenn, Douglas & Kelsey, Tim & Jaenicke, Edward. (2015). Resident vs. Nonresident Employment Associated with Marcellus Shale Development. Agricultural and Resource Economics Review. 44. 1-19. 10.1017/S1068280500010194. Similarly, a Princeton-CMU study found that the Marcellus development in Ohio, Pennsylvania, and West Virginia created the equivalent of 40,000 full-time jobs annually across these three states. Erin Mayfield et al "Cumulative Environmental and Employment Impacts of the Shale Gas Boom," Nature Sustainability 2 (2019): 1122-1131.

[152] Max Harleman and Jeremy Weber estimate that local residents capture 8.5 percent of value of production of the typical well. Max Harleman and Jeremy Weber, "Natural resource ownership, financial gains, and governance: The case of unconventional gas development in the UK and the US," *Energy Policy* 111 (2017): 281-296.

[153] Marcellus Shale Coalition, "Pennsylvania's Impact Fee", Accessed May 31, 2021. http://marcelluscoalition.org/wp-content/uploads/2018/06/2018-Impact-Fee-Fact-Sheet-062118.pdf

[154] Caroline White-Nockleby et al., "Changes in the Contribution of Coal to Tax Revenues in Greene County, PA, 2010-2019" (MIT Environmental Solutions Initiative Here & Real Project, March 2021), https://environmentalsolutions.mit.edu/wp-content/uploads/2021/03/MIT-ESI-White-Paper-Changes-in-the-Contribution-of-Coal-to-Tax-Revenues-in-Greene-County-PA-2010-2019.pdf.

West Virginia. Further, the net benefits have been far greater than the costs in rural counties, but the health care costs have far exceeded the economic benefits in Allegheny County.[155]

Second, development of Marcellus gas has driven down the price of natural gas, leading to a steep drop in demand for coal. Some parts of central Appalachia have enjoyed an economic windfall from gas, but other parts of the region are experiencing economic dislocations due to the drop in demand for coal. We focus on southwest Pennsylvania, though other areas of Appalachia have been much harder hit by recent declines in coal mining.

Policies designed to reduce greenhouse gases will also affect specific activities. Electric power generation accounts for the lion's share of the greenhouse gases that are emitted *inside the region*. According to the Department of Environmental Protection, 78 percent of the GHG emissions in this region come from utilities. Manufacturing accounts for another 12 percent of the region's GHGs, and energy extraction releases 5 percent of the GHGs emitted in this area.[156]

Most of the carbon attributed to energy production in the region is emitted *outside* the region. Most of the natural gas extracted in Southwest Pennsylvania goes to other states, especially Ohio, New York, New Jersey, and Maryland. In 2018, the GHG content of fuels exported from (rather than energy generated or products made in) the region amounted to 336 MMT of GHGs – more than 5 times the GHG content of all economic activity inside the region.[157] If the neighboring states decarbonize their energy and industrial sectors, there will be a significant decrease in demand for gas from southwest Pennsylvania.

Carbon Capture and Hydrogen

There are two pathways for continued use of the region's fossil fuels from with significantly lower carbon emissions: (i) carbon capture, utilization, and storage (CCUS), and (ii) hydrogen from natural gas. These two pathways work in tandem. Carbon capture can be used in processes that use natural gas to produce hydrogen, or blue hydrogen.[158]

Southwest Pennsylvania is ideal for the deployment of these technologies. The geology of the region has extensive deep underground saline formations that are suitable for large-scale permanent storage of carbon or temporary storage of hydrogen fuel. The promise of hydrogen storage, which we view as of particular importance 20 to 30 years in the future, means that the underground assets of the region can have long-term economic value if managed properly. The region has extensive expertise in fossil fuel generation, including a skilled workforce and local companies capable of large-scale industrial development. The region also has research and development capacity, with the National Energy Technology Laboratory and the area's

[155] Erin N. Mayfield, Jared L. Cohon, Nicholas Muller, Ines Azevedo, Allen L. Robinson, "Cumulative Environmental and Employment Impacts of the Shale Gas Boom," *Nature sustainability* 2 (2019): 1122-1131. doi: 10.1038/s41893-019-0420-1

[156] PA Department of Environmental Protection, 2020 Pennsylvania Greenhouse Gas Inventory Report, July 2020. https://www.dep.pa.gov/Citizens/climate/Pages/GHG-Inventory.aspx

[157] Ibid.

[158] Hydrogen may also be produced using other electricity sources, such as nuclear, wind, or solar power.

university research laboratories. Such expertise will be necessary for systems analysis and planning as well as improvement in chemical and industrial processes.

Carbon capture and hydrogen at scale will require government agencies and private companies to make choices that shape the industry. The region will need to plan, site, and construct pipelines and storage facilities suitable for carbon dioxide and hydrogen. The Commonwealth will need to establish and enforce appropriate environmental, safety, management, and ownership rules. Many of the opportunities in the region cross state boundaries. Federal involvement or regional cooperation is essential to realize the full value of carbon capture and hydrogen pathways.

B. 1. Carbon Capture

Carbon capture is a suite of technologies and associated infrastructure that allow for the extraction of CO2 from fuel directly or during combustion or chemical processing. There are three phases to this process: carbon capture, transportation, and storage.

Industry in southwest Pennsylvania provides a wide variety of opportunities for carbon capture, including power generation and manufacturing of industrial products, such as petrochemicals and steel. Power generation is perhaps the most obvious large-scale application for carbon capture. Capture may occur pre-combustion or post-combustion. Capture technology is well-known, but remains expensive, and current DOE research is focused on reducing costs. Investment in carbon capture research is vitally important to an economically successful deployment of this technology at a regional scale.

Post-combustion capture separates carbon dioxide (CO2) from the flue gas stream produced by conventional fossil fuel combustion. The CO2 is separated from nitrogen in the flue gas and can be stored underground or used for other purposes. The cost of post combustion capture is estimated to be approximately $50 per metric ton of carbon from coal and $70 per metric ton of carbon from conventional natural gas. (See Appendix).

Pre-combustion capture converts a feedstock, such as coal, into a gas that is a mixture of hydrogen, carbon monoxide, carbon dioxide, and other elements. This synthesis gas, or syngas, can be separated into hydrogen for fuel and carbon dioxide. The CO2 can be separated and, later, used for other purposes or stored as a pollutant. Under today's commercially viable technology, the cost of CO2 capture in power generation is around $60 per a metric ton of carbon.[159] While carbon capture is cheaper for each ton of carbon captured from coal than it is from natural gas, it must be kept in mind that the carbon density of coal is much higher, making the cost of capture per unit of *energy* produced cheaper for natural gas than for coal.

To make carbon capture feasible on a national, or even global, scale, it is essential to reduce the cost of the technologies. Current DOE research at NETL is focused on multiple technologies to

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[159] "Pre-Combustion Carbon Capture Research," Department of Energy, accessed June 2, 2021, https://www.energy.gov/fe/science-innovation/carbon-capture-and-storage-research/carbon-capture-rd/pre-combustion-carbon; "Pre-Combustion CO2 Capture," National Energy Technology Laboratory (NETL), accessed June 2, 2021, https://netl.doe.gov/coal/carbon-capture/pre-combustion.

improve the efficiency and lower cost of pre-combustion and post-combustion capture.[160] Such research will likely need to be expanded.

Carbon capture can also occur in manufacturing processes, either in the generation of power for the process or manufacture itself. The Shell ethane cracker facility nearing completion in Beaver County, PA, can be retrofitted for carbon capture, as can steel manufacturing in the Mon Valley and at Clairton in Allegheny County. The costs for capture from such heavy industrial processes is typically higher than for power generation using coal or gas. The capture technologies are expensive to retrofit to existing facilities, and they make the facilities operate less efficiently.

New electricity generation and manufacturing technologies are being developed and deployed with the aim of improving the ability to capture carbon dioxide and other pollutants without significant loss in efficiency. One of the most promising recent developments is the Allam cycle natural gas power plant design. This process can operate at 59 percent efficiency, almost the same as the most efficient conventional gas power plants (at 62 percent), and the Allam cycle captures 100 percent of the carbon dioxide.[161] North Carolina-based NET Power has constructed a 50 MW Allam cycle demonstration plant in La Porte, Texas, and, in collaboration with Exelon, is expanding that facility to a full scale, 300 MW operation.[162] The Allam cycle is an example of a promising new technology that will improve the efficiency of carbon capture.

The second part of the problem is what to do with the captured carbon. In the near term, storage is perhaps the most immediate option at a very large scale. Storage involves pumping CO2 underground, a task that requires substantial deep-underground geologies that are sufficiently stable and non-porous to allow for permanent storage without high risk of leakage. Deep underground saline formations are ideal for CO2 storage.

Pennsylvania has such formations in abundance. A recent report of the Pennsylvania Department of Conservation and Natural Resources estimates that Pennsylvania's geology has the capacity to store roughly 300 years' worth of CO2 emissions at current rates, which would correspond to a total of almost 90 billion metric tons of CO2.[163] The potential for deep underground storage is greatest in western Pennsylvania, exactly the region most at risk of economic dislocation with deep decarbonization.

Industrial production in the southwest Pennsylvania region has the potential to create a robust market for carbon as an input. A market for carbon as an industrial input will create a price on carbon that makes capture more economical. Common current uses of carbon dioxide are in

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[160] Ibid.

[161] Other carbon capture technologies for conventional natural gas reduce the efficiency of the power plant to at most 48 percent and capture 90 percent of the CO2. David W. Yellen, "Carbon Capture and the Allam Cycle: The Future of Electricity or a Carbon Pipe(Line) Dream?," Atlantic Council, December 22, 2020, https://www.atlanticcouncil.org/blogs/energysource/carbon-capture-and-the-allam-cycle-the-future-of-electricity-or-a-carbon-pipeline-dream/

[162] Sonal Patel, "Inside NET Power: Gas Power Goes Supercritical ," POWER Magazine, April 1, 2019, https://www.powermag.com/inside-net-power-gas-power-goes-supercritical/?printmode=1

[163] "Geologic Carbon Sequestration Opportunities in Pennsylvania," Pennsyvlania Environmental Council (Pennsylvania Department of Conservation and Natural Resources, August 14, 2009), https://pecpa.org/wp-content/uploads/Geologic-Carbon-Sequestration-Opportunities-in-PA-2009-1.pdf.

beverages and in enhanced oil recovery (EOR). [164] One promising possibility is cement. Cement manufacturing is one of the most carbon intensive industrial activities. Use of captured carbon from power generation in cement production can further reduce carbon emissions from cement production, and the cement itself can become a medium for storage of the carbon.[165]

CCUS may be especially important for the decarbonization of industrial production, which has been the slowest sector to decarbonize. According to the Pennsylvania Department of Environmental Protection, the industrial sector accounts for approximately 80 MMT CO2 annually, 31 percent of all emissions in the Commonwealth. That amount has not declined since 2000. By comparison, carbon emissions from electricity production have declined by almost 40 percent since 2000.[166] Developing a large-scale carbon capture, storage, and utilization system in southwest Pennsylvania can help reduce the carbon intensity of the industrial sector and protect the region's industrial production from becoming uncompetitive in the event that there are stricter regulations on carbon or increased demand for low-GHG products.

To fully develop a carbon capture and storage system will require significant planning and investment in infrastructure. Existing coal and gas-fired power plants will need to be retrofitted with capture technology, and plants using new designs, such as the Allam cycle, may be built. Other industrial facilities, such as steel, petrochemical, and cement plants will also need to be retrofitted for capture. In addition to capture technologies, the region will need to develop appropriate pipelines and storage facilities.

The region has taken some initial first steps toward developing CO2 infrastructure. The states of Ohio, Pennsylvania, and West Virginia have conducted extensive geological studies of suitability and feasibility of carbon storage.[167] The Department of Energy's National Energy Technology Laboratory, American Electric Power Services Corporation, and the State of West Virginia collaborated in a successful 15-year deployment of commercial scale carbon capture and sequestration at the Mountaineer Power Plant in Mason County, WV.[168] Working with NETL in this development as part of the Department of Energy's Coal FIRST program, Consol plans to build a zero-emission coal power plant in Washington and Greene counties. This facility will be

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[164] "NETL Explores Expanded Use for CO2 to Enhance Oil Recovery," NETL, accessed June 2, 2021, https://www.netl.doe.gov/node/10291.

[165] Maria Gallucci, "Capture Carbon in Concrete Made with CO2," IEEE Spectrum, February 7, 2020. https://spectrum.ieee.org/energywise/energy/fossil-fuels/carbon-capture-power-plant-co2-concrete

[166] Pennsylvania DEP, *Pennsylvania Climate Action Plan*, December 2020. https://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/Climate%20Change%20Advisory%20Committee/2020/12-22-20/2021_PA_CAP_Initial_Draft_12-15-20.pdf

[167] Douglas Patchen, Richard Bajura, Tim Carr, and Michael Hohn, "Research Support Program for the West Virginia Division of Energy" (National Research Center for Coal & Energy, December 31, 2011), https://www.energywv.org/assets/report-archive/W.Va.-Geological-and-Economic-Survey-Reports/Final-report-Phase-II_10-31-11.pdf.

[168] "Mountaineer Commercial Scale Carbon Capture and Storage Project Draft Environmental Impact Statement Summary," NETL (U.S. Department of Energy, February 2011), https://netl.doe.gov/sites/default/files/environmental-policy/eis-mountaineer/Summary.pdf; "Battelle Completes 15-Year CO2 Storage Project at Mountaineer Power Plant," Battelle, October 6, 2017, accessed June 2, 2021, https://www.battelle.org/newsroom/press-releases/press-releases.

capable of capturing nearly all of its carbon emissions.[169] Those projects establish a foundation for CCUS in the region.

As of now, there are no large-scale CO2 storage sites and no CO2 pipelines in southwest Pennsylvania, eastern Ohio, or West Virginia.[170] Nor are there any below ground storage facilities or containers in the region dedicated to CO2.

What would a capture and storage system at scale look like?

A handful of studies have examined large-scale development of CCS in this region. In 2009, the Pennsylvania Department of Conservation and Natural Resources prepared a study of carbon capture and storage for the largest emitting coal-fired power plants in Southwest and central Pennsylvania.[171] This study scoped out a CO2 pipeline system running from Armstrong and Indiana counties to Montour County in the center of the state. NETL has studied CCS in neighboring parts of Ohio. But, to our knowledge the Commonwealth has not done a subsequent study of CCS at scale.[172]

We have conducted an assessment of CCS at scale in this region based on analysis of four recent studies of carbon capture, transportation, and storage elsewhere.[173] We envision a pipeline and storage network that would run east-to-west, connecting power plants in Indiana and Armstrong counties in Pennsylvania to Coshocton Ohio, and north-south, connecting Beaver County to Greene County and extending into West Virginia. This plan would bridge the proposed development considered by the state of Pennsylvania in its 2009 report and the development in Ohio proposed by NETL.

Our estimates of the costs of a CCS hub in the region have three components. First, we gauge the scale and costs of capture at all industrial facilities in Southwest Pennsylvania. Second, we estimate the cost of constructing a CO2 pipeline through the region and of transporting CO2. Third, we estimate the cost of building and operating large-scale storage facilities.

First, to calculate the approximate carbon capture costs, we examined all major industrial and electricity point sources for greenhouse gases in Southwest Pennsylvania. Using the EIA database of energy facilities, we located each facility with more than 100,000 Mt CO2 emissions annually in the 13 counties in Southwest Pennsylvania. We, further, identified the fuel source

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[169] Rick Shrum, "Consol Hoping to Build Coal-Fired Plant with Zero Emissions," Observer-Reporter, January 9, 2021, https://observer-reporter.com/business/consol-hoping-to-build-coal-fired-plant-with-zero-emissions/article_e1718c04-3a36-11eb-826b-e3287b12b0e2.html.

[170] Vincent Gonzales, Alan Krupnick, and Lauren Dunlap, "Carbon Capture and Storage 101," Resources for the Future, May 6, 2020, accessed June 2, 2021, https://www.rff.org/publications/explainers/carbon-capture-and-storage-101/.

[171] Clinton Climate Initiative, "Viability of a Large-Scale Carbon Capture & Sequestration Network In Pennsylvania," Pennsylvania Department of Conservation and Natural Resources, November, 2009, https://pecpa.org/wp-content/uploads/Viability-of-a-Large-Scale-CCS-Network-in-PA-2009.pdf.

[172] Interviews with the relevant state agencies confirmed that no such studies have been conducted since 2009.

[173] "NETL Develops Flexible Carbon Capture, Utilization, and Storage Analysis Tools and Resources," NETL, accessed June 2, 2021, https://netl.doe.gov/node/9384.

and production technology used, as the capture costs vary considerably by fuel source. Using estimates from CarbonSafe, McCoy and Rubin, and Schmeltz et al. we computed the cost to retrofit each facility and the cost of capturing CO2 from each source.

The capture costs per ton of carbon vary by type of fuel used and process. The total cost for this portion of the project came to $500 million. Averaging across studies, levelized costs of capturing a ton of carbon dioxide are $61 per ton for a coal fired power plant, $81 for a natural gas fired power plant, and $128 for cement manufacturing. The cost of capture may be offset with tax incentives such as 45Q and prices for carbon as an input to other processes.

Second, to calculate the approximate transport costs, we assumed that there would be a backbone CO2 pipeline connecting eastern Ohio, northern West Virginia, and Southwest Pennsylvania. This pipeline would run from Coshocton, OH, to Indiana County, PA, and from Beaver County, PA, to Morgantown, WV. We chose Coshocton, OH, as that is the location of a carbon capture and enhanced oil recovery proposed by a team of researchers at NETL. Connecting Beaver County and Morgantown would connect the Shell ethane cracker plant in Beaver to coal generating facilities in West Virginia. To estimate the cost of such a pipeline, we rely on figures published by Kinder Morgan and NETL for pipeline development in mountainous terrain.

Third, to calculate storage costs, we assumed that three storage facilities would be constructed in the area, at suitable locations. This would require construction of pumping stations and above ground short-term storage, as well as operation and maintenance costs.

The total cost over 30 years for a pipeline and storage system for this region would come to approximately $8 billion. This is an approximate estimate based on existing recent research and modeling of the costs of carbon transportation and storage.

B. 2. Hydrogen

Hydrogen offers a second possible pathway for the development of low carbon fuels and technologies in this region. Large-scale hydrogen development requires a reliable supply of water, access to energy (preferably non-carbon emitting), and safe storage for hydrogen fuel produced. Southwest Pennsylvania, eastern Ohio, and West Virginia have these resources in abundance and are perfectly suited for region-wide, industrial development of hydrogen.[174]

Several large-scale hydrogen facilities in the region are planned or under construction.

- KeyState Agri and Frontier have announced plans for and are raising the funds for the construction of a $500 million synthesis gas plant in Clinton County, PA. The company plans to "extract natural gas and capture CO2" in the manufacturing process producing (i) low-carbon hydrogen for fuel, (ii) low-carbon ammonia, (iii) low-carbon nitrogen fertilizer, and (iv) exhaust treatment for power plants and diesel engines to reduce emissions from those processes.[175]

[174] Jeffrey Tomich, "Energy Transitions: Gas Plant Developer Bets Big on CO2-Free Hydrogen," E&E News (Politico, December 10, 2020), https://www.eenews.net/stories/1063720337.
[175] Chase Bottorf, "Innovative Natural Gas Project Gaining Investors," (Lock Haven, January 20, 2021), https://www.lockhaven.com/news/local-news/2021/01/innovative-natural-gas-project-gaining-investors/.

- Long Ridge Energy Terminal in Hannibal, Ohio (90 miles from Pittsburgh), in collaboration with New Fortress Energy and GE Gas Power is building a 485 MW combined-cycle power plant that will run initially on a gas-hydrogen mix but will transition to 100 percent hydrogen. Long Ridge is also locating a 300 MW Data Center Campus at that site.[176]
- Ember Partners and Mitsubishi are developing a 1 GW power plant in Harrison County, Ohio (70 miles from Pittsburgh) that will initially burn a mix of 70 percent gas – 30 percent hydrogen and eventually transition to 100 percent hydrogen. That partnership is also planning a 485 MW gas-hydrogen power plant in Lackawanna County, PA.[177] Similar facilities are under development in New York, Virginia, Utah, and Florida.

Hydrogen also can serve as a transportation fuel, especially for large vehicle fleets, with centralized fueling stations. Pennsylvania has been a first mover in the development of alternative fuels, such as compressed natural gas, hydrogen, and other alternative transportation technologies. The Department of Energy has selected two locations in Pennsylvania for the development of Alternative Fuels Corridors (I-80 and the I-78/I-81 corridors). Penn State University, Carnegie Mellon, and NETL have significant research activities in hydrogen fuel cells and alternative fuel vehicles. We leave the question of hydrogen and transportation to the Heartland case study, which examines the energy transition and the automotive industry.

The emergence of hydrogen for power, transportation, and manufacturing provides near and mid-term economic benefits for Southwest Pennsylvania. Each of the planned hydrogen facilities in the region will employ hundreds of people locally. The KeyState Agri facility, for example, will employ 150 to 200 people. The location of new hydrogen facilities in areas where there has been a loss of coal mining jobs or the closure of steel or coal generating facilities can help off-set some of the employment hit that the energy extraction and industrial sectors have taken over the past two decades.

Natural gas is critical to the development of hydrogen. For projects such as the Ember-Mitsubishi facilities, natural gas is a bridge fuel. Initially, these plants will burn a mix of natural gas and hydrogen, but eventually burn hydrogen produced from solar, wind, or another power source with zero GHGs. Natural gas is necessary in the near term to allow for scaling up the use of hydrogen.[178] These facilities will increase demand for hydrogen, raising the price of the product, and making production of hydrogen from gas, wind, solar, and other means more economical.

Large-scale deployment of hydrogen, however, will require a substantial infrastructure investment. Hydrogen alone will require development of a transportation network, including pipelines and storage facilities. Deployment of hydrogen with natural gas at an industry-wide scale will likely require a carbon capture and storage system as well as an additional system of hydrogen pipelines and storage. Given the wide range of hydrogen technologies, from fertilizer

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[176] Long Ridge Energy, accessed June 2, 2021, https://www.longridgeenergy.com/.

[177] Gersen Freitas, Jr., "The Fossil Fuel Industry Is Talking About ESG Like Never Before," Bloomberg News, March 23, 2021, https://www.bloomberg.com/news/articles/2021-03-23/the-fossil-fuel-industry-is-talking-about-esg-like-never-before

[178] International Energy Agency, "The Future of Hydrogen," June 2019, https://www.iea.org/reports/the-future-of-hydrogen

production to fuel cells to power generation, it is difficult to give a simple estimate for the cost of infrastructure needed.

In the long-term, the hydrogen for fuel may be produced using technologies, such as nuclear, solar or wind, that have no GHG emissions. Such green or related hydrogen could become the feedstock for an entirely carbon free power and industrial sector in the region. The near and mid-term prospect is that hydrogen mixed with gas or produced from gas with carbon capture provides the pathway to transition to zero emission electricity generation and manufacturing.

The location of hydrogen facilities can also reduce the economic impact of the decline of coal mining or eventual decline of natural gas extraction. As an industrial, workforce, and remediation strategy, it makes sense to locate new hydrogen facilities at or near fossil fuel facilities that are decommissioned or inactive. Those facilities have the infrastructure to support large-scale power generation, such as transmission lines and real estate, and a labor pool experienced in working with energy. Reuse of such sites will lessen the environmental impact of new energy and industrial development in the state.

What's Needed?

To create an innovation hub and to support CCUS deployment will require substantial investment in research on CCUS and hydrogen at NETL and university labs. Innovations in entire systems, such as the Allam cycle, and in materials that more effectively remove carbon from flue gas will improve the cost effectiveness of carbon capture. New methods for developing carbon fibers and related materials from carbon will improve the value chain for carbon, making carbon capture commercially attractive.[179] These innovations come directly from investments in lab research. The federal government and industry should increase their financial commitment to research, development, and deployment of CCUS.

A system of CO2 or hydrogen infrastructure will raise a complex set of management issues. Stakeholder deliberations concerning CCUS development elsewhere in the United States have identified six key issues.[180]

1. Regulation and enforcement of underground injection control. The US Environmental Protection Agency oversees the Underground Injection Control program. The state of Pennsylvania will need to request and be granted by EPA primacy over class VI wells for permanent storage of CO2 or hydrogen in order to move forward with CCS.
2. Long term liability. Liability associated with leakage or failure of a storage facility creates uncertainty and risk for the public and that makes firms unwilling to commit to storage. A rigorous evaluation and clear standards are needed to ensure that these risks are minimal, both for the health and safety of the public and to clarify long-term liabilities.
3. Pore space access. The underground space is an important resource, and there may be competing uses, such as the injection of other gases. The management of underground CO2

[179] "8 Future Technologies for Carbon Capture, JWN Energy, March 8, 2017, https://www.jwnenergy.com/article/2017/3/8/8-future-technologies-carbon-capture/

[180] Kenneth B. Medlock, III, and Keily Miller, "Expanding Carbon Capture in Texas," Working Paper, Center for Energy Studies, Rice University's Baker Institute for Public Policy, January 20201. https://www.bakerinstitute.org/media/files/files/8e661418/expanding-ccus-in-texas.pdf

must be developed in a way that allows for multiple intended uses. Further, there may be problems of "subsurface trespass," when carbon migrates to other spaces.

4. Unitization. Because underground storage space is an aggregate, a natural problem is how to treat the leasing rights underground. Some states treat the entire underground formation as a unit, and negotiate pooling agreements among the private interests using the underground resource. Developing clear unitization rules to create greater certainty about storage.
5. Eminent domain. Development of pipelines and underground storage caverns will likely require state legislation asserting eminent domain for purposes of siting.
6. Fiscal incentives. Tax incentives, such as the federal credit for CO2 sequestration, help make CCUS commercially viable. Especially in the early phases of CCUS, tax incentives, direct grants or loans to CCUS projects, allowing utilities to pass on costs to ratepayers, and clean energy standards, are likely necessary.

These issues need to be considered and resolved by stakeholders in the region, especially state and local governments, companies, and people involved in or directly affected by the development of CCUS.

The Commonwealth of Pennsylvania has taken several important initial steps to develop CCUS and related hydrogen and petrochemical industries. For example, the Commonwealth has joined several multi-state agreements and initiatives, such as the Midwest Regional Carbon Initiative and the Great Plains Institute, to reduce carbon emissions. These multi-state collaborations are driving the development of CO2 pipeline development and storage systems.[181]

First, we recommend creating a Carbon Management Task Force that includes representatives of companies, local, state, and federal governments, NGOs and foundations, and universities and research labs, and the public. The Task Force should meet regularly to consider in detail the six key issues identified above and related issues, to negotiate specific proposals to resolve these issues, including proposed rules and legislation, and to present plans for regional and state development of CCUS to the governor and state legislative leaders of the State of Pennsylvania.

Second, we recommend that the Pennsylvania Department of Environmental Protection, the Pennsylvania Department of Conservation and Natural Resources, and the National Energy Technology Laboratory collaborate on the development of at least three region-wide proposals that focus on siting of carbon dioxide pipelines and storage facilities.

Third, we recommend that the Commonwealth of Pennsylvania conduct a series of public engagements to learn what sort of carbon transport and storage developments people in the region as a whole want and what their concerns are. One such model is the deliberative polling used by the Texas Public Utility Commission in the late 1990s when planning their electricity development.[182] Public input should guide decisions about the scale and location of

[181] Diane McFarlane, "New Analysis: Carbon Capture and Storage Infrastructure for Midcentury Decarbonization," Great Plains Institute, Accessed June 2, 2021.https://www.betterenergy.org/blog/new-analysis-carbon-capture-and-storage-infrastructure-for-midcentury-decarbonization/

[182] R.L. Lehr, W. Guild, D.L. Thomas, and B.B. Swezey, "Listening to Customers: How Deliberative Polling Helped Build 1,000 MW of Renewable Energy Projects in Texas," National Renewable Energy Laboratory NREL/TP-620-33177, June 2003. https://www.nrel.gov/docs/fy03osti/33177.pdf

developments, monitoring and enforcement of environmental impact of CO_2 and hydrogen infrastructure, and safety and liability.

A final critical issue is who pays for and who owns CCUS infrastructure. There are many possible models, from complete public finance and management to complete private finance and management, and there are examples of each currently operating in the US. [183] It is likely that there will need to be a public-private partnership for the development of pipelines and storage facilities. An immediate, practical difficulty for southwest Pennsylvania, and Central Appalachia generally, is that there has been little or no private development in carbon transportation and storage. Public financing and management may be necessary to jump start the development of CCUS in Southwest Pennsylvania and to achieve economies of scale. The Carbon Management Task Force should propose a financing and management model that works for this region.

Conclusion

By all accounts, the economic opportunities for Southwest Pennsylvania created by the development of Marcellus natural gas will continue to grow for the next 5 to 10 years. All scenarios considered by the Roosevelt Project and by other studies predict increases in gas production in the region in the near-term.

Beyond that time, the trajectory for the region's energy and industrial sectors is less clear. These sectors are highly dependent on other states' policies. Most of the natural gas produced in the region is exported to other states, including New York, New Jersey, Ohio, and Maryland. If other states adopt low-carbon requirements or develop alternative energy sources, the demand for Pennsylvania natural gas will fall. That is precisely what drives the pessimistic forecasts of many models of the future energy industry in the state, including the REMI forecast of the Roosevelt Project.

Carbon capture and hydrogen offer southwest Pennsylvania two extremely promising pathways for the long-term development of fossil fuel resources in-line with increasing global demand for low-carbon fuels and products. The region has the opportunity to create an innovation hub that will foster entirely new industries around CCUS and hydrogen production. Setting a new course for the development of natural gas and coal use in Pennsylvania will take foresight, planning, and investment, and those efforts will need to begin soon for the region's fossil fuels to remain competitive in a carbon constrained world.

[183] Heather Greenley, "The Strategic Petroleum Reserve: Background, Authorities, and Considerations," Congressional Research Service Report R46355, May 13, 2020. https://crsreports.congress.gov/product/pdf/R/R46355/2

Chapter 5

Revitalizing Communities with Diversification in Clean Energy and Related Advanced Manufacturing

Kathleen Araújo, Yiran He

Introduction

If 19th century Pittsburgh industrialists George Westinghouse or Andrew Carnegie looked at southwestern Pennsylvania today, they would see a region that has led industrial booms in steel, coal, oil, nuclear power and natural gas. The currently diversified economy is led by healthcare, but energy and manufacturing are significant. The region has the potential to leverage the adaptive capacity of its workforce, research and educational hubs, as well as its entrepreneurial ecosystem to take advantage of the low carbon transition that is underway.[184] Clean energy and related advanced manufacturing are the sectors that will be most directly affected by energy and environmental policies, so they are examined here. The clean energy sector will grow as low carbon policies come online. The manufacturing sector is more complex. Much existing manufacturing, such as metals and petrochemicals, may be adversely affected by low carbon policies, but other sectors, such as advanced and additive manufacturing, have potential to get a boost. How the region positions its energy and manufacturing bases as low carbon priorities evolve remains to be seen. A key will be to prime the region's workforce expertise and supply chain strategically with the markets that are emerging.

This chapter focuses on the status, potential and what may be needed for clean energy and related manufacturing in the region for the next 30 years. For the purposes of this analysis, *clean energy* includes renewables, nuclear energy, grid modernization, efficiency and weatherization. Related *clean and associated advanced manufacturing* includes traditional manufacturing or newer manufacturing that integrates less carbon-intensive processes and/or less inputs. The chapter begins with clean energy and is followed by related manufacturing.

Clean Energy

Solar Power

Solar power is booming in the US and the trends are no different in Pennsylvania.[185] In the last decade, installed solar power capacity increased nationally by an average annual rate of 42%, while within Pennsylvania, similar capacity grew by more than a factor of five from 2010 to

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[184] For more on low carbon change, *see* National Academies, Accelerating Decarbonization in the United States, Report, 2020; K. Araújo, *Low Carbon Energy Transitions: Turning Points in National Policy and Innovation*. (New York: Oxford University Press, 2017).

[185] This is due to declining costs, federal policies like the investment tax credit, plus private and public sector demand for clean electricity. Prices decreased by 70+% in the last decade. For this and related development, *see* "Solar Industry Research Data," Solar Energy Industry Associations (Solar Energy Industry Associations), accessed July 2, 2021, https://www.seia.org/solar-industry-research-data.

2020,[186] representing about 6% of the state's renewable electricity in 2019.[187] During this time, Allegheny County became a leading solar county for installations and installed capacity, as the market grew across the state.[188] Large retailers, including IKEA, Johnson and Johnson, and Crayola, as well as cultural-educational centers, such as the Philadelphia Eagles Stadium, are among local, solar power adopters.[189] Penn State University, the University of Pittsburgh, and the city of Philadelphia now have power purchase agreements for solar power.[190] Farmers, including the Amish, are also notable among those adopting solar power.[191]

Closer inspection of Pennsylvania's solar market shows that nearly half of Regional Transmission Organization PJM's approval queue is solar projects.[192] Pennsylvania's solar industrial base also currently consists of 395 companies, with clusters in southwestern Pennsylvania and southeastern Pennsylvania, and jobs estimated at 4,310.[193] The industrial base appears to be comprehensive; however, there is not enough in-state labor to support a larger boom,[194] so a review and realignment of training programs is recommended.

Potential areas exist for repurposing with solar power at, for instance, retired power plant sites, where the power infrastructure is 'plug and play' ready. To attract new investment, the Pennsylvania Department of Community and Economic Development has been developing 'playbooks' to provide redevelopment assessments for former power plant sites.[195] The former Talon Coal Plant site in Sudbury is one example where a 300 MW solar project is being built.

In policy terms at the state-level, there is a net metering program and solar renewable energy credits (SRECs).[196] A limited solar carve out of 0.5% expired in May 2021 with the Alternative Energy Portfolio Standard (AEPS). To date, Pennsylvania utility rules do not allow community solar installations.[197] However in March 2021, bipartisan state legislation was introduced to

[186] Ibid.

[187] "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis," Pennsylvania - State Energy Profile Analysis (U.S. Energy Information Administration (EIA), accessed July 2, 2021, https://www.eia.gov/state/analysis.php?sid=PA.

[188] Interview, 2021.

[189] "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis," Pennsylvania - State Energy Profile Analysis (U.S. Energy Information Administration (EIA), accessed July 2, 2021, https://www.eia.gov/state/analysis.php?sid=PA; Interview, 2021.

[190] Interview, 2021.

[191] Crable, Ad. "Lancaster County tops in state for renewable energy and solar panels." *LancasterOnline*, October 22, 2016. https://lancasteronline.com/news/local/lancaster-county-tops-in-state-for-renewable-energy-and-solar-panels/article_06a92342-97ca-11e6-beb9-7fe1f32049a5.html; Robinson, Ryan. "Amish lead the way in solar power." *LancasterOnline,* October 3, 2013. https://lancasteronline.com/news/amish-lead-the-way-in-solar-power/article_0c04761d-2aed-5f85-a983-3f952d6b769f.html.

[192] "Planning," PJM, accessed July 2, 2021, https://www.pjm.com/planning.

[193] "Pennsylvania Solar," Solar Energy Industry Associations (Solar Energy Industry Associations), accessed July 2, 2021, https://www.seia.org/state-solar-policy/pennsylvania-solar.

[194] Interview, 2021.

[195] DCED, Coal-Fired Power Plant Redevelopment Playbooks (n.d.), https://dced.pa.gov/programs-funding/coal-plant-redevelopment-playbooks/

[196] "Pennsylvania Rebates and Incentives Help You Save on Solar," Energy Sage (Energy Sage), accessed July 2, 2021, https://www.energysage.com/local-data/solar-rebates-incentives/pa/; "Solar Alternative Energy Credits," DSIRE (NC Clean Energy Technology Center), accessed July 2, 2021, https://programs.dsireusa.org/system/program/detail/5682.

[197] Kelsey Misbrener et al., "Pennsylvania Senate Considers Bipartisan Community Solar Legislation," Solar Power World, March 25, 2021, https://www.solarpowerworldonline.com/2021/03/pennsylvania-senate-considers-bipartisan-community-solar-legislation/.

allow such projects.[198] Analysis by Pennsylvania State University indicates that new construction of community solar projects would generate roughly $1.8 billion in economic gains, create over $793 million in labor income, and support over 11,000 jobs in various sectors across the Commonwealth. Once operational, these projects would annually generate about $83+ million in economic output and support 520 full-time jobs in Pennsylvania, plus an additional $574,260 in annual property tax collections for municipalities in 48 rural and urban counties.[199]

In September 2021, Pennsylvania cleared one of the final hurdles to join the Regional Greenhouse Gas Initiative (RGGI), a regional cap and trade system that sets a limit and utilizes a market for trading GHG emissions certificates.[200] Joining RGGI provides conditions that would allow low carbon energy, like renewables and potentially nuclear, to thrive in Pennsylvania. However, the measure is challenged by political gridlock and what may be described as the favoring of the natural gas industry.

Beyond RGGI, Governor Wolf also announced one of the largest state government procurement commitments to solar energy as part of his GreenGov challenge. Pennsylvania will source 50% of the state government electricity from solar power (361,000 MWh/year; 191 MW) to be operational by January 1, 2023.[201]

The above measures align with the federal policy support that was announced in early 2021 by the Biden Administration for a federal clean electricity standard of 100% carbon free power by 2035; a mandate for system modernization; R&D for demonstration; renewable tax credits/investment tax credits to attract investment in large transmission projects to electricity demand hubs (at least 20 GW of high-voltage capacity power lines), connecting regions with solar and wind resources to electricity demand hubs; and the removal of fossil fuel subsidies and tax incentives.[202] As of September 2021, such support is making its way through Congress as lawmakers continue to debate provisions.[203]

Wind Power

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198 Ibid.

199 Kelsey Misbrener, "Penn State study finds opening community solar market could generate $1.8 billion in economic impact for Pennsylvania," Solar Power World, October 13, 2020, https://www.solarpowerworldonline.com/2020/10/penn-state-study-new-community-solar-projects-economic-impact/.

200 "PennLive, What is a RGGI? A PennLive primer on Gov. Wolf's big move on climate change policy," Penn Live, Oct 4, 2019, https://www.pennlive.com/news/2019/10/what-is-a-rggi-a-pennlive-primer-on-gov-wolfs-big-move-on-climate-change-policy.html.

201 "Gov. Wolf Announces Largest Government Solar Energy Commitment in the U.S.," Pennsylvania Government March 22, 2021, https://www.governor.pa.gov/newsroom/gov-wolf-announces-largest-government-solar-energy-commitment-in-the-u-s/

202 "FACT SHEET: The American Jobs Plan," The White House (The United States Government, May 4, 2021), https://www.whitehouse.gov/briefing-room/statements-releases/2021/03/31/fact-sheet-the-american-jobs-plan/; Herman K. Trabish, "Biden's $2.3 trillion infrastructure plan meets power system needs but leaves room for political dealing," Utility Dive, April 28, 2021, https://www.utilitydive.com/news/bidens-23-trillion-infrastructure-plan-meets-power-system-needs-but-lea/598587/.

203 Hagen, Lisa. "The Changing Climate on Capitol Hill," *U.S. News & World Report,* September 10, 2021, https://www.usnews.com/news/the-report/articles/2021-09-10/lawmakers-consider-climate-change-amid-backdrop-of-hurricanes-heat-waves

Similar to solar power, wind power is experiencing rapid growth globally and nationally. Despite the COVID 19 global pandemic, the global wind industry recorded its strongest year ever in 2020 with a record 93GW of new capacity additions, equal to a 53% increase.[204] In the US, wind power has grown by more than a factor of 50 between 2000 and 2020 to 338 billion kWh.[205] The US is also the home to one of the largest and fastest-growing wind markets in the world. [206]

Specific to Pennsylvania, the Commonwealth has a manufacturing hub that includes 30 manufacturing facilities which are focused on components.[207] Pennsylvania also has an estimated 1,459 MW of wind power generation installed, and 90 MW under construction.[208] At least 27 wind farms provide electricity to power nearly 350,000 Pennsylvania homes, with almost 3,000 people employed in the wind energy field.[209] Beyond Pennsylvania's existing base, there is potential within the Commonwealth to expand its onshore wind market from the currently installed capacity of approximately 1,500 MW to 109,000 MW, in addition to targeting a much broader market in the Eastern U.S. region.

If energy-related legislation for infrastructure and jobs is passed with the current Congress, alongside additional policy for offshore wind (detailed below), a surge in wind power adoption is expected, particularly within the Eastern US. The Commonwealth's wind industry and adjacent industries in steel, materials and coatings are positioned to support increased demand. Even if the in-state adoption remains flat, new expansion in the region and nationally allows Pennsylvania to export equipment, lubricants and services to out-of-state customers.

Offshore Wind Deployment Potential: The US is primed for considerable, near-term development in offshore wind. Based on significant technical potential,[210] falling technology costs, energy

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204 "Global Wind Report 2021," Global Wind Energy Council (Global Wind Energy Council, April 30, 2021), https://gwec.net/global-wind-report-2021/.

205 "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis," Electricity generation from wind - U.S. Energy Information Administration (EIA), accessed July 2, 2021, https://www.eia.gov/energyexplained/wind/electricity-generation-from-wind.php#:~:text=Electricity%20generation%20with%20wind&text=Total%20annual%20U.S.%20electricity%20generation,U.S.%20utility%2Dscale%20electricity%20generation.

206 "Wind," Department of Energy (Department of Energy), accessed July 2, 2021, https://www.energy.gov/science-innovation/energy-sources/renewable-energy/wind.

207 Interview, 2021. Workforce Development Needs Assessment & Gap Analysis, (Pennsylvania: BW Research Partnership, April 2021), https://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/2021CleanEnergyGapAnalysis/PA_2021_Clean_Energy_Gap_Analysis_Report.pdf.

208 "Wind Energy in Pennsylvania," WIND Exchange (U.S. Department of Energy), accessed July 2, 2021, https://windexchange.energy.gov/states/pa.

209 "Wind Power," Department of Environmental Protection (Department of Environmental Protection), accessed May 29, 2021, https://www.dep.pa.gov/Business/Energy/Wind/Pages/default.aspx.

210 A 2016 DOE-DOI study indicates that U.S. offshore wind has a technical resource potential of more than 2,000 GW of capacity, or 7,200 TWh of generation per year -- nearly double the nation's electricity use.
"National Offshore Wind Strategy: Facilitating the Development of the Offshore Wind Industry in the United States," U.S. Department of Energy (U.S. Department of Energy), accessed July 2, 2021, https://www.energy.gov/eere/wind/downloads/national-offshore-wind-strategy-facilitating-development-offshore-wind-industry.
A companion study found that developing just 86 GW, or about 4% of the U.S. offshore wind technical resource potential by 2050 would support 160,000 jobs.

demand linked to high population centers plus limited onshore space, the East and West Coasts of the US are recognized as key markets for growth.[211]

The region surrounding Pennsylvania has been actively engaged in developing offshore wind projects, including the Great Lakes region which Pennsylvania borders.[212] Recognizing the enormous opportunity for jobs, industry and clean energy, the Biden Administration launched an ambitious plan to catalyze the nascent offshore wind industry with a goal to generate 30 GW of offshore wind by 2030. With it, the Administration aims to streamline and accelerate permitting, invest in R&D, provide low-interest loans to industry and fund changes to ports.[213] *For the offshore wind market, southwestern Pennsylvania could leverage its capabilities in steelmaking and materials; deploy electrical experts; and produce components, materials, coatings and lubricants. Joint ventures with already engaged companies, like many in New Jersey, would provide Pennsylvania industries an on-ramp to the market that has been preparing for years. Pennsylvania workforce strategies should also leverage unions across the Eastern Seaboard states for reskilling and points of access.*

Onshore Wind Deployment Potential: There is limited policy in place today to support wind power deployment in Pennsylvania. In terms of adoption targets, the AEPS (as noted with solar power) expired in May 2021, and questions remain about whether the State will put forward a new and more robust target for wind power. The most promising policy driver at the commonwealth level currently is entry into RGGI.

Looking back at an earlier wind power surge in Pennsylvania 2005-2012, the state had engaged in targeted outreach to companies to site their facilities in-state. Today, this type of strategy would be advantageous to mobilize local capabilities in manufacturing of wind technology components, materials and lubricants; and a local workforce to support the build-out in the regional markets. *The region's union and technical capabilities could be leveraged in the anticipated, regional and national wind build-out. If national/regional transmission modernization and expansion occur in connection with offshore wind and/or other infrastructure aims, southwestern Pennsylvania unions and capabilities could enable such efforts.*

Hydropower

Wind Vision, (Washington D.C.: Department of Energy, March 2015), https://www.energy.gov/sites/prod/files/WindVision_Report_final.pdf

[211] "Computing America's Offshore Wind Energy Potential." US Department of Energy. Last modified September 6, 2016. https://www.energy.gov/eere/articles/computing-america-s-offshore-wind-energy-potential; McClellan, Stephanie. *Supply Chain Contracting Forecast for U.S. Offshore Wind Power.* University of Delaware, 2019. https://sites.udel.edu/ceoe-siow/files/2020/01/SIOW-White-Paper-Supply-Chain-Contracting-Forecast-for-US-Offshore-Wind-Power-FINAL.pdf; *Offshore*. "US offshore wind energy market could reach $70 billion." February 21, 2020. https://www.offshore-mag.com/field-development/article/14168420/us-offshore-wind-energy-market-could-reach-70-billion; "US Market Overview." Business Network for Offshore Wind. Last modified October 18, 2018. https://www.offshorewindus.org/about-offshore-wind/usmarketoverview/.

[212] Interview, 2021.

[213] Eilperin, J. and Dennis, B. "Biden Administration Launches Major Push to Expand Offshore Wind Power," *Washington Post*, March 29, 20121, https://www.washingtonpost.com/climate-environment/2021/03/29/biden-wind-power/; "Energy Secretary Granholm Announces Ambitious New 30GW Offshore Wind Deployment Target by 2030," U.S. Department of Energy (U.S. Department of Energy), accessed July 2, 2021, https://www.energy.gov/articles/energy-secretary-granholm-announces-ambitious-new-30gw-offshore-wind-deployment-target.

As with solar and wind power, Pennsylvania is home to a hydropower hub. The state has two global manufacturers of hydroelectric equipment: Voith Hydro and Weir American Hydro,[214] and as of 2015, the Commonwealth was a base for 250+ companies in the hydroelectric industry supply chain, accounting for over 5,000 jobs.[215] The locally-based hydropower hub positions Pennsylvania to supply equipment for an increase in hydropower demand or modernization that may be driven by clean energy priorities. While most domestic hydropower expansion tapered off since the 1990s, prospective domestic capacity growth could occur with efficiency improvements at existing dams, the expansion of pumped hydro storage, and the installation of power generating equipment at existing locks and dams that were constructed for other purposes (e.g., river navigation, flood control, etc.).[216]

Pennsylvania also has untapped potential for hydropower from its 83,000 miles of streams and rivers, as well as existing infrastructure for industry and water treatment.[217] Currently, Pennsylvania has 892 MW of conventional hydropower and 1,583MW of pumped storage hydropower capacity.[218] A 2014 DOE study by Oak Ridge National Lab found that Pennsylvania ranked 6th nationally in terms of hydropower potential, with an estimated 679 MW of untapped capacity available by using existing water control infrastructure.[219] Such projects include the Allegheny Lock and Dam No. 2 for which the University of Pittsburgh committed to purchasing 100% of power output.[220] Importantly, the above potential doesn't account for hydropower applications at municipal or privately-owned dams, conduits, and other water features. It also does not include increases in efficiency and generating capacity at existing powered dams.

According to the Army Corps of Engineers and National Hydropower Association, there are 24 non-powered dams (used for non-electric purposes) in the Pittsburgh area alone, located along the three major rivers: Allegheny River, Monongahela River and Ohio River, which had been estimated to have potential to generate a total of 904 MW of hydropower capacity. Within this, approximately 520 MW is deemed economically feasible.[221]

Specific to the southwestern Pennsylvania region in 2021, Allegheny County and the University of Pittsburgh are committing to new hydropower. Allegheny County expects to buy roughly 40%

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214 Alternative Energy Portfolio Standards Act Compliance for Reporting Year 2019, (Pennsylvania: PA DEP, 2019), https://www.pennaeps.com/wp-content/uploads/2020/09/2019-AEPS-Annual-Report.pdf.

215 "Low-Impact Hydropower," Pennsylvania Environmental Council (Pennsylvania Environmental Council, November 15, 2017), https://pecpa.org/program/hydropower-permitting/.

216 "ITA Top Markets Series," International Trade Administration (International Trade Administration), accessed July 2, 2021, https://legacy.trade.gov/topmarkets/.

217 "Low-Impact Hydropower," Pennsylvania Environmental Council (Pennsylvania Environmental Council, November 15, 2017), https://pecpa.org/program/hydropower-permitting/.

218 "Hydro-electric Power," Pennsylvania Environmental Council (Pennsylvania Environmental Council), accessed July 2, 2021, https://www.dep.pa.gov/Citizens/Energy/Renewables/Pages/Hydroelectric.aspx.
'Pumped storage hydropower produces electricity to supply high peak demands by moving water between reservoirs at different elevations. At times of low electrical demand, the excess generation capacity is used to pump water into the higher reservoir. When the demand becomes greater, water is released back into the lower reservoir through a turbine.'

219 Oak Ridge National Laboratory, U.S. Department of Energy (2014). New Stream-reach Development: A Comprehensive Assessment of Hydropower Energy Potential in the United States.

220 "University of Pittsburgh to Purchase Local Hydropower," University of Pittsburgh, November 29, 2018, http://www.news.pitt.edu/news/university-pittsburgh-purchase-local-hydropower.

221 Hydropower resource assessment at Non-powered USACE sites (2013). Portland, OR: U.S. Army Corps of Engineers, HDC; https://www.hydro.org/wp-content/uploads/2020/07/Dang-Full-Report-PA-NPDs.pdf

of the electricity that is generated from a 17.8-megawatt (MW) plant which Rye Development will build at the Emsworth Locks and Dams on the Ohio River around Pittsburgh.[222] This reflects new hydropower on existing dam infrastructure. The University of Pittsburgh also plans to purchase all the power that will be produced by an 11 MW Rye plant planned for the Allegheny River near the Highland Park Bridge.[223] In total, Rye will develop 10 hydropower projects in the region.[224]

Nuclear Energy

Nuclear energy has played a critical role in the Commonwealth's long-standing history as a technology leader. Pennsylvania is the home of the 1st commercial U.S. nuclear power plant in Shippingport.[225] The Keystone State is also the headquarters for Westinghouse, a major global player in nuclear technology, which has been restructuring after emerging from bankruptcy. The company's strategic focus today centers on new builds with the AP1000 design and commercializing the eVinci microreactor design. Westinghouse was recently also listed as a DOE contract vendor among a pool of vendors to support deactivation, decommissioning and removal services for a 10-year period and a maximum award value of $3 billion.[226]

Looking beyond its first commercial nuclear plant and Westinghouse, the Pennsylvania nuclear ecosystem consists of key actors from national labs and academia. It is home to the Bettis Atomic Power Lab/Nuclear Naval Lab, a U.S. leader in creating the nuclear navy. In addition, Penn State has one of the earliest nuclear engineering programs in the country,[227] supporting the workforce needs of utilities, national labs, and the broader industry, with recent programming adapted to include safeguards, nuclear medicine, etc.

In March 2021, nuclear generation was the second largest fuel in Pennsylvania's electricity mix at 33% of the total (Appendix). Despite a strong track record for nuclear energy, Pennsylvania has been experiencing, along with other states within the US, early retirement of nuclear plants that are based within competitive markets. Such plants are being shut down ahead of their licensed life because exceptionally low-cost natural gas and increasingly competitive renewables (without subsidies) are out-competing nuclear energy.[228]

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222 Adam Smeltz, "New Hydroelectric Facility on Ohio River to Power County Government Operations," Pittsburgh Post-Gazette (Pittsburgh Post-Gazette, June 10, 2021), https://www.post-gazette.com/local/region/2021/01/28/Allegheny-County-government-hydroelectric-generation-Emsworth-Locks-Dams-Ohio-River-Rye-Development/stories/202101280159.

223 Bill Schackner, "Pitt Planning to Buy All Power Generated from Planned Hydroelectric Plant," Pittsburgh Post-Gazette (Pittsburgh Post-Gazette, November 29, 2018), https://www.post-gazette.com/business/powersource/2018/11/29/University-of-Pittsburgh-Pitt-sustainable-renewable-energy-hydroelectric-Rye-Development-environment/stories/201811290092.

224 Adam Smeltz, "New Hydroelectric Facility on Ohio River to Power County Government Operations," Pittsburgh Post-Gazette (Pittsburgh Post-Gazette, June 10, 2021), https://www.post-gazette.com/local/region/2021/01/28/Allegheny-County-government-hydroelectric-generation-Emsworth-Locks-Dams-Ohio-River-Rye-Development/stories/202101280159.

225 Pennsylvania's plant was by some accounts, the world's first full-scale nuclear power plant devoted to peacetime use. "December 23, 1957: Shippingport." US Department of Energy. Accessed July 2, 2021. https://www.energy.gov/management/december-23-1957-shippingport.
"History." Nuclear Powers Pennsylvania. Last modified July 18, 2017. https://nuclearpowerspennsylvania.com/issue/history/.

226 "Westinghouse Awarded U.S. Department of Energy Contract," Westinghouse Electric Company, July 6, 2020, https://info.westinghousenuclear.com/news/westinghouse-awarded-u-s-department-of-energy-contract.

227 Marcus, G. *Nuclear Firsts: Milestones on the Road to Nuclear Power Development.* (La Grange Park, Il: ANS, 2010).

228 "Nuclear and Coal Will Account for Majority of U.S. Generating Capacity Retirements in 2021 - Today in Energy - U.S. Energy Information Administration (EIA)," U.S. Energy Information Administration (U.S. Energy Information Administration), accessed July 2, 2021, https://www.eia.gov/todayinenergy/detail.php?id=46436.

To some observers,[229] the nuclear industry in Pennsylvania is riding out a downturn, tied in part to the premature closure of Three Mile Island (TMI) Unit 1 and a national slow-down of nuclear adoption. The Pennsylvania nuclear industry sought state support with Zero Emission Credits (ZECs), similar to ones used in New York and Illinois to value the stable and low carbon, baseload power that nuclear energy supplies. Pennsylvania's decision to pass on the ZEC support means the industry is functioning, but below the radar.

Despite the downturn, there are signs of traction for nuclear energy in new applications, and research and development. Bitcoin mining, for example, is an industrial application that is emerging in Pennsylvania in connection to nuclear energy. Joint ventures are being formed between cryptocurrency companies and nuclear plant owners to provide electricity that is necessary to run the energy-intensive computer centers that mine the virtual currency.[230] Integrated nuclear systems are also receiving attention for applications such as with hydrogen production, utilization and storage.[231] Exelon, for example, the nation's largest nuclear power generator with plants in Pennsylvania and other states, was awarded $7.2 million in partnership with Nel Hydrogen to demonstrate an integrated facility at an existing nuclear plant site.[232] Beyond crypto-currency mining and hydrogen production, an international competition is underway to commercialize advanced nuclear technology with small modular reactor (SMR) and microreactor designs.[233] Pittsburgh- headquartered Westinghouse has one of the designs to watch in this potentially disruptive playing field.[234] In 2020, Westinghouse was awarded $9.3 million by the DOE Advanced Reactor Demonstration Program to advance eVinci's design of a heat pipe-cooled microreactor to support demonstration by 2024 and to develop an economically viable refueling process, among other factors.[235]

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[229] Interviews, Spring 2021.

[230] Bitcoin is a peer-to-peer virtual currency that operates without a central authority, and which can be exchanged for traditional currency.
Maykuth, Andrew. "Zero-carbon bitcoin? The owner of a Pennsylvania nuclear plant thinks it could strike gold." *Philadelphia Inquirer,* August 6, 2021. https://energycentral.com/news/zero-carbon-bitcoin-owner-pennsylvania-nuclear-plant-thinks-it-could-strike-gold.

[231] Darrell Proctor, "Hydrogen from Nuclear Power Test Set at Idaho Lab," POWER Magazine (POWER Magazine, May 18, 2021), https://www.powermag.com/hydrogen-from-nuclear-power-test-set-at-idaho-lab/.

[232] Sonal Patel, "Exelon Is Exploring Nuclear Power Plant Hydrogen Production," POWER Magazine (POWER Magazine, August 29, 2019), https://www.powermag.com/exelon-is-exploring-nuclear-power-plant-hydrogen-production/?itm_source=parsely-api.

[233] In line with this, the U.S. Government identified advanced nuclear as a strategic priority with enabling legislation and notable R&D awards or cost-sharing. https://energycentral.com/c/ec/dod-awards-39m-three-firms-design-microreactors; Nuclear Energy Innovation Capabilities Act of 2017 (NEICA, P.L. 115-248); Nuclear Energy Innovation and Modernization Act (NEIMA, P.L. 115-439). Recent Congressional budgets have appropriated considerable funding for advanced nuclear development. CRS, Advanced Nuclear Reactors, April 18, 2019, R45706, https://crsreports.congress.gov/product/pdf/R/R45706. *See also* D. Shropshire et al., Global Market Analysis of Microreactors, INL/EXT 21-01302 Report, June 2021; G. Black et al., "Small Modular Reactor Adoption: Opportunities and Challenges for Emerging Markets," in *The Handbook of Small Modular Reactors.* Eds. D. Ingersoll, and M. Carelli (Cambridge, MA: Woodhead/Elsevier, 2020); "IAEA Discusses Opportunities and Challenges of Microreactors," Nuclear Engineering International (Nuclear Engineering International), accessed July 2, 2021, https://www.neimagazine.com/news/newsiaea-discusses-opportunities-and-challenges-of-microreactors-8718789.

[234] Ibid.

[235] "Energy Department's Advanced Reactor Demonstration Program Awards $30 Million in Initial Funding for Risk Reduction Projects," *Office of Nuclear Energy*, December 16, 2020, https://www.energy.gov/ne/articles/energy-department-s-advanced-reactor-demonstration-program-awards-30-million-initial.

A development of relevance to Pennsylvania's nuclear industry may be seen in coal-rich Wyoming. Like southwestern Pennsylvania, Wyoming is a state that is encountering challenges with declines in coal mining. In June 2021, Wyoming announced that it would site a demonstration project for Terrapower's SMR design at a former coal plant.[236] Terrapower was awarded $80 million in initial funding by the DOE in October 2020 to construct and demonstrate its advanced nuclear reactor design.[237] Pennsylvania, with its existing nuclear hub and history, may diversify its nuclear technology activity with SMR/micoreactor demonstration.

In policy terms, Pennsylvania passed on support of the local nuclear industry with Zero Emission Credits, yet if the Commonwealth joins RGGI, the remaining eight nuclear plants may sustain. In fact, the announced closure of the twin-unit 1,872-MW Beaver Valley Nuclear Power Station in Shippingport, Pennsylvania that employs 1,000 people was reversed by Energy Harbor Corporation when Governor Wolf announced his intention for Pennsylvania to join RGGI.[238] This industry and market are by no means written off, but are ones to watch.

Bioenergy

Pennsylvania produces several forms of bioenergy: biomass and biogas-based combustion for heat and power production, and biofuels for transport. As a state with agriculture as a cornerstone to its economy,[239] Pennsylvania's production and use of bioenergy leverages its agriculture strengths.

Pennsylvania ranks among the top states for electricity generated from biomass.[240] Pennsylvania also ranks 9th for biogas production potential, up to 45.54 billion cubic feet of renewable methane from biogas each year. For the period from 2000 to 2018, Pennsylvania biogas production increased by a factor of 8.[241] Biogas is produced with anaerobic digesters at dairy, poultry, and swine farms; water resource recovery facilities; food scrap systems; and with gas at landfills where flaring is done. [242] Penn State was recently awarded a USDA grant with Iowa State to conduct research on ways to optimize this agriculture-energy process.[243] In the

236 "Bill Gates' Terrapower to build reactor demo project in Wyoming," Power Engineering International, June 3, 2021, https://www.powerengineeringint.com/nuclear/bill-gates-terrapower-to-build-reactor-demo-project-in-wyoming/.

237 "Energy Department's Advanced Reactor Demonstration Program Awards $30 Million in Initial Funding for Risk Reduction Projects," *Office of Nuclear Energy*, December 16, 2020, https://www.energy.gov/ne/articles/energy-department-s-advanced-reactor-demonstration-program-awards-30-million-initial.

238 Darrell Proctor, "Pennsylvania Move to Join RGGI May Save Nuclear Plant," POWER Magazine (POWER Magazine, March 15, 2020), https://www.powermag.com/pennsylvania-move-to-join-rggi-may-save-nuclear-plant/.

239 In 2021, Pennsylvania reported the state's agriculture's economic impact equaled $132.5 billion annually with more than 590,000 jobs paying nearly $33 billion in wages per year.
Team Pennsylvania. *The Economic Impact of Agriculture in Pennsylvania: 2021 Update.* PA Department of Agriculture, 2021. https://teampa.com/wp-content/uploads/2021/04/TeamPA_Agriculture2020EISUpdate_FINAL-1.pdf.

240 "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis," Pennsylvania - State Energy Profile Analysis (U.S. Energy Information Administration), accessed July 2, 2021, https://www.eia.gov/state/analysis.php?sid=PA.

241 *Energy Assessment Report for the Commonwealth of Pennsylvania,* (Pennsylvania: Department of Environmental Protection, April 16, 2018), https://files.dep.state.pa.us/Air/AirQuality/AQPortalFiles/Advisory%20Committees/CCAC/2018/4-24-18/DRAFT%20PA%20Energy%20Assessment%20Report.pdf.

242 "Biogas Market Snapshot," American Biogas Council (American Biogas Council, June 23, 2020), https://americanbiogascouncil.org/biogas-market-snapshot/.

243 Daniel Ciolkosz, "Penn State Extension to Explore New Frontiers in Biogas," Penn State Extension, June 27, 2021, https://extension.psu.edu/penn-state-extension-to-explore-new-frontiers-in-biogas.

southwestern Pennsylvania region, biogas production occurs on farms. As is discussed in a later section on Urban-Rural Considerations, there is potential for expansion in biogas production.

Specific to its biofuels profile, Pennsylvania's single ethanol production plant is the largest on the East Coast, with a capacity of about 128 million gallons per year.[244] As of May 29, 2021, Pennsylvania has 1 biodiesel fueling station (20% biodiesel and above) and 146 E85 (85% ethanol) fueling stations.[245] The Commonwealth ranks sixth in annual fuel ethanol consumption of 488 million gallons. [246] Within Pennsylvania, ethanol consumption increased by a factor of 35 from 2000 to 2018, primarily driven by the ethanol mandate provision in the Energy Independence and Security Act of 2007.[247] Pennsylvania also has two biodiesel manufacturing plants that can produce 90 million gallons annually, and it is the 11th largest biodiesel-consuming state at nearly 40 million gallons a year.[248]

Specific to policies and research, the Commonwealth has measures in place to encourage bioenergy development. It has blending mandates for biodiesel and cellulosic ethanol based on specific fuel production attainment schedules; an alternative fuel tax; and an alternative fuels incentive grant program.[249] In the Pittsburgh region, drivers in the summer must use motor gasoline that has lower evaporative emissions, which is favorable for biofuels.[250] Specific to industrial and university research, Erie-based biodiesel company Hero BX has invested in Penn State's Advanced Manufacturing and Innovation Center for a biofuels lab.[251] As Pennsylvanian ethanol imports have been increasing, farmers in southwestern Pennsylvania may have potential to scale their output for biofuels production.

Hydrogen

As has been discussed earlier,[252] hydrogen production is a potential gamechanger, especially for hard-to-decarbonize industries. Whether the aim is to reduce emissions associated with hydrogen production in existing applications, or to introduce hydrogen as an energy carrier or industrial feedstock in new applications, hydrogen can be produced from fossil fuel (blue hydrogen, if done

[244] U.S. EIA, U.S. Fuel Ethanol Plant Production Capacity (August 26, 2019); U.S. EIA, State Energy Data System, Table F25, Fuel ethanol consumption estimates, 2018.

[245] "Alternative Fueling Station Counts by State," Alternative Fueling Station Counts by State (Alternative Fuels Data Center), accessed July 2, 2021, https://afdc.energy.gov/stations/states.

[246] U.S. EIA, Monthly Biodiesel Production Report (July 31, 2020), Table 4; U.S. EIA, State Energy Data System, Table F26, Biodiesel Consumption Estimates, 2018.

[247] Energy Assessment Report for the Commonwealth of Pennsylvania, (Pennsylvania: Department of Environmental Protection, April 16, 2018), https://files.dep.state.pa.us/Air/AirQuality/AQPortalFiles/Advisory%20Committees/CCAC/2018/4-24-18/DRAFT%20PA%20Energy%20Assessment%20Report.pdf

[248] U.S. EIA, Monthly Biodiesel Production Report (July 31, 2020), Table 4; U.S. EIA, State Energy Data System, Table F26, Biodiesel Consumption Estimates, 2018.

[249] "Alternative Fueling Station Counts by State," Alternative Fueling Station Counts by State (Alternative Fuels Data Center), accessed July 2, 2021, https://afdc.energy.gov/stations/states.

[250] U.S. Environmental Protection Agency, Gasoline Standards, Programs, Reformulated gasoline and Reid vapor pressure; Larson, B. (January 2018), U.S. Gasoline Requirements, ExxonMobil.

[251] "Biofuels Lab Opens at Penn State Behrend," Penn State Extension (Penn State Extension, June 25, 2021), https://extension.psu.edu/biofuels-lab-opens-at-penn-state-behrend.

[252] *See* Chapter 4.

with carbon capture and sequestration), renewables (green hydrogen) and nuclear energy (pink hydrogen).

In 2021, the first green hydrogen plant will be built in Pennsylvania's Lancaster County on the Susquehanna River.[253] Plug Power is partnering with dam operator Brookfield Renewable Partners to use power from hydroelectricity and Susquehanna River water to produce 15 metric tons of liquid hydrogen per day. This is reportedly enough to power 1,500 heavy duty trucks. In line with Penn State University's Hydrogen Energy Center and the above activity, Pennsylvania has elements for becoming a hydrogen leader. It should competitively pursue proposed funding from the Biden Administration for climate research, development and demonstration that includes hydrogen. With such funding, Southwestern Pennsylvania could engage in production of hydrogen, by leveraging hydropower or nuclear power in the region. More broadly, Pennsylvania could leverage its nuclear, hydrogen, combined heat and power and steelmaking (discussed below) capabilities to test and optimize an integrated system of low carbon steel, clean energy and related co-benefits**.**

Grid Modernization and Build-Out

By 2030, the US may require between $30-90 billion in new investment for grid robustness, flexibility, and resilience, and $200-600 by 2050, according to a Brattle Group study.[254] Specific to Pennsylvania and the broader PJM power market, modernizing the grid is increasingly necessary, as transmission equipment continues to age. As of 2019, two-thirds of transmission is more than 40 years old; over one third is more than 50 years old, and some local equipment approaches 90 years old.[255] Modernization is made more urgent by extreme weather, and increased penetration of electric vehicles (EVs) and renewable energy sources. [256] To that end, PJM has initiatives designed to enhance reliability and cost-effectiveness. PJM is planning for the connection of microgrids, distributed energy resources, and offshore wind generation, reporting that $6.4 billion in onshore grid upgrades will be required to accommodate the planned 15.6 GW of offshore wind projects. [257] PJM also plans to increase charging infrastructure for the expected rollout of EVs in the next 5-10 years.[258] With such build-outs, modernization and/or upgrades, opportunities exist for Pennsylvania and its southwestern region in the production of the grid infrastructure materials, as well as the construction and servicing of the grid.

Efficiency, Weatherization, ENERGY STAR, HVAC, and Geothermal Heating

[253] "Pennsylvania's First Green Hydrogen Plant Planned for Lancaster County | StateImpact Pennsylvania," NPR (NPR, April 2, 2021), https://stateimpact.npr.org/pennsylvania/2021/04/02/pennsylvanias-first-green-hydrogen-plant-planned-for-lancaster-county/.

[254] Dr. Jürgen Weiss, J. Michael Hagerty, María Castañer, The Coming Electrification of the North American Economy, (The Brattle Group, March 2019), https://wiresgroup.com/wp-content/uploads/2020/05/2019-03-06-Brattle-Group-The-Coming-Electrification-of-the-NA-Economy.pdf.

[255] *The Benefits of the PJM Transmission System,* (PJM Interconnection, April 16, 2019), https://www.pjm.com/-/media/library/reports-notices/special-reports/2019/the-benefits-of-the-pjm-transmission-system.pdf.

[256] K. Araújo and D. Shropshire, A Meta-Level Framework for Evaluating Resilience in Net-Zero Carbon Power Systems with Extreme Weather Events in the United States, *Energies,* July 2021, https://www.mdpi.com/1996-1073/14/14/4243.

[257] *The Benefits Of The Pjm Transmission System,* (PJM Interconnection, April 16, 2019), https://www.pjm.com/-/media/library/reports-notices/special-reports/2019/the-benefits-of-the-pjm-transmission-system.pdf.

[258] Ibid.

Additional clean energy potential exists with efficiency and associated work in ENERGY STAR products, weatherization, heating, ventilation & air conditioning (HVAC) as well as geothermal heating.[259] Prior to the onset of the pandemic, energy efficiency was the fastest growing job sector in the U.S. energy industry, accounting for nearly half of the entire energy industry's new jobs in 2018.[260] Trends in Pennsylvania align with this estimate, with 10% growth in energy efficiency jobs between 2016 and 2018. In the Commonwealth, 14% of all construction jobs are involved in energy efficiency. The majority of Pennsylvania's nearly 69,000 energy efficiency jobs fall into servicing tied to HVAC (34,994), ENERGY STAR appliances and efficient lighting (14,286), and building materials and insulation (13,105).[261] Primary types of efficiency jobs in Pennsylvania include energy auditors, retrofit installer technicians, crew leaders who manage, and quality control inspectors, among others.[262] For the 13 counties in southwestern Pennsylvania, energy efficiency represented over 16,100 jobs in 2019.[263] Specific to the ENERGY STAR program that is sponsored by the U.S. Government, Pennsylvania has more than 519 businesses and organizations participating, including a manufacturing hub with 81 manufacturers.[264] In southwestern counties of Pennsylvania, this area had nearly 2,350 jobs in 2019.[265] As demand for these products increases, nationally and/or within the state, more job opportunities are expected. The HVAC field includes installation, servicing and repair for the residential, commercial and industrial building. In 2019, the traditional HVAC work had roughly 4,635 jobs in southwestern Pennsylvania. This is seen as a long-term area of service need, with low entry barriers, and flexibility in which to train and work.

Another key area of clean energy build-out is in geothermal heating. Geothermal energy has potential to be tapped in Pennsylvania for direct heating and heat pumping systems.[266] Geothermal resources can be utilized for newer and redeveloped residential and commercial buildings as well as campuses to heat or cool a building or water without burning any fuel or releasing emissions. Large-scale geothermal heat-based systems have been installed in the Commonwealth to replace campus district heating.[267] The installation of geothermal heat systems or pumps is done generally by skilled contractors who could also work in HVAC

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259 Note: Cogeneration or combined heat and power is another form of efficient energy that will be covered with clean and advanced manufacturing.

260 https://e2.org/energy-efficiency-jobs-in-america-faq/

261 Alison Diehl, "Opportunities Are Heating Up for PA's Weatherization Workforce," PA Department of Community & Economic Development (PA Department of Community & Economic Development, November 10, 2020), https://dced.pa.gov/paproudblog/opportunities-are-heating-up-for-pas-weatherization-workforce/.

262 Ibid.

263 BW Research data by Pennsylvania county.

264 "Pennsylvania Energy Star Fact Sheet," U.S. Environmental Protection Agency, April 2017, https://www.energystar.gov/sites/default/files/asset/document/Pennsylvania_2017.pdf.

265 BW Research data by Pennsylvania county.

266 Geothermal energy can be tapped for a number of applications, namely for power and heat. "Geothermal," Department of Environmental Protection, accessed July 2, 2021, https://www.dep.pa.gov/Business/Energy/OfficeofPollutionPrevention/Renewables/Pages/Geothermal.aspx; "PHMC Geothermal Energy," Energy Resources (PHMC), accessed July 2, 2021, http://www.phmc.state.pa.us/portal/communities/energy/geothermal.html.
For background on the science, technology, social and environmental aspects of geothermal types, see https://global.oup.com/academic/product/low-carbon-energy-transitions-9780199362554?cc=us&lang=en&

267 "Geothermal," Department of Environmental Protection, accessed July 2, 2021, https://www.dep.pa.gov/Business/Energy/OfficeofPollutionPrevention/Renewables/Pages/Geothermal.aspx.

systems, weatherization and other forms of energy efficiency. This clean and efficient heat presents another flexible job track, especially when done with efficiency or HVAC work.

Rural-Urban Considerations

Among the 13 counties of this study, Allegheny, Beaver and Westmoreland are classified as urban, based on population density, with the remaining 10 counties being rural, namely Armstrong, Butler, Cambria, Clarion, Fayette, Greene, Indiana, Lawrence, Somerset and Washington.[268] This report recognizes that decarbonization and other changes in the regional economy can and are affecting urban and rural communities differently. Among differences, the urban counties appear to have diversified more than rural counties in recent years.[269] This report nonetheless sees opportunity for both types of communities. Rural counties can be sites of innovation to build out energy co-production on underutilized farm land. This can be done with solar and wind energy, geothermal heating, biofuel feedstock production, and biogas from farm animal methane, based on optimal leveraging of area natural resources. Urban counties, in turn, are seen as having greater development opportunities with municipal gas, green roofs, modernization and decarbonization of public transport, hydropower and solar energy in areas with good resources, and integrated energy systems on campuses. Both types of counties can benefit from improved building efficiencies and weatherization.

Outlooks: *<u>Near to mid-term</u> (1 to 10 years):* Looking at clean energy jobs in the near-term, two recent studies (2020-2021) of the state's clean energy industry and workforce identified important insights:[270]

- Pennsylvania is a strong manufacturing hub for wind energy technology and ENERGY STAR products;
- Eight out of ten Pennsylvanian clean energy employers indicated challenges finding qualified applicants at the end of 2019. Reasons included the lack of applicant experience or industry-specific knowledge, and employer competition for applicants.
- As the economy recovers from the pandemic, a share of the employers has indicated that project development pipelines are behind. This presents an opportunity for greater hiring of skilled workers.

Seven clean energy jobs were identified as being high growth occupations prior to the pandemic in Pennsylvania. Table 1 summarizes their wages, education/training, and common certifications.

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268 "Rural Urban Definitions," The Center for Rural PA (The Center for Rural PA), accessed July 2, 2021, https://www.rural.palegislature.us/demographics_rural_urban.html.

269 Interviews, 2021.

270 Note: Clean energy is defined as energy efficiency, clean energy generation, alternative transportation, clean grid and storage, and clean fuels—as well as various sub-sectors within each such as solar, wind, efficient lighting, hydropower, smart grid, electric vehicles, and biomass fuels. Importantly, this job study does not include low carbon industries, like nuclear power, which the Roosevelt study does include. *Workforce Development Needs Assessment & Gap Analysis*, (Pennsylvania: BW Research Partnership, April 2021), https://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/2021CleanEnergyGapAnalysis/PA_2021_Clean_Energy_Gap_Analysis_Report.pdf.

Table 1: Clean Energy Workforce[271]

Job	Wages	Entry Level Education	On the Job Training	Common Certification
Assemblers or Fabricators	$12.00 – 24.41	High school diploma or equivalent	Moderate term on-the-job training	Coil Processing FMA Certification, Soldering Certification, Electronics Assembly IPC Certification
Insulation workers	$15.35 – 32.80	No formal educational credential	Short term on-the-job training	EPA Asbestos Training, Energy Appraiser Certification
HVAC Mechanics, Installers, or Technicians	$18.90 – 39.42	Postsecondary nondegree award	Long term on-the job training	EPA 608 Certification, Local Licensing, NATE Certification, HVAC Excellence Certification
Solar Photovoltaic Installers	$13.86 – 23.35	High school diploma or equivalent	Moderate term on-the-job training	NABCEP, OSHA 10
Energy Auditors	$21.04 – 50.91	Bachelor's degree	None	Certified Energy Auditor (CEA), Certified Energy Manager (CEM). BPI Building Analyst
Electricians	$19.93 – 46.23	High school diploma or equivalent	Apprenticeship	Local Licensing, NABCEP
Plumbers, pipefitters and steamfitters	$19.50 – 46.52	High school diploma or equivalent	Apprenticeship	n/a

These jobs all represent potential for near-term transitioning by the clean energy workforce that will be covered more fully in Chapter 6 on the workforce. In addition to the above positions, there is opportunity in the near to mid-term for expansion of regional, clean energy industry development with ramped manufacturing of wind and solar equipment components and materials for the regional market; manufacturing, installation and servicing of grid infrastructure in the region; build-outs of in-state geothermal heating, efficiency, biogas and biofuel production, plus replacement and adaptation of the retiring nuclear workforce. *Mid to longer term (6-30 years)*: Looking further ahead, the level of grid build-outs and upgrades, particularly for an emergent offshore wind market and expansion of electric vehicles, can be expected to be ongoing at least for the next 15 years. In addition, there is growth potential with advanced nuclear which will require lead time for a specialized nuclear workforce, particularly at the intersection of nuclear and cyber capabilities.[272] If Westinghouse is successful with its microreactor design, this could translate to new, in-state manufacturing jobs.

What is Needed to Leverage Diversification Opportunities in Cleaner Advanced Energy?

The passage of some form of the federal government's infrastructure and jobs package, a clean energy standard and RGGI participation for Pennsylvania are likely to be three of the most important catalysts to spur in-state, clean energy jobs and related advanced manufacturing. For on and offshore wind, siting will also need to be addressed for the substantial and untapped opportunity to be leveraged. Moreover, passage of a state-level, community solar law is necessary to allow new growth by interested customers. Finally, to close the skills gap for clean energy jobs, the DEP should partner with the Southwestern Pennsylvania Commission, and training/certification centers and programs to more fully align course offerings with skills demand, streamline the modes of access, and use a share of the stimulus and/or jobs legislation to

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271 Ibid.

272 Araújo, K. and Pepper, S. Human Factors in Cyber-Nuclear Risk: A Strategic Assessment for Advanced Resilience, Report, Brookhaven National Laboratory and Stony Brook University, 2018.

support members of the unemployed workforce with training that may have a net zero cost with capability gains.

Additional Diversification with Associated, Cleaner and Advanced Manufacturing

Cleaner and advanced manufacturing presents another area for revitalizing southwestern Pennsylvania with traditional or newer manufacturing that integrates less carbon-intensive processes and/or less inputs.

Combined Heat and Power/Cogeneration

Combined heat and power/cogeneration holds considerable potential for added efficiencies in a diversifying economy. Pennsylvania's long-standing strengths in manufacturing are naturally suited for process streamlining and optimization by capturing industrial heat that is often a waste and then utilizing it through combined heat and power (CHP)/cogeneration. CHP-based companies are able to add a revenue stream by producing electricity for on-site use or to send to the grid. The Mid-Atlantic CHP Technical Assistance Partnership estimates that Pennsylvania has significant untapped potential in CHP relative to other regional states.[273] This finding is supported by estimates by the U.S. Department of Energy with further breakdowns of potential by manufacturing industries.[274] Southwestern Pennsylvania's industrial, commercial and institutional utilization of CHP is an area to evaluate more fully for economically viable energy co-production.

Advanced Manufacturing, Materials and Robotics: The Commonwealth also has a long history of steel and glass manufacturing.[275] Building on the region's strong manufacturing base, universities, government laboratories and industry have been conducting research and investing in innovative technology to improve products, processes and materials. In 2018, the Allegheny Conference reported that growth in advanced manufacturing is one of Pittsburgh's most significant innovation assets.[276] This area, combined with advanced materials and robotics, represents an avenue for specialization. The region is drawing attention and investment from large corporations, such as Dow, that are interested in leveraging local capabilities. As noted earlier, project sectors of relevance range from medical devices and energy to consumer goods.

Robotics: Robotics is a field that can be disruptive for industries from manufacturing to healthcare. The Boston Consulting Group estimated global growth potential for robotics from

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[273] *Combined Heat and Power (CHP) Snapshots –Pennsylvania,* (Arlington, VA: Alliance for Industrial Efficiency), accessed July 2, 2021, https://www.districtenergy.org/HigherLogic/System/DownloadDocumentFile.ashx?DocumentFileKey=3db04a6c-f659-c2f2-9595-f531275f8c49&forceDialog=1.

[274] *The State of CHP: Pennsylvania,* (Washington D.C.: U.S. Department of Energy), accessed July 2, 2021, https://www.energy.gov/sites/prod/files/2017/11/f39/StateOfCHP-Pennsylvania.pdf.

[275] K. Kobus. *City of Steel: How Pittsburgh Became the Steelmaking Capital in the Carnegie Era.* (New York, NY: Rowman & Littlefield, 2015); "History of Steel in Johnstown." Johnstown Area Heritage Association. Last modified November 4, 2016. https://www.jaha.org/attractions/heritage-discovery-center/johnstown-history/history-steel-johnstown/; "Glass: Shattering Notions." Heinz History Center. Last modified December 21, 2016. https://www.heinzhistorycenter.org/exhibits/glass-shattering-notions; "Stories from PA History: Making Steel." ExplorePAHistory. Last modified September 1, 2015. https://explorepahistory.com/story.php?storyId=1-9-15.

[276] Inflection Point 2017-18: Supply, Demand and the Future of Work in the Pittsburgh Region, (Pennsylvania: Allegheny Conference of Community Development), accessed July 1, 2021, https://www.alleghenyconference.org/wp-content/uploads/2017/12/018_InflectionPoint.pdf

$15 to $67 billion in the period from 2010 to 2025.[277] As discussed earlier in this report, Pittsburgh is a pioneering hub for the robotics field with work done at Carnegie Mellon (CMU) and the University of Pittsburgh. The schools produce graduates with many of the skills the robotics industry demands in programming, project management, and engineering skills. Importantly, robotics expertise aligns well with the healthcare strengths of the region. *Medical device* production, for example, could be advanced with strategic adaptations.

*Autonomous vehicle*s: The pool of engineering graduates in robotics and automation from CMU and the University of Pittsburgh has spilled over into autonomous vehicles. This emerging industrial cluster has drawn companies to invest in the region. Argo AI, Delphi, Aptiv, and Aurora (which recently acquired Uber's Advanced Technologies Group) are leading companies that are posting job openings.[278] To continue the momentum of this emergent cluster, Pittsburgh must retain and grow the talent pool it creates (*see* Venture Capital section). Pittsburgh outlined its expectations in 2019 for safe autonomous vehicle testing in its Autonomous Vehicle Principles. This preemptive move may help Pittsburgh maintain its position at the vanguard of the industry, as incoming companies have a clear set of guidelines to follow and can be sure of their welcome in the region.[279] With development of autonomous vehicles, the southwestern region of Pennsylvania could leverage overlapping strengths in manufacturing materials and components for electric vehicles that is covered more fully in the Roosevelt Project Heartland case.

Advanced materials: Southwestern Pennsylvania's capabilities in coatings, glass, materials and petroleum lubricants position it to be a supplier of advanced components and lubricants for electric and autonomous vehicles, wind turbines, and solar panels. The traditional automotive region around Detroit will likely maintain its automotive manufacturing lead with EVs. Nonetheless, Pennsylvania is geographically situated with strong manufacturing capabilities to support the Heartland's supply chain.

Additive manufacturing: Additive manufacturing, which uses 3D printing to electronically design and then produce physical objects with additions of material layers, is viewed as a disruptive field of development. The global additive manufacturing market has been projected to grow to $6 billion by 2022.[280] Pittsburgh has had recent investment in this area by Alcoa, CMU, University of Pittsburgh and Robert Morris University. Before the pandemic, the Pittsburgh region evidenced some of the fastest job growth for this field (128% year over year growth vs. 9% for the US). The majority of the jobs for the region skewed toward chemical engineering, reflecting prominent materials manufacturing with Alcoa, Arconic and PPG. The Pittsburgh region produces not only finished products, but the underlying materials that drive the sector.

Low Carbon Steel: Decarbonizing the industrial sector is in line with broadly increased climate mitigation ambition and targets. Manufacture of steel, iron, cement, and chemicals are some of

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[277] Allegheny Conference, citing BSG, 2014.

[278] Inflection Point 2017-18: Supply, Demand and the Future of Work in the Pittsburgh Region, (Pennsylvania: Allegheny Conference of Community Development), accessed July 1, 2021, https://www.alleghenyconference.org/wp-content/uploads/2017/12/018_InflectionPoint.pdf

[279] "Autonomous Vehicle Principles," City of Pittsburgh (City of Pittsburgh), accessed July 2, 2021, https://pittsburghpa.gov/domi/autonomous-vehicles.

[280] Allegheny Conference on Community Development, 2018.

the most challenging to decarbonize.[281] Steelmaking is a longstanding expertise of southwestern Pennsylvania, so it is the primary focus here.

Recent analysis of decarbonization in steelmaking indicates that integrating CCS or CCU technology to blast furnaces may add roughly $122 (100 Euros) per ton for crude steel, and hydrogen-based steel production could cost roughly $207 (170 Euros) per ton of crude steel.[282] Pennsylvania has not yet made such investments, though there is stated interest in cleaner steel.[283]

For the steel industry in the US, the best pathway to decarbonization may be improvements in sorting and collection of scrap metal, combined with renewable energy-powered electric arc furnaces. In theory, steel is 100% recyclable, but scrap metal is often found with contaminants that are severely detrimental to material performance. The industry would be well-served in both economic and environmental benefit by improvements in the pipeline for clean, high-quality scrap metal.

Another option could leverage advanced nuclear technology which is naturally suited for extremely high temperatures and is being developed for new industrial applications, like energy-intensive sectors.[284] As indicated earlier, Pennsylvania has key capabilities to test and demonstrate clean and advanced energy and manufacturing with integrated energy systems that include nuclear, hydrogen, CHP, and low carbon steel. Nuclear engineering experts at Penn State and the University of Pittsburgh could partner with industry and CMU experts in iron and steelmaking to develop this opportunity.

Specific to southwestern Pennsylvania, the region has a unique opportunity for technology leadership in low carbon steel. U.S. Steel, which is headquartered in Pittsburgh, committed to leading steel and steel manufacturing to a sustainable future with a target to reduce greenhouse gas emission intensity by 20% by 2030 versus 2018 baseline levels.[285] With its scale of operations, the company is a primary player in the region. The Biden Administration also proposed creating a climate research agency with goals that include "decarbonizing industrial heat needed to make steel, concrete, and chemicals."[286] Research funding support for universities or university-industry partnerships could help technology experts in the Pittsburgh area identify and test scalable, clean steel-making processes. Steel suppliers and producers in the Association for Iron and Steel Technology (AIST) are already moving to create a committee dedicated to understanding the pathways toward decarbonization for the industry as a whole. Similar shifts toward prioritizing decarbonization can be seen in the aluminum industry (its biggest player is Alcoa, also headquartered in Pittsburgh).

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281 High temperature heat requirements and long-lived assets for these sectors mean that there are limited alternative means for production.

282 Ajitesh Anand et al., "Tackling the Challenge of Decarbonizing Steelmaking," McKinsey & Company (McKinsey & Company, May 18, 2021), https://www.mckinsey.com/industries/metals-and-mining/our-insights/tackling-the-challenge-of-decarbonizing-steelmaking#.

283 Interview, 2021.

284 D. Shropshire et al., Global Market Analysis of Microreactors, INL/EXT 21-01302 Report, June 2021.

285 "Building a More Sustainable Future," Sustainability - Overview (United States Steel), accessed July 2, 2021, https://www.ussteel.com/sustainability/overview.

286 Michael Pooler, "'Green Steel': The Race to Clean up One of the World's Dirtiest Industries," Financial Times (Financial Times, February 15, 2021), https://www.ft.com/content/46d4727c-761d-43ee-8084-ee46edba491a.

A Challenge for Pittsburgh: Labs, Incubators and Venture Capital: The Pittsburgh region has a mixed outlook for new, advanced manufacturing. The city is well-positioned with universities, producing a talented workforce. Relevant labs and incubators, such as U-PARC @ Pitt and CMU Hazelwood Green, mentioned earlier in the report, foster the innovation system. Resources are also relatively abundant. Yet there is a venture capital problem. Ample funding exists for ideas. However, the talented graduates often leave the state for other regions, thereby creating a gap between the early ideas and the supply chain. Autonomous vehicle sensors illustrate this point, as the technology was invented at CMU, but it is now being produced elsewhere. This is a challenge for Pittsburgh that may not have a simple solution. Nonetheless, it is part of the diversification playing field that may shape the economy.

Outlooks for Cleaner and Advanced Manufacturing: *Near-term**:*** Looking ahead for the near-term, CHP presents one of the only mature technology paths for clean and advanced manufacturing in the region. Additive manufacturing appears to be a promising disruptive path. *Mid-longer term:* The EV supply chain, autonomous vehicles and low carbon steel are areas to watch. If CCUS is scaled for the fossil fuel industry, carbon management could also be integrated into traditional manufacturing to sustain in the decarbonized economy. If done in a way that innovates the process, the companies could lead nationally or internationally with products and processes that serve an increasingly carbon-conscious business environment.

Clean Energy and Associated, Advanced Manufacturing Recommendations

Looking across the prospects for clean energy and associated, advanced manufacturing in southwestern Pennsylvania, the **region** would benefit from a considerably more cohesive strategy, led by champions, that pools/builds on the resources and expertise of the Allegheny Conference and the Southwestern Pennsylvania Commission. In doing so, the focus should amplify and more fully connect reskilling with prime employer needs in high growth areas, while also bringing new visibility to local strengths. At the ***Commonwealth level***, joining RGGI and implementing a more robust, clean energy standard could foster new growth in renewables, nuclear, hydrogen, clean steel, and CHP. Passing enabling legislation for community solar would also allow interested customers to act in a new market. Similar legislation to clarify wind siting would broaden promising, local opportunities. At the ***federal level***, passage of robust legislation on jobs and infrastructure with measures to extend the 48C Advanced Energy Manufacturing Credit and to take special account of rural communities has the potential to catalyze nearly all options covered in this diversification section. A Clean Energy Standard at the federal level would also send a strong signal, spurring active deployment in low carbon growth and industrial adaptation. Finally, policy support and cross-jurisdictional streamlining for transmission build-out, especially for offshore wind, would enable a major regional market to emerge, and for Pennsylvania to engage through its supply chain and grid service jobs.

Chapter 6

The Region's Workforce in a Clean Energy Transition

Valerie Karplus, Kathy Araujo, Yiran He, Rachel Reolfi

A low carbon energy transition will imply changes for the workforce of Southwest Pennsylvania in the coming decades. Individuals' employment choices reflect their unique histories, identities, aspirations, and contexts. We start from the anatomy of the state's present workforce and consider its relationship to greenhouse gas emitting activities as well as the ways clean energy growth and economic diversification could create new, good-paying jobs. Given that the unemployment rate in 10 of the 13 counties is above the state's average rate of 7.3%, we go beyond a focus on transitioning the existing workforce and ask how to expand opportunities. A regional strategy that embraces *multiple paths* to deep decarbonization will allow for the creation of new jobs in clean energy alternatives and less energy-intensive economic activities (e.g., robotics, healthcare) alongside an evolution of energy-intensive and extractive industry jobs, which are major sources of regional employment.

This chapter is organized around understanding opportunities to reimagine the region's energy workforce. Several findings emerge:

(1) In **coal mining, coking, and power generation**, transition is already well underway, as natural gas continues to displace coal for economic and local environmental reasons. The transition path will differ by age cohort: older workers may prefer generous retirement packages, while younger workers can find skills matches or develop new or augmented skills in growth areas. Transitioning workers may be well suited for jobs in methane remediation or construction in the near term and jobs related to hydrogen production and transport or carbon capture and sequestration (CCS) in the long term, given potential for comparability in wages and union support.

(2) In **natural gas production**, job opportunities locally will depend on developments in the market for natural gas nationwide and globally. Domestic and overseas demand for natural gas, which is cleaner than coal, will face less pressure, limiting the near-term impact on jobs related to its extraction. Longer term, these jobs could persist if natural gas can be used with very low CO_2 emissions, for instance, if natural gas or blue hydrogen production facilities are retrofitted with CCS. Transitioning these workers over the medium term through retraining or generous retirement packages is less urgent than for coal but identifying viable paths for transition assistance should still be a priority.

(3) Supporting **innovations in energy-intensive industries** that are compatible with deep decarbonization could create new employment opportunities. The economic viability and future scale of an expanded **chemicals industry** in the region is highly uncertain, especially under climate constraints. Despite access to inexpensive natural gas feedstock, the region faces difficulty competing with the Gulf Coast and other locations. However, the region does have an opportunity to develop its comparative advantages in manufacturing. As discussed earlier in this report, low carbon steel and industrial robotics are two options.

(4) **Economic diversification** can generate new jobs that can provide substitute or supplemental employment for workers likely to be most affected by the transition. These jobs will be especially needed in heavily rural or industrial counties. Most importantly, workers will need information on how they can access retraining programs and certainty that skills acquired will help them secure high quality jobs in the future. These initiatives are also important to broaden opportunity for all workers, not just those in energy.

While transition pressure will be concentrated on activities that directly emit GHGs, upstream (supplier), downstream (buyer), and adjacent or supporting industries will also be affected indirectly. More research is needed to understand how changes in sectoral activity will affect each other. For instance, the transition may affect downstream industries that rely on energy carriers, such as electricity and heat, by increasing variable costs. Employers may respond by adjusting wages or reducing their workforces. However, this category of employment impacts is perhaps the most difficult to estimate because cost pass-through and competitiveness impacts are uncertain. Finally, industries, especially in services, that coexist alongside fossil energy activities, will face new pressures. For example, if coal plants close, firms that exclusively service coal-fired power plants will face pressure to downsize or pivot to new activities.

Figure 1 shows jobs related to Pennsylvania's energy cluster. While direct employment in primary energy and energy carrier industries is relatively low, there is substantial employment that depends on the existence of these activities, as show by the three right bars (supporting industries, fossil fuel and energy consumers (refining, cement, and iron and steel), and energy consumers (other manufacturing, e.g. the chemical industry). This employment is disproportionately located in the SW PA region. Figure 2 shows average wages by category for the states workers – compared to energy consumers (other manufacturing), average wages are substantially higher, especially in electric power generation. Aggregation based on underlying NAICS codes is described in Appendix Table 1 for Chapter 6.

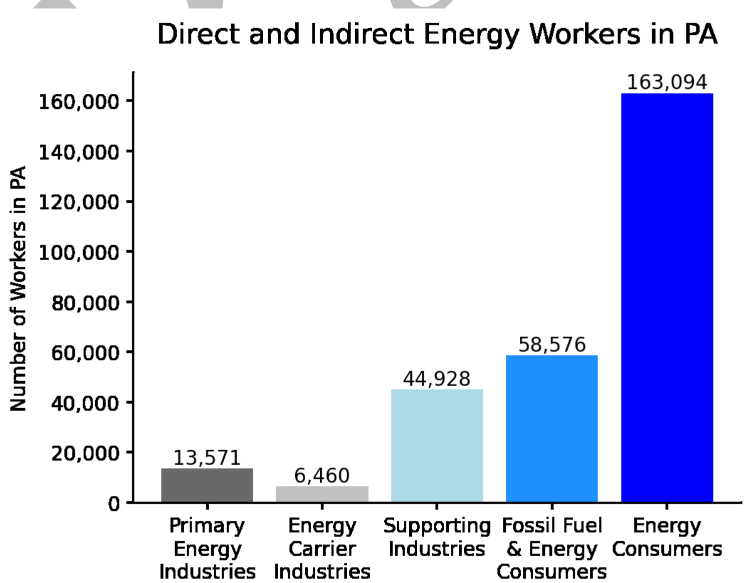


Figure 1. The energy workforce in SW PA in 2018. Data are from the Bureau of Labor Statistics Quarterly Census of Employment and Wages (QCEW).

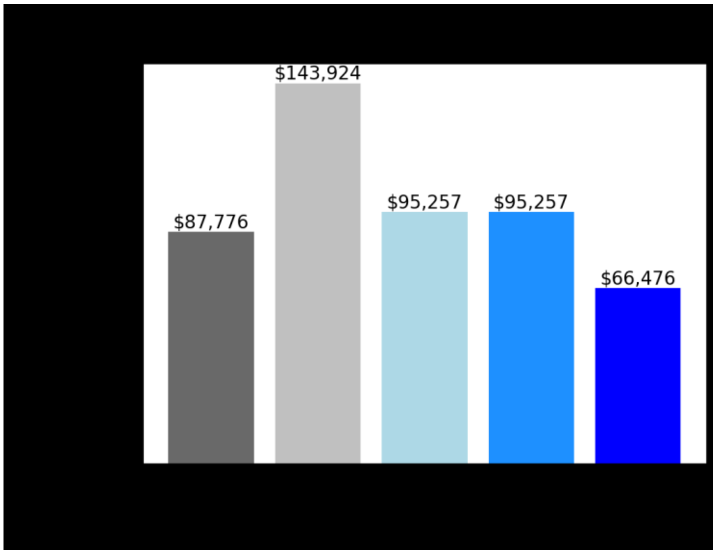


Figure 2. Average wages in 2018 for major categories of the energy workforce. Data are from the Bureau of Labor Statistics Quarterly Census of Employment and Wages (QCEW).

Impacts of transition on fossil energy jobs

While numerically a small share of the workforce, fossil energy has a long history in the region and represents a culturally important contribution to the region's economy. Together, direct employment in these activities accounted for 1.9% of employment in our 13 county block in 2018. GHG-intensive jobs in utilities, mining, and oil and natural gas will face direct pressure in a transition but on different time scales.

Table 1. Contribution of major energy-intensive industries to regional totals.

2018	Percent of Gross Regional Product	Employment, Number and Percent of Region	Greenhouse Gas Emissions (t CO_2e) (Total = 59,150,372)
Mining and Energy Extraction (natural gas, oil, coal)	7%	15,324 (1.2%)	Internal = 3,212,910 (5% of in-region) [Export = 336,148,857]
Utilities	2%	9,389 (0.7%)	45,924,460 (78% of in-region)
Manufacturing	10%	107,870 (8.4%)	7,205,431 (12% of in-region)

Source: GRP - Bureau of Economic Analysis, employment - Bureau of Labor Statistics Quarterly Census of Employment and Wages (QCEW), and GHG emissions - PA DEP.

The contribution of mining and extraction and utilities to employment, gross regional product, and greenhouse gas emissions is relatively modest, as shown in Table 1. Manufacturing is a more substantial share and could continue to thrive if successfully transitioned to low-carbon energy sources at limited additional cost. Moreover, even if a transition were to abruptly reduce fossil fuel use in the region, a subset of the jobs in Table 1 will remain – and manufacturing jobs could thrive, if they can successfully shift to using cleaner forms of energy.

Coal jobs

For coal power, the energy transition is already underway. Compared to 2003-2008, nationally the contribution of coal to power generation has fallen from 50% to 39% (BGA, 2016). Multiple plant closures have occurred in the region. Prior closures have occurred largely due to pressures unrelated to decarbonization, including lower natural gas prices, higher coal costs, and local environmental regulation. For example, the 2013 closure of two FirstEnergy plants, the Hatfield's Ferry Power Station in Washington County and the Mitchell Power Station in Greene County, resulted in approximately 400 layoffs and had far-reaching effects on a range of jobs in industries that support the plant, including in equipment maintenance and coal transport. Most of these job losses were concentrated in Washington, Greene, and Fayette counties. While recent employment numbers by plant were not available, these facilities are estimated to employ a few thousand individuals, and support several thousand jobs in related and supporting industries. Our interviews revealed that it is important to communicate early and consistently around plant closures and to have transition assistance in place at the time a closure is announced. Many expressed that there is a general fear that jobs will disappear "overnight" as a result of the transition. Here, early, consistent, and supportive communication could go a long way.

Some counties face outsized exposure to potential future closures. Beaver and Indiana counties have the largest shares of employment in the utility sector at 2.7% each (see Chapter Appendix). The Conemaugh plant (2.0 GW), Homer City Generating Station (2.0 GW), and Seward plant (585 MW) are important local employers in Indiana county.[287] Capacity factors of these facilities are already relatively low. The larger facilities (e.g., Conemaugh) could be candidates for carbon capture and storage, although substantial investment would be required to train workers and develop suitable systems.[288] Given that the pressures that led to the region's earlier plant closures persist and the decarbonization imperative only adds to them, it will be important to plan well in advance to retrain or otherwise transition workers at these facilities.

Natural gas jobs

While natural gas extraction has been a major growth industry and source of public revenue, its role in expanding job opportunities for the region's population is less clear. Pennsylvania's Department of Labor and Industry estimates that natural gas extraction supports between 20,000 and 50,000 jobs in the state, including related and supporting industries. The thirteen southwest

[287] In addition to those listed, the Cheswick plant (637 MW) is located in Allegheny county and the Keystone plant (1.9 GW) is located in Armstrong county.

[288] Feasibility of installing CCS at several of the region's power plants was examined in 2009 in this report: https://pecpa.org/wp-content/uploads/Viability-of-a-Large-Scale-CCS-Network-in-PA-2009.pdf

counties account for a substantial fraction of this total. While hard to classify precisely, interviews suggested that many of these jobs are occupied by workers relocated from out of state, although supporting industries such as transportation employ locals. The oil and natural gas industry directly engages 4,000 workers, which represent a mixture of in-state and out-of-state workers (see Appendix Table 1). These jobs have already come under pressure as the economics of natural gas extraction in the region grows more challenging. A decade ago, studies claimed the industry would create 450,000 jobs in Ohio, Pennsylvania, and West Virginia, but only a fraction of these materialized. High GDP growth due to the expansion of shale gas development was not paralleled by a substantial expansion in employment – job growth in the counties involved barely kept pace with the state average. In 2019, CNX, EQT, and Range Resources -- major players in natural gas extraction in the region – reportedly reduced their workforces by 400 jobs, and Chevron announced that it was exiting the region.

The future viability of natural gas extraction in the region will depend on developments in domestic and international export markets. Even if industries, such as electric power and chemicals, expanded their use of natural gas in the region in the coming decades, the share of local natural gas use would not rise substantially. Achieving carbon neutrality globally by mid-century would reduce demand for unabated uses of natural gas. The extraction plus transport costs place the marginal cost of Marcellus natural gas above most other domestic sources and renders it largely uneconomic at current natural gas prices. Given this uncertainty, important questions include how employers can signal early and consistently around any potential closures or layoffs and how local governments and nonprofits can anticipate transition assistance and retraining needs.

Clean energy jobs

A low carbon energy transition will create new job opportunities, but these are likely to be more diverse compared to previous boom cycles tied to fossil energy. Our interviews suggested that here it is important not to be anchored by the assumption that clean energy jobs will displace traditional, fossil fuel-based employment. Potential opportunities will include low carbon fossil to renewable energy technologies. As above, this will include job creation in both low carbon energy production and adjacent industries. These jobs will be in the construction and operation of clean energy assets ("production," e.g. solar and energy efficiency) as well as provision of key inputs ("supply chain," e.g. solar PV module manufacturing or cement production). The former is likely to be local, while supply chain opportunities will depend on the comparative advantage of the region.

While there is some overlap in the types of jobs that would support specific decarbonization paths, the extent of this overlap is uncertain. Construction jobs will almost certainly be required regardless of the technology pathways emphasized, for instance, for local deployment of renewables (although the extent to which these would be located in the region is not known) and for the expansion of carbon capture and sequestration, and hydrogen infrastructure. Jobs operating and maintaining low carbon energy infrastructure in the region are more difficult to assess, but in many cases depend on the presence of the infrastructure in the region itself, i.e. no jobs will be created if the region imports electricity generated from solar or wind energy.

An open question is what share of the clean energy jobs are likely to be well-paying, unionized positions. Traditional energy jobs in the state have historically paid well and offered attractive benefits, whereas salaries for non-college-educated workers are comparatively lower in emerging clean energy industries (e.g., for solar technicians or energy efficiency auditors). In 2018, average wages in Pennsylvania's fossil fuel extraction and refining industries were $95,718, compared to the average wages across all energy sector categories (see Appendix Figure 1) of $73,267.

Methane remediation (e.g., well-capping) could provide an opportunity to expand clean energy employment in rural areas. A state- and industry-backed cleanup program could provide an immediate source of employment and a viable pathway for transitioning workers out of traditional fossil energy activities, including shale gas development. However, it should be noted that these jobs will largely depend on government support and the long-term path for these workers should be considered at the outset.

Beyond energy jobs

The health care, technology, and manufacturing sectors are important contributors to employment in the region today. Jobs are concentrated in Allegheny County, but workers commute frequently from surrounding counties. Across these sectors, dynamics are very different: health care and technology businesses are growing, while manufacturing still accounts for a substantial share but is in decline. The result is an increasingly diversified economy, with skills requirements that differ substantially from the historically dominant industries. Helping workers from a wide variety of employment backgrounds, socioeconomic groups, and urban as well as rural settings connect with opportunities in an increasingly pluralistic economy is important to realizing steady and long-term regional growth and community health.

Several waves of industrial transition and offshoring have dramatically transformed the region, and especially Pittsburgh's, employment base. In 2019, the region's manufacturing employment reached its lowest level at 82,000 (7% of the total), a 78% since decline from peak manufacturing employment of 382,000 in the 1950s. Today, the economy has migrated far from its traditional industrial roots, with the city of Pittsburgh gaining 26,000 positions in what has been dubbed the "super creative core." These are largely jobs in tech and corporate headquarters. Although a shadow of its former self, energy-intensive manufacturing accounts for the largest share (8%) of energy-intensive employment in the region, and at present includes mainly coking, iron and steel, and chemical and fertilizer production.

Economic diversification has meant new bottlenecks to workforce development, with many interviews suggesting that managerial and professional skills, not technical skills, are most often in short supply.

Many have focused on the potential of a regional chemicals hub to create high quality union jobs for local employees, including those who might be displaced from other sectors in a transition. However, the chemical industry will face substantial headwinds in a low carbon transition. To remain viable, these facilities will need to invest in carbon capture and storage, or purchase CO_2 offsets. A Shell ethylene cracker plant is proving an early test of the viability of the chemicals hub concept. Slated for completion in 2022 after delays related to COVID-19, the Shell cracker plant would emit 2.25 million tons of carbon dioxide, in addition to substantial local pollutants. It is projected to create 600 permanent jobs, in addition to near-term construction jobs, many of which are relatively high paying (e.g., in welding).

Economic diversification has the potential to provide new sources of livelihoods that do not depend on high-emitting activities and go beyond one-size-fits-all, "big" industry solutions. Within our 13 county region, Pittsburgh (Allegheny County) is an important example of how cooperation among foundations, universities, industry, and local government can broaden the economic base: healthcare and now tech/AI have grown as export-oriented manufacturing declined. This has contributed to a shift in the city's identity but has exposed tensions between those who see the city's future in industrial mega-projects (e.g., the Shell Cracker Plant) and those who envision it as a leading tech and medical hub.

An important challenge involves building collective momentum around a diverse collection of activities, which can be easier to do in the case of large projects with numerous, well-organized beneficiaries. Important here is what resonates most with individuals' economic and cultural identity, which in the case of our 13 counties has historically involved fossil energy and the industrial growth it enabled. However, complementary efforts to promote diversification may help to buffer the jobs impact of low carbon transition and help to broaden opportunity for the region's workforce in ways that will contribute to reimaging identity, as it has begun to do in Pittsburgh.

Economic diversification may offer an important opportunity for rural areas to limit adverse impacts of transition while allowing residents to continue living where they are from, an important consideration for many. Importantly, diversification in rural areas is likely to look very different from urban examples. Our interviews reveal the importance of the informal economy, of being able to do "hands work," and of enabling entrepreneurial activities that connect with rural culture. Interviewees pointed out that one of the region's greatest strengths stems from the "values and work ethic" of prospective employees. Training programs that help candidates obtain managerial, professional, and leadership skills can combine with these preexisting enablers to produce powerful examples of success. For instance, "Solar Holler" is a solar energy company that reflects its rural roots, from its name to its workforce and market focus. The efforts of local entrepreneurs like Brandon Dennison, founder of Coalfield Development, can provide a model for strengthening rural communities and creating diverse employment possibilities at the same time.

Looking to the future, in our interviews we heard that the region has an opportunity to build on its historical strength in manufacturing and combine it with its emerging strengths in the innovation economy. For instance, advanced robotics is one area where the region has the potential to become particularly strong; investments are already in place in the form of Hazelwood Green, local offices of large tech companies, and the computer science and engineering strengths of Carnegie Mellon University. Green steel production may offer another opportunity to combine a similarly diverse set of local strengths. Dedicated grant programs and innovative financing arrangements could help to expand these activities to the point where they preserve or create new jobs and career paths anchored in the region.

Preparing the Workforce

Our interviews suggested that if governments and employers can anticipate workforce needs in a transition, work with employees to develop and adjust viable transition assistance plans, and consistently and effectively communicate to employees around implementation, it would help to mitigate worker dislocation in a transition. Any transition assistance or retraining program should consider the diversity of situations involved: needs will differ depending on career stage and the degree to which a job category faces pressure in a transition. At the same time, any programs must integrate into the economic fabric of each community and county and its links to the region.

Table 2 shows examples of transition paths depending on the career stage of the worker and the GHG intensity of their respective industry at the outset of the transition. The table reveals that there is no one-size-fits-all approach to workforce transition in the region. Even within categories, options will hinge on GHG mitigation actions, and will materialize over very different time scales.

When it comes to the existing workforce, a jobs gap that could emerge in the near term if decarbonization leads to the displacement (non-creation) of jobs in the hydrocarbon-oriented sectors. For local workers involved in these sectors, there is a need for training options followed by relatively concrete opportunities. In Table 2, this challenge affects employers primarily in mid-career GHG intensive and GHG adjacent industries. It is here that training programs, for instance those offered by regional community colleges, could usefully focus, in order to provide a bridge to careers with adjacent skills. Our interviews currently reveal that potential skills matches include remediation of emissions from oil and gas wells, jobs in HVAC and landscaping, and construction. An important open question is how to make these jobs attractive for transitioning employees, especially union workers, given that salary and worker protections are generally less attractive for these activities.

Table 2. Interventions to strengthen regional workforce development as a function of worker career stage and GHG intensity of activities.

	GHG Intensive	**GHG Adjacent**	**GHG Independent**
Early career	Training in "low carbon fossil" - emissions abatement, H2, CCS	Training in remediation, HVAC, landscaping, etc. / longer term in clean steel, clean energy manufacturing	Need incubators, venture financing, include rural areas
Mid-career	Retraining for "low carbon fossil," shift to GHG Adjacent	Reskilling to focus on remediation, HVAC, landscaping, etc.	Reskilling to focus on entrepreneurship, health care, gig economy
Late career	Retirement with generous severance	Mobility limited; focus on repurposing fossil-linked jobs	Opportunities for seniors - volunteering, arts and culture

The impact of plant closures on workers and communities varies depending on how the transition is handled. In past coal plant closures, targeted transition assistance has played an important role in connecting workers with retraining opportunities and the support needed (cost-of-living stipends, transportation, child care, class materials, and housing) to take full advantage of them. Developing guidance on transitioning workforces and redeveloping coal plant sites is currently underway, and has the potential to improve outcomes by learning from relatively successful past transitions involving coal plant closures in the broader Appalachian region. A similar approach could be taken for employees of GHG-intensive manufacturing facilities (e.g., coking) and, as needed, for local employees in natural gas drilling.

Broadening the set of options for transitioning employees, including in the growing knowledge economy and in entrepreneurship, can help to reinforce the reality that the region's economy is diversifying. Further understanding the role that gig economy jobs, revenue streams to landowners (e.g., from natural gas extraction or wind farms), allocation of jobs within families, the informal economy, and combining jobs might play in shaping the possible paths to maintaining and growing household income will also be important to designing acceptable transition strategies.

Recommendations

Based on the observations developed in this chapter, we outline several recommendations to help the region's workforce transition:

Create a Council for Regional Career Transitions. Bring together representatives of large employers, unions, career counselors, community colleges, employers, and incubators to support and guide the creation of a free skills-matching service for employees and trainees in the region, bringing multiple existing and needed functions under one umbrella. This service would provide information to employers on employee skills and goals, while at the same time helping employees to identify a broader range of future career paths that are compatible with an economy that is diversifying away from fossil fuels. Paths could also include options for holding multiple part-time jobs, which is common in rural areas, which together represent attractive compensation.

Develop Best Practices for Managing Career Transitions in Industries Facing Transition Pressure. Provide state assistance to employers to allow paid leave for new skills acquisition, paid out of the revenues recycled from a carbon tax or RGGI.

Strengthen Entrepreneurship in Rural Areas. Expand mentorship and seed capital opportunities for rural entrepreneurs, both those connected with clean energy as well as broader economic diversification. Messaging should avoid a focus on remote concepts such as "decarbonization" and instead on the potential for workers to contribute to local community revitalization and building connections to the broader national and global economy. Broadband infrastructure expansion will be important to enable this integration.

Explore Opportunities at the Intersection of the Manufacturing and Knowledge Economy. Explore the potential to revitalize manufacturing (e.g., in high quality green iron and steel) in the region, through a combination of additive methods and clean industries that can draw on historic strengths in manufacturing and emerging strengths in robotics, AI, and health care.

Conclusion

The global transformation of energy systems presents both challenges and opportunities for Southwest Pennsylvania. The region's energy and manufacturing industries, which are driven primarily by coal and natural gas, account for 20 percent of domestic product and 10 percent of employment. If there is a significant global reconfiguration of energy production, industrials, and manufacturing, as many now anticipate, demand for southwest Pennsylvania's energy and manufacturing products may decline. The energy transition also presents opportunities to develop entirely new industries around emerging energy and manufacturing technologies.

This report has examined ways that the Commonwealth of Pennsylvania and stakeholders in the southwest Pennsylvania region can anticipate and adapt to potential changes in the energy sector. As coal, and later gas, are displaced in energy markets, many workers and communities will need to find new economic opportunities. Industrial, civic, and government leaders will need to pursue strategies that reposition the energy and manufacturing industries for the long run. Now is an ideal time to begin to set a new course for the energy and manufacturing sectors.

In the near term (5 to 10 years), the Commonwealth should undertake a substantial environmental remediation program that focuses on well-capping, brownfields, and water contamination. Any effort to reduce the region's greenhouse gases will have to address the leakage from over 400,000 wells in Southwest Pennsylvania. Almost all of these wells and pipelines are legacy wells from a century and a half of gas exploration.

The Commonwealth should stand up a substantial well-capping and well monitoring program. Similarly, large projects should target brownfield sites and water pollution, as these are major environmental and public health problems. These efforts will require that the Commonwealth support workforce training programs, develop and enforce standards, and create incentives and commit resources to sustain a significant remediation program. Addressing well leakage, brownfields, and water contamination will help the Commonwealth meet its environmental and climate goals and create significant employment in the region.

In the medium to long term (10 to 30 years), the Commonwealth can reposition its energy and manufacturing sectors along two tracks.

The first track is to deploy carbon capture, utilization, and storage (CCUS) at region-wide scale in order to maintain the competitiveness of the region's gas and coal sectors and fossil-fuel driven industrials and manufacturing. CCUS and hydrogen are game changing technologies for fossil fuels. They have the potential to alter the way we use gas, coal, and oil from one in which the fuels are combusted for energy and the waste is sent into the atmosphere and water, into one in which the fuel is transformed into a low-carbon fuel – natural gas or coal with all or most of the greenhouse gases extracted – or into a new, clean burning fuel – hydrogen – that can be used for electricity, transportation, and industrials.

Quite apart from its potential for clean energy production, CCUS represents a substantial new industry for this region. As the world races to meet international carbon emissions targets, there is growing global demand for technologies and systems that can help companies reduce greenhouse gases from their existing power generation, industrial, and manufacturing processes.

Southwest Pennsylvania's political and industrial leaders should work with NETL and area research universities to establish a research-driven industrial hub for the development of CCUS technologies for energy and manufacturing.

A second track for the development of clean energy and manufacturing in southwest Pennsylvania is to develop energy sources that have little or no carbon emissions, including wind, solar, and nuclear power, as well as energy efficiency and grid development. Surprisingly, efficiency and grid account for many more jobs in the region than does fossil fuel extraction, and these sectors are growing quickly. There is an immediate need in the region for development of a workforce with skills specific to energy efficiency and grid employment.

The region has nascent wind and solar industries. Capturing the potential of these resources will require changing regulations, such as restrictions on community solar, and development of industrial scale storage. Existing industries in the Pittsburgh area can supply these needs, including steel, glass, and coatings, and in recent years they have attracted increasing numbers of firms working on these and other energy platforms.

In addition, the region has a significant nuclear power industry, along with substantial nuclear research capability. Nuclear power provides roughly 20 percent of the Commonwealth's electricity, and this resource is predicted to be a steady presence in the electricity mix through 2050. As new nuclear technologies are beginning to be explored and developed,[289] the Pittsburgh area, home to Westinghouse and the Betts Naval Research Lab, may experience a renaissance in its nuclear industry.

Finally, it should be stressed that southwest Pennsylvania has a robust, diversified economy, with strength in health care, education, tech, and finance, and emerging strength in robotics, autonomous vehicles, artificial intelligence, and additive and advanced manufacturing. Energy and traditional manufacturing (including metals, petrochemicals, glass, and coatings) are a significant part of the industrial mix in the region. The strength of a diversified economy will make it possible for the region to adapt to a changing energy industry.

With these observations in mind, we have the following recommendations.

1. *Establish a substantial remediation program with the objective of cutting greenhouse gas emissions from leaking wells in half within 10 years.*

The natural gas industry and the Commonwealth of Pennsylvania should develop standards for methane emissions and well leakage. The Commonwealth and industry, working together, should develop a sufficiently well-financed program for well-capping to provide for remediation of legacy wells, as well as active wells. The Commonwealth, working with industry and communities, should conduct an evaluation of environmental and other regulations that bear on remediation in order to streamline regulations and accelerate remediation efforts.

2. *Develop a region-wide infrastructure for carbon capture and storage and, eventually, hydrogen at industrial scale.*

The Commonwealth of Pennsylvania, working with industry, research labs, communities, and other state governments, should plan and develop CO2 pipeline and storage facilities with the

[289] "Bill Gates' Terrapower to build reactor demo project in Wyoming," *Power Engineering International,* June 3, 2021, https://www.powerengineeringint.com/nuclear/bill-gates-terrapower-to-build-reactor-demo-project-in-wyoming/.

aim of connecting to other carbon storage infrastructure being developed or planned in neighboring states. Over the next three years the Commonwealth, with NETL, industry, communities and partners in other states (such as the Great Plains Institute and the Midwest Regional Carbon Initiative), should conduct comprehensive studies of carbon capture and storage and of hydrogen with the objective of proposing feasible CCUS and hydrogen infrastructure to develop at scale. The Commonwealth should reach consensus on plans by establishing a task force of stakeholders that meets regularly to identify key issues and obstacles to CCUS and develop strategies for its implementation. Finally, the Department of Environmental Protection, working with the US EPA, should develop standards for carbon capture and storage. The agency should have the power and staff to monitor facilities and level significant fines for leaks or other pollution. As part of this standard setting effort, the Commonwealth of Pennsylvania should develop "low-carbon" fuels and "low-carbon" products standards to aid in the commercialization of its energy and products manufactured in line with carbon reduction initiatives.

3. *The federal government should establish a research-driven CCUS innovation hub in southwest Pennsylvania.*

The US Department of Energy should establish a Carbon Management program within the National Energy Technology Lab. The federal government should increase research funding for capture technologies, carbon utilization processes, and systems analysis for carbon storage. These investments should prioritize lowering the costs of carbon capture and deploying capture and storage technologies. This research hub should proceed in consultation with industry in order to develop technologies that feed directly into the energy, manufacturing and industrial sectors in the region.

4. *Develop a comprehensive approach to wind, solar, biofuels, nuclear power, and other energy sources in order to build a more diverse energy portfolio.*

One concern with the emerging energy picture of the region and the Commonwealth as a whole is that it is projected to become increasingly dependent on natural gas. A more diversified energy sector would be more robust to price changes, technology shifts, or supply disruptions. The Department of Environmental Protection should conduct a study to gauge the potential contribution of each of these energy sources, and the regulatory obstacles to their deployment. The Commonwealth should remove regulatory barriers to community solar and streamline regulations that slow the development of its wind industry.

5. *Launch a workforce development initiative.*

Regional stakeholders should create a Regional Council for Career Transitions that regularly brings together large companies, unions, community colleges, employers, and other stakeholders, to discuss the region's employment and workforce needs and identify successful models and programs. The Commonwealth of Pennsylvania should adapt workforce programs that align with the findings and recommendations of the Regional Council. The Commonwealth should expand satellite campuses of PSU and community colleges and locate these arms of the education and training system in areas where there will be the greatest future need.

6. *Invest in developing the capacity of local communities.*

Foundations and regional planning councils, such as the Appalachian Regional Commission and the Southwestern Pennsylvania Commission, should invest resources to build the physical capital and the human capital of communities throughout the region. Improve regional transportation networks to expand people's job opportunities; extend broadband infrastructure throughout the region to improve communication and create opportunities to work and learn remotely and to bridge the digital divide that isolates many communities. Invest in programs that help people understand how they can improve their own towns and neighborhoods.

Southwest Pennsylvania sits on a golden egg. It is not the trillions of cubic feet of natural gas in the Marcellus shale. Rather it is the incredible assets of its communities. In past economic transitions, the region's communities -- its civic organizations, government leaders, companies, universities, foundations, and other organizations -- have come together to remake the region. Southwest Pennsylvania has reaped the reward: today it has a rich, diversified economy.

The lesson of past transitions is that, although it is tempting to seek the one big solution or the next big thing, strength is to be found in pursuing many different possibilities. There is not one single industry around which to build the region's future economy or, even, one way to transform the energy sector. We have offered what we see as the obvious opportunities for the creation of new, clean energy and manufacturing sectors for Southwest Pennsylvania. In navigating the coming changes in energy and manufacturing, we encourage the region to continue its course of developing a wide range of opportunities to maintain a strong, diversified economy.

Appendix

List of People Interviewed

Last	First	Organization
Althoff	David	PA DEP - Energy Programs
Anderson	Brian	National Energy Technology Laboratory
Anderson	Loren	Marcellus Shale Coalition
Ban	Heng	University of Pittsburgh
Blumsack	Seth	Penn State University
Blumsack	Erin	Penn State University
Bright	Hillary	Blue Green Alliance
Brinley	Denise	PA DCED
Burke	Brandon	Business Network for Offshore Wind
Campbell	Kerry	PA DEP - Energy Programs
Carter	Kris	PA DCNR
Charlton	Alex	Exelon
Chen	Kevin	University of Pittsburgh
Conway	Tom	United Steelworkers
Dennison	Brandon	Coalfield Development
Deutch	John	Massachusetts Institute of Technology
Eichenbaum	Pam	Carnegie Mellon University
Fidler	Jacquie	CONSOL
Giovannitti	Jen	Benedum Foundation
Gohl	Earl	Appalachian Regional Commission
Gohn	Andrew	Clean Power/AWEA
Gould	Ross	Business Network for Offshore Wind
Harr	Heather	Reimagine Beaver County
Harstein	Roy	Responsible Energy Solutions
Hunt	Mary	Benedum Foundation

Kang	Mary	McGill University
Kelly-Pitou	Katrina	University of Pittsburgh
McIntyre	Elizabeth	TEAM Consortium
McQuade	Mike	Carnegie Mellon University
O'Brien	Kiera	Students for Carbon Dividends
Pelepko	Seth	PA DEP
Pillar	Sharon	PA Solar Center
Pistorius	Chris	Carnegie Mellon University
Place	Andrew	Clean Air Task Force
Plants	Luke	Plants & Goodwin, Inc.
Robertson	Kathy	Exelon
Rusco	Frank	US GAO
Schuldt	Rhonda	PSU New Ken/Synergos
Siger	Rick	Carnegie Mellon University
Sinclair	Jessica	University of Pittsburgh
Smith	Phil	United Mine Workers of America
Smith	Zach	CONSOL
Snider	Kevin	PSU New Kensington
Stewart	Susan	Penn State University
Szybist	Mark	NRDC
Taylor	David	PA Manufacturers Assoc
Tedesco	Dominic	Marcellus Shale Coalition
Teeter	Valerie	Exelon
Tyree	Stephanie	WV Community Development Hub
Webler	Bryan	Carnegie Mellon University
Winfield	Cindy	Just Transition Foundation

Appendix Chapter 4

CCUS Calculations in Appalachian Pennsylvania

The purpose of this report is to describe the process for calculating the cost of a Carbon Capture and Storage system (CCS) for industrial and power plants in the case’s 13 county region.

Calculations in this analysis are based on estimates for the region and CCS plans for nearby states, Ohio and West Virginia.

The calculations were divided into four steps: (1) identifying high-emitting plants that could be retrofitted with CCS, (2) estimating the cost of installing CCS on each plant type, (3) estimating the component of levelized cost of CO_2 abated associated with transporting CO2 based on pipeline design capacity and distance to storage site, and (4) estimating storage cost based on storage capacity and geology. For each step, Equation 1 computes the levelized cost of CO_2 abated by comparing the NPV of a similar project with and without CCS, and dividing it by CO_2 reduced by that CCS project. [1]

Cost of CO_2 abated ($/$tCO_2$):

$$\frac{(NPV)_{low-C} - (NPV)_{ref}}{(tCO_2)_{ref} - (tCO_2)_{low-C}} \quad \text{(eq 1)}$$

The incremental NPV (change in NPV) of a CCS project was derived by rearranging Equation 1 so that the CO_2 reduced by CCS is multiplied by the cost of CO_2 abated. Equation 2 gives the change in NPV.

Incremental NPV ($):

$$\frac{\$}{tCO2}\left[(tCO_2)_{ref} - (tCO_2)_{low-C}\right] \quad \text{(eq 2)}$$

Step 1: High emitting plants

In this study, “high-emitting” is defined as any facility (industrial or electricity generation plant) emitting over 100,000 tons of CO_2/year. This is the lower bound for facilities in the Carbonsafe study, which finds CCS is not economically viable below this threshold. [2] To identify facilities to include, the study used Pennsylvania's Department of Environmental Protection’s (DEP) Air Quality Reports, a database of facilities and their annual emissions.[3] The focus of this study includes facilities that exceeded the “high-emitting” threshold of 100 kt of CO_2/year in 2019 in the Southwest, Northwest, and North central regions, which could be connected via a single CCS transport and storage infrastructure.

The final list includes 44 facilities emitting a total of 60 Mt CO_2/year. Facilities belong to the following NAICS industry classifications: Fossil Fuel Electric Power Generation (both coal-fired and natural gas combined cycle), Manufacturing (Iron and Steel Mills and Ferroalloy Manufacturing; Lime Manufacturing; Ethyl Alcohol Manufacturing; Rolled Steel Shape Manufacturing; Reconstituted Wood Product Manufacturing; and Gypsum Product Manufacturing), Electric Bulk Power Transmission and Control, Petroleum Refineries, and Natural Gas Extraction. Cost calculations are customized for each of these industries. Nine facilities could not be matched with a corresponding capture cost estimate from the Carbonsafe or Schmelz *et al.*[4] studies, so these plants were omitted, resulting in 35 facilities in the analysis.

Differences in plant size and associated emissions can affect CCS cost estimates. The Carbonsafe and Schmelz *et al.* studies focus on high emitting facilities emitting above 1.7 Mt CO_2/year and assume a 50 Mt storage capacity over 30 years. The present study applies a similar approach for the nine high emitting plants that are above this threshold. There are nine of these high emitting plants that are within the same scale as the cost estimates used in most of the studies (Carbon safe, McCoy and Rubin, and Schmelz *et al.*[5]). Therefore, these cost estimates should more accurately represent the true system cost.

Figure 1: DEP Air Quality Map of High emitting plants (emitting above 100 kt CO_2/year) in the Northeast, North central, and Southwest areas of Pennsylvania.

Step 2: Carbon capture costs

The literature values for levelized capture costs of CO2 abated (hereby referred to as levelized capture costs) describe the cost per ton needed for just the capture process. These values were taken from the Carbonsafe study and Schmelz et al studies. These literature values are broken down by facility type and are presented in Table 1 below.

Process Type	**Levelized Capture Cost of CO_2 abated (2018$ / ton of CO_2 captured)**
Fossil Fuel generation - Coal	47 (Schmelz) 60 (Carbonsafe) 54 (average)
Fossil Fuel generation - Natural Gas	76 (Schmelz) 72 (Carbonsafe) 74 (average)
Fossil Fuel generation of unknown fuel type	61 (average of the coal and natural gas average)
Cement Manufacturing	121 (Carbonsafe)
Steel Manufacturing	95 (Carbonsafe)
Natural Gas processing	17 (Carbonsafe)

Table 1. Process type and levelized capture cost. Numbers were taken from Schmelz et al. or the Carbonsafe study, or averaged. The numbers that were used to calculate the levelized cost are

underlined, which are averages of these studies for the Fossil Fuel generation, or the ones determined from Carbonsafe study for manufacturing processes.

The Carbonsafe study provides 30-year levelized capture costs by power generation type and manufacturing or refining processes with 85% capture capacity, according to Table 4 and 5 of Attachment 3. More detailed assumptions are listed in Table 7 of Attachment 3 in the Carbonsafe report, including the total plant cost, fixed O&M, variable O&M, fuel consumption costs capture rate, and CO_2 captured. The literature did not specify a discount rate, but the underlying project NPVs used to calculate levelized capture cost imply a discount rate (as in Equations 1 and 2. Since the facilities studied in the Carbonsafe are the more common type of fossil fuel generation facilities, capture costs of the 13-county region facilities were approximated using these values. Also, because the plants were based in Ohio and near Pennsylvania, general electricity, energy, and labor costs can be approximated to have similar values.

Schmelz *et al*. gave similar cost estimates for the natural gas and coal electricity generating retrofit carbon capture technology, in 2018 dollars, as reported in Table 1. Schmelz *et al*. examined the top 138 largest emitters among the 343 electricity-generating power plants, but did not report the magnitude of emissions from individual plants. The 343 plants they reported produced a total of 409 Mt CO_2/year, which comes out to an average of 1.2 Mt CO_2/year per plant. Nonetheless, without knowing the distribution of these plants' emissions, it is hard to determine if their parameters match our plant size and type. Also, this report considered plants in both the Midwest and Northeast region, leading to an underestimate of Northeastern average energy prices and labor costs.

The incremental NPV associated with retrofitting each facility type with CCS was found using Equation 2 and the framework presented by Schmelz *et al*. The 30-year levelized cost of CO2 abated at each facility type was multiplied by 85% (capture capacity) of the total amount of CO2 emitted. Finally, the numbers were adjusted for inflation to 2018, as the Carbonsafe study reported their numbers in 2015 dollars.

For all plants emitting above 100 kt CO_2/year (high emitting plants), the final capture cost comes out to be 2.9 bn 2018$/year, and the 30-year incremental NPV comes out to 86 bn 2018$. Following the same framework for plants emitting above 1.7 Mt CO_2/year (top emitting plants), the capture cost is 2.3 bn 2018$/year, and the 30-year incremental NPV comes out to 69 bn 2018$.

<u>Step 3: Transport costs</u>

Literature values from McCoy and Rubin were used to estimate transport via pipeline costs. The cost estimates depended on pipeline distance, design capacity (how much transported), and pipeline size parameters. The first step was to find the distance from the plants to a potential storage facility. The one proposed in the Carbonsafe study found optimal storage geology in Coshocton, Ohio. Most of the high emitting plants run across the northern border of the Southwest Pennsylvania region and along the Ohio-Pennsylvania border. Connecting these plants, the predicted the pipeline system in Pennsylvania should run from Pittsburgh to Coshocton (200 km pipeline) and include another pipeline that branches from the bigger one, connecting Beaver to Greene county (130 km pipeline). Pipeline capacity of 5 Mt and 10 Mt were both considered, as capacity pipelines depends on the CO_2 capacity at the storage sites.

Schmelz *et al*. used natural gas pipeline data to calculate CO_2 pipeline transport costs due to similarities between the two types of infrastructure. The study cited pipeline parameters of 8-15 in. diameter and pressure of 15.3 MPa and provided cost estimates of materials, labor, right-of-way (ROW), and miscellaneous charges. The levelized transport cost of CO_2 abated (referred to as levelized transport cost) describe the cost per ton needed for just the transport via pipeline process. These estimates are presented below:

Levelized transport cost (in 2018 $/ton CO_2 stored)	**5 Mt/year**	**10 Mt/year**
130 km length	$2.41	$2.16
200 km length	$3.01	$2.05

Table 2. Levelized cost of storage in 2018 $/ton CO_2 stored. Literature values were taken from Schmelz et al. and adjusted for inflation.

Because the cost estimates were relatively similar, pipeline costs were averaged across capacity size and length for an average levelized transport cost of 2.41 2018$/ton. To find the total cost for all 35 high emitting plants using Equation 2, the levelized transport cost was multiplied by 85% of the 30-year total emissions. For the high emitting plants, the cost of transport via pipelines came out to be 114 mn 2018$/year, and over 30 years, the incremental NPV is 3.4 bn 2018$. For the top emitting plants, the average distance was assumed be about the same as the case for 35 plants. These numbers come out to 91 mn 2018$/year and a 30-year incremental NPV of 2.7 bn 2018$.

<u>Step 4: Storage costs</u>

To calculate storage costs, literature values from Schmelz *et al* were used. For this, assumptions were made about similar geology characteristics that Carbonsafe concluded for Coshocton, which included onshore storage with oil and gas depleted and saline reservoirs, as well as an injection capacity of 30 years. This models closely to the geology in Pennsylvania, where there are both saline reservoirs and depleted oil and gas reservoirs. The study reported levelized storage cost of CO_2 abated (referred to as levelized storage cost) which describe the cost per ton needed for just the storage process. The study found similar values for between depleted oil and gas reservoirs and saline reservoirs of $5 and $6, respectively. I approximated the storage cost to be $5/ton CO_2. According to Schmelz *et al*, the storage capacity under these costs were at 2.9 Gt CO_2 but only increased slightly for higher capacities, which are negligible for our purposes.

Using Equation 2 and multiplying levelized storage cost by 85% of the total CO2 emissions (adjusted for capture capacity) to estimate the amount reduced, the cost of storage for the 35 high emitting plants comes out to $236 mn $2018/year and a 30-year incremental NPV of 7.1 bn

$2018. For the top emitting plants, the total cost of storage becomes 189 mn $2018/year, and the 30-year incremental NPV is 5.7 bn $2018.

Summary of Cost analysis

Facility Type	**Levelized Cost of CO_2 abated (2018$ / ton of CO_2 captured)**
Coal Powered Generation Plant	61
Natural Gas Powered Generation Plant	81
Fossil Fuel generation of unknown fuel type	68
Cement Manufacturing	128
Steel Manufacturing	102
Lime Manufacturing	128
Natural Gas processing	24

Table 4: Summary of levelized costs per ton by facility type. The levelized cost of CO_2 abated was calculated by adding the levelized cost of capture, transport, and storage for each facility. The capture costs factored in the different costs for each facility, but the storage and transport cost were the same across facility type.

The values shown in Table 4 compare similarly to EIA estimates for levelized cost of CO_2 capture[6] for coal and natural gas generation facilities, which are 40-80 $2019/ton of CO_2.

	High emitting facilities Total Annual Cost	Top emitting Total Annual Cost (in millions 2018$)

	(in millions of 2018$)	
Capture	2,900	2,300
Transport	110	91
Storage	240	190
Total	3,200	2,600

Table 5: Annual costs. High emitting facilities are those that emit >100 kt CO_2/year, and top emitting are ones that emit >1.7 Mt CO_2/year. The capture costs factored in the different costs for each facility. Total cost was calculated by multiplying total costs by 85% of total annual emissions to account for 85% capture capacity.

	High emitting facilities Total 30-year incremental NPV (in billions of 2018$)	Top emitting Total 30-year incremental NPV (in billions of 2018$)
Capture	86	69
Transport	3.4	2.7
Storage	7.1	5.7
Total	97	77

Table 6: 30-year Incremental NPV. High emitting facilities are those that emit >100 kt CO_2/year, and top emitting are ones that emit >1.7 Mt CO_2/year. The capture costs account for the different costs of each facility type. Total cost was calculated by multiplying total costs by 85% of total 30-year emissions to account for 85% capture capacity

<u>Other calculation methodologies</u>

The scale of a CCS system in Pennsylvania was calculated from literature values and Equations 1 and 2. Not all the discount rates were reported but the NPV can be derived from the levelized cost per ton of CO2 abated for 30-year capture, pipeline, and storage project lifetime. Other ways of calculating the carbon capture system cost are:

- Fixed vs variable costs
- Capital vs Operating costs

NETL released stimulations that estimated costs for CCS along the value chain. Some of these simulations include CCSI toolset[7] and SimCCS[8]. CCSI looks at a material's behavior within the CCS system, and SimCCS is an open-source tool for optimizing CO_2 capture, transport, and storage infrastructure.

Conclusion

Most literature on carbon capture rarely estimates total cost, because they focus on describing a representative plant rather than making an estimate of cost for retrofitting a specific plant population. There are frameworks that explain reporting methods like Roussanaly *et al.*[9] and Rubin *et al*.[10]. However, given the lack of data availability that would be needed to gain a more accurate CCS cost analysis, this report generates rough cost estimates. Creating a CCS system connecting the high emitting plants across 30 years would cost approximately $96 bn 2018$. This estimate does not account for scaling factors based on individual plant emission amounts. A more accurate estimate can be generated for CCS systems connecting the top highest emitting plants. For the highest emitting plants, the NPV of a CCS system is approximately $77 bn in 2018 dollars across 30 years. Since most studies only focus on these highest emitting plants and suggest lower costs for these facilities, it makes sense to prioritize connecting the highest emitting plants first.

Appendix Chapter 5

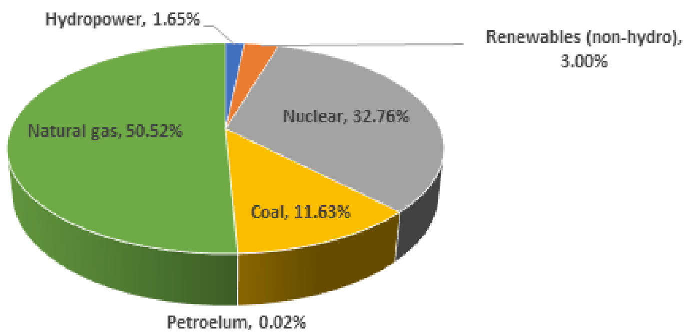
Table 1: Net Electricity Generation for Pennsylvania and the United States[290]

	Pennsylvania			US
Fuel type	**March 2021 monthly (1000 MWh)**	**% Net Generation**	**Change vs. March 2020**	**Change vs. March 2020**
Hydropower	319	1.65%	(7.2%)	(9.5%)
Non-hydro renewables	579	3.00%	1.5%	29.6%
● Wind	N/A	N/A	N/A	34.0%
● Solar thermal and PV	N/A	N/A	N/A	43.8%
● Wood and wood derived fuels	N/A	N/A	N/A	0.2%
● Other Biomass	N/A	N/A	N/A	(4.7%)
● Geothermal	N/A	N/A	N/A	(16.6%)
Nuclear	6,318	32.76%	0.2%	(0.5%)
Oil	4	0.02%	(38.2%)	40.2%

290 https://www.eia.gov/electricity/monthly/xls/, Tables 1 10a, 1 11a, es 1a, 1 09 a, 1 05a, 1 04a, 1 03a, 1 07a.

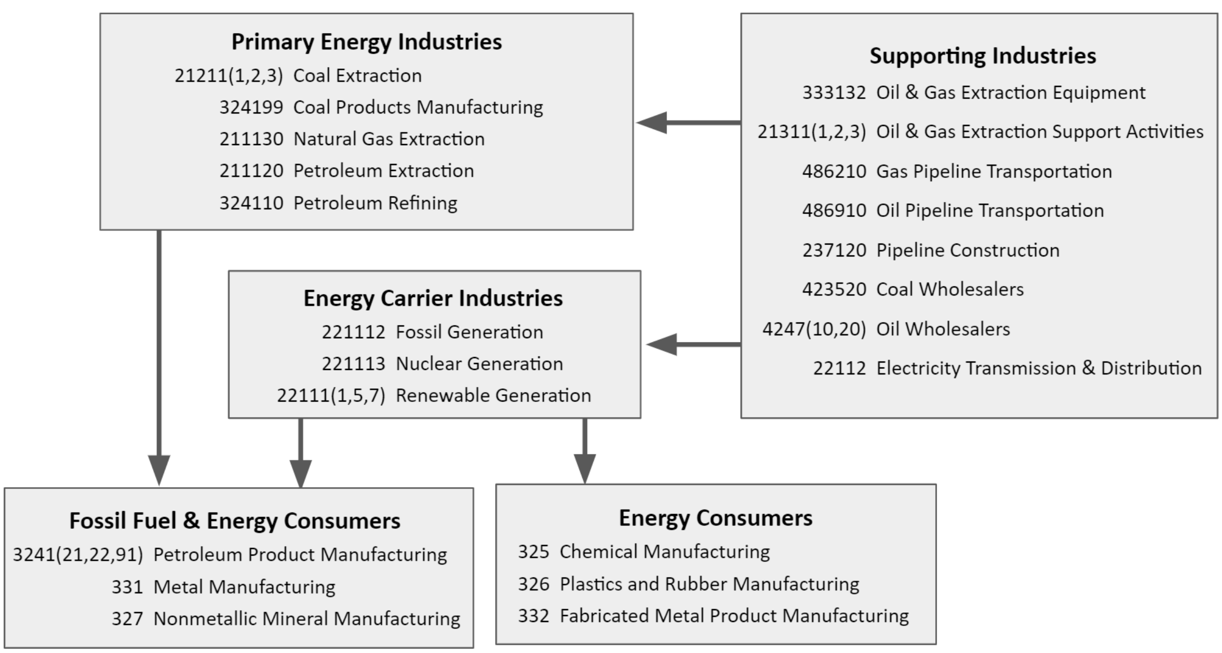
Coal	2,242	11.63%	25.5%	22.5%
Natural Gas	9,741	50.52%	4.7%	(14.8%)
Total net generation	19,283	18,398	4.8%	1.0%

Figure 1: Share of Pennsylvania's Net Generation, March 2021



Appendix Chapter 6

Appendix Figure 1. NAICS codes used to generate categories for Figures 1 and 2 in Chapter 6.



Appendix Table 1. Number of employees (shares of regional employment) in each sector by county in 2021.

Location	Utilities	Mining (except Oil and Gas)	Oil & Gas Extraction
Pennsylvania	34,608 (0.6%)	9015 (0.2%)	4191 (0.1%)
Allegheny	4171 (0.6%)	N.A.	692 (0.1%)
Armstrong	179 (1.1%)	348 (2.7%)	178 (1.4%)
Beaver	1510 (2.7%)	N.A.	N.D.
Butler	360 (0.4%)	141 (0.2%)	141 (0.2%)
Cambria	437 (0.9%)	N.A.	N.D.
Clarion	148 (1.1%)	67 (0.7%)	62 (0.6%)
Fayette	395 (1.0%)	N.A.	N.A.
Greene	218 (1.7%)	1427 (16.4%)	151 (1.7%)
Indiana	810 (2.7%)	N.A.	N.A.
Lawrence	261 (0.9%)	105 (0.4%)	N.A.
Somerset	161 (0.7%)	554 (3.1%)	N.D.
Washington	613 (0.7%)	N.A.	N.A.
Westmoreland	903 (0.7%)	218 (0.2%)	70 (0.1%)
Total 13 Counties	10,166 (1.2%)	I.D.	I.D.

Notes: N.A. - Confidential, N.D. - No data, I.D. - Insufficient data, SOURCE Data from Pennsylvania Dept. of Labor and Industry. Utilities from County Profiles; remaining columns from Quarterly Census of Wages and Employment.

Appendix Table 2. Average wages by county in 2021 in U.S. dollars (ratio of local wages relative to 13 county average in the sector).

	Utilities	Mining (except Oil and Gas)	Oil & Gas Extraction
Pennsylvania	99,248 (1.17)	69,992	116,792
Allegheny	88,275 (1.01)	N.A.	201,968
Armstrong	72,080 (0.82)	72,748	76,700
Beaver	123,769 (1.41)	N.A.	N.D.
Butler	85,165 (0.97)	61,724	133,380
Cambria	75,138 (0.86)	N.A.	N.D.
Clarion	81,887 (0.94)	52,676	53,872
Fayette	80,438 (0.92)	N.A.	N.A.
Greene	82,499 (0.94)	98,124	90,272
Indiana	117,467 (1.34)	N.A.	N.A.
Lawrence	100,742 (1.15)	52,832	N.A.
Somerset	59,832 (0.68)	71,032	N.D.
Washington	86,314 (0.99)	N.A.	N.A.
Westmoreland	84,947 (0.97)	63,024	94,900
Total 13 Counties	87,581		

Note: SOURCE Data from Pennsylvania Dept. of Labor and Industry. Utilities from County Profiles; remaining columns from Quarterly Census of Wages and Employment.

Appendix Table 3. Workforce characteristics for our 13 counties.

	PA	Allegh.	Arm.	Beaver	Butler	Cambria	Clarion
Worker age							
55+ years	33	33	38	36	34	37	34
35-54 years	24	24	25	25	26	24	23
<35 years	43	43	37	39	40	39	43
Race							
White	81	80	98	90	96	94	96
Non-white	19	20	2	10	4	6	4
HH income							
Median	61,744	61,043	51,410	57,807	70,668	46,659	46,680
Total employment (2019)	12,791,530	1,221,744	65,867	165,833	186,899	133,009	38,715

	Fayette	Greene	Indiana	Lawr.	Somer.	Wash.	West.
Worker age							
55+ years	36	33	32	39	37	39	38
35-54 years	25	26	22	24	26	25	25
<35 years	39	41	46	39	37	39	37
Race							
White	93	94	95	93	95	94	95
Non- white	7	6	5	7	5	6	5
HH income							
Median	47,364	54,776	49,320	50,204	49,089	63,543	60,471
Total employment (2019)	131,302	36,870	85,032	86,727	74,361	207,212	352,590

Source: PA.gov county profiles (2021).

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