INDUSTRY
OVERVIEW
SEGMENTS

NATURAL GAS: CARBON CAPTURE

ENERGY & MANUFACTURING in Appalachia

Table of Contents

ENERGY & MANUFACTURING® in Appalachia

Industry Overview

MARKET SIZE & GROWTH FORECASTS

- Natural gas is currently the largest source of energy used for electricity production in the United States, making up 43% of electricity generation in 2023 [1]. Natural gas produces 59% of the electricity in Pennsylvania, thanks in large part to the Marcellus shale region [2].
- The growth of the carbon capture market is expected to produce between 390,000 and 1.8 million employment opportunities, maintaining and creating well-paying union jobs in various industries, including, but not limited to, the fields of raw materials (solvents, steel, cement, etc.), engineering and design (design of carbon capture, pipelines, injection sites, etc.), construction (retrofitting, pipeline development, injection sites, trucking), and operation and maintenance (O&M) [3].
- The United States leads the global carbon capture industry and its carbon capture capacity is expected to shoot up to 1500 Mt CO_2/year by 2050, and almost half of that capacity comes from the fossil Electricity sector (which will primarily be natural gas) [3].

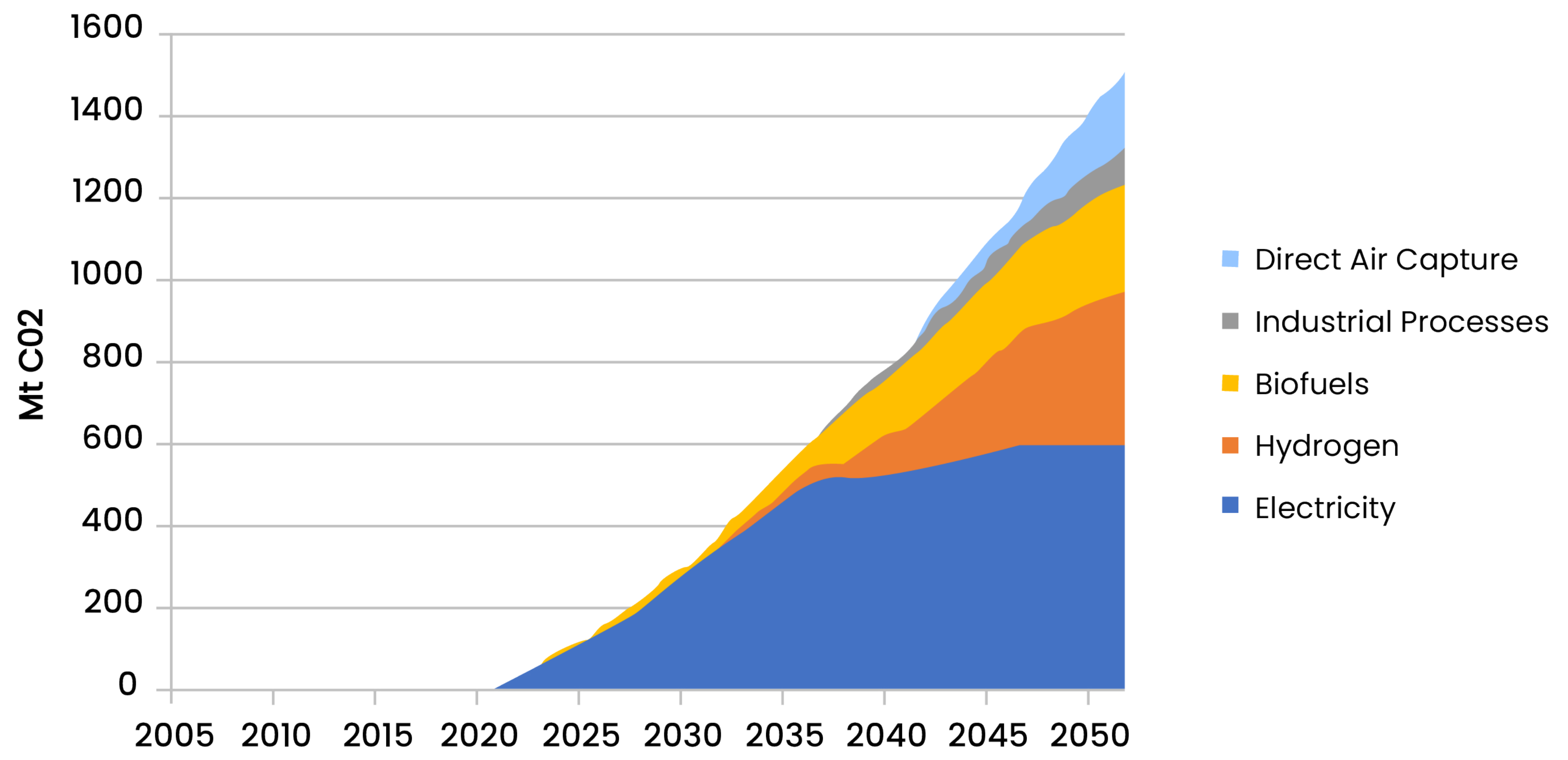

Figure 1. Forecasted annual CO_2 capture capacity of the US based on The Long-Term Strategy of the United States report released by the White House in 2021 [3].

MARKET DRIVERS

- **Government Support.** Carbon capture from fossil sources like natural gas has historically received bipartisan support in the US, and should continue to receive support in the forms of federal incentives (e.g. 45Q) under the new presidential administration [4]. Former President Biden's Bipartisan Infrastructure Law invested $2.3 billion into carbon capture [5].
- **Environmental Goals**. Climate change initiatives to reduce CO_2 emissions are the main driving force for carbon capture technology. Global emissions reduction goals like the Paris Agreement paired with national and state-level initiatives are the primary motivation for investing in carbon capture technology.
- **Need for Natural Gas.** A combination of natural gas and nuclear power are necessary long-term to maintain baseload power in the United States, and carbon capture is the best avenue to sustainably produce power from natural gas long-term.

CHALLENGES & CONCERNS

- **Capital Cost.** Significant investment (~$1 billion) is needed to build a carbon capture system for a large natural gas power plant, and it's unclear who will foot the bill if government subsidies were to go away.
- **Low Capacity Factors.** Many natural gas plants are considered "peaker" plants that only run during peak electricity demand hours. Plants with low capacity factors- like these peaker plants- are less than ideal for carbon capture due to the rapid ramp-up and the long idle times that make it hard to pay off the large capital investment with carbon credits.
- **Environmental Concerns.** Some of the leading chemicals used for carbon capture are toxic solvents that can vaporize and escape into the environment. However, many safer alternatives (e.g. solid sorbents) have since been developed.
- **Carbon Storage.** The large quantities of CO_2 that would be captured from a natural gas plant would need to be transported and stored underground. The US doesn't currently have extensive CO_2 pipelines and there's public fear about underground CO_2 storage despite its proven safety.

Natural Gas Carbon Capture System Overview

Carbon capture (CO_2 removal from a gas mixture) can be performed on power plant or industrial flue gas, air or seawater. The focus of this overview, however, is on carbon capture from natural gas exhaust, which contains ~4% CO_2. There are a range of carbon capture approaches that could be applied to natural gas exhaust- ranging from liquid solvents to membranes to solid sorbents- but the focus of this overview will be on a liquid solvent system called CANSOLV developed by Shell that has been used as a benchmark in the Department of Energy carbon capture reports.

A representative block flow diagram of a natural gas combined cycle (NGCC) power plant with carbon capture is shown in Figure 2. This system represents a 945 MWe gross NGCC plant with a liquid solvent (CANSOLV) carbon capture system capturing 90% of the CO_2 from the plant exhaust. This carbon capture system is estimated to cost $567M ($642/kW) and require 41.8 MWe. To put these numbers in context, this carbon capture system costs 40% of the total NGCC + carbon capture system price ($1593/kW) and constitutes 67% of the total auxiliary load of the plant (62 MWe). Adding a carbon capture system to a natural gas plant therefore requires significant financial investment and electricity, and only makes sense in the context of subsidies (e.g. carbon tax credits) that offset these costs.

This theoretical system NGCC + carbon capture system is described in extensive detail under Case B32B.90 of the latest National Energy Technology Laboratory (NETL) baseline report for fossil energy plants [6].

In the block flow diagram (Figure 2), exhaust gas from the heat recovery steam generator (HRSG) of the NGCC plant (**state 4** in Fig. 2) flows into the solvent capture subsystem at a flowrate of 5.2M kg/hr, where it gets pushed through a large solvent absorber column by a blower. Around 90% of the CO_2 in that gas gets captured by the liquid solvent in that absorber column before the gas leaves (**state 8**) and is sent to an exhaust stack. The CANSOLV solvent gets pumped to the stripper column once it's loaded with CO_2, where steam extracted from the NGCC plant enters (state 5) to strip the CO_2 out of the solvent. This steam condenses after removing the CO_2 in the stripper and is sent back to the plant (**state 6**), the stripped solvent is recirculated back to the absorber, and the stripped CO_2 (**state 7**) is sent through a series of compressors and dryers to remove any excess water and pressurize it to ~15 MPa for CO_2 pipeline transportation (**state 16**). A breakdown of the key components of this carbon capture system is given in the next section.

Natural Gas Carbon Capture System Overview

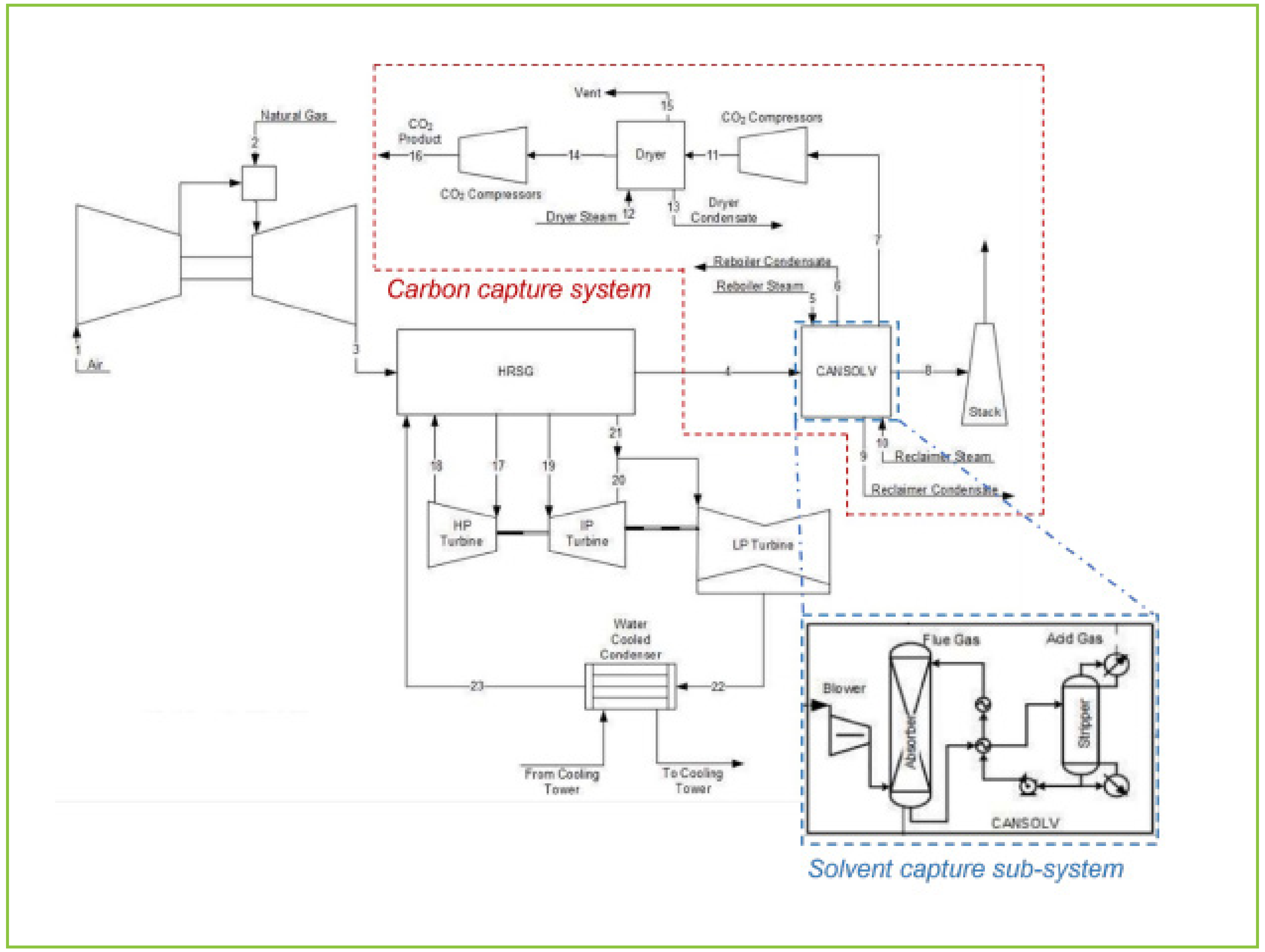

Figure 2. Block flow diagram of a natural gas combined cycle (NGCC) power plant with solvent carbon capture. This diagram is adapted from the NETL baseline report for fossil plants with carbon capture [6].

ENERGY & MANUFACTURING in Appalachia

Component List of a Typical Natural Gas Carbon Capture System

Table 1 provides a list of all of the major components of the carbon capture system shown in Figure 2. This table includes all of the major vessels, heat exchangers and pumps/blowers needed to move the flue gas, CO_2, and solvent through this system. However, this list does not account for pipes or ductwork, and it also doesn't account for steam extraction from the power plant for the absorber column. Various components embedded in the CANSOLV capture system (but not listed in Table 1) can be obtained by requesting Shell's CANSOLV fact sheet [7].

Table 1. Major components of a carbon capture system for an NGCC power plant [6].

COMPONENT	NAICS		DESCRIPTION	DESIGN CONDITIONS	QUANTITY
CANSOLV	325199	Methylamine manufacturing	Amine-based CO_2 capture solvent	5,757,000 kg/hr 6.3 wt % CO_2 concentration	1
CANSOLV LP Condensate Pump	333914	Centrifugal pumps manufacturing	Centrifugal pump that circulates a low-pressure stream of the solvent	871 lpm @ 1 m H_2O	1
CANSOLV HP Condensate Pump	333914	Centrifugal pumps manufacturing	Centrifugal pump that circulates a high-pressure stream of the solvent	8 lpm @ 5 m H_2O	1
CO_2 dryer material	325199	Ethylene glycol manufacturing	Triethylene glycol (TEG) used to dry out the captured CO_2 before compression.	Inlet: 86 m^3/min @ 2.8 MPa Outlet: 2.7 MPa Water Recovered: 526 kg/hr	1

ENERGY & MANUFACTURING in Appalachia

Component List of a Typical Natural Gas Carbon Capture System

COMPONENT	NAICS		DESCRIPTION	DESIGN CONDITIONS	QUANTITY
CO_2 Compressor	423830	Compressors (except air-conditioning, refrigeration) merchant wholesalers	Integrally geared, multi-stage centrifugal	4.0 m3/min @ 15.3 MPa, 82°C	2
CO_2 Aftercooler	332410	Heat exchangers manufacturing	Shell and tube heat exchanger	Outlet: 15.3 MPa, 30°C Duty: 47 GJ/hr	2
Blower	423830	Blowers, industrial, merchant wholesalers	For flue gas entering absorber column	Inlet: 5,233,836 kg/hr, 103°C, 103.4 kPa	1
Reactor vessels	332420	Absorbers, gas, heavy gauge metal, manufacturing	For the absorber and stripper columns	Absorber flue gas inlet: 5,233,836 kg/hr, 103°C, 103.4 kPa CANSOLV flowrate through both vessels: 5,757,000 kg/hr	2
CO_2 dryer vessel	332420	Vessels, heavy gauge metal, manufacturing	For drying CO_2 using TEG before CO_2 compression	Inlet: 86 m3/min @ 2.8 MPa Outlet: 2.7 MPa Water Recovered: 526 kg/hr	1

Carbon Capture & Natural Gas Resources

CARBON CAPTURE RESOURCES:

DOE Office of Fossil Energy and Carbon Management (FECM): This is the primary government office in the United States that oversees carbon capture and storage projects, including investment in R&D and funding for pilot testing of carbon capture technologies.

- **FECM Funding Opportunities:** This is a list of all FECM funding solicitations.
- **FECM CONNECT Toolkit:** CONNECT Toolkit includes the location and other details of publicly announced and federally funded carbon management research, development, and demonstration projects.
- **FECM Carbon Matchmaker:** Carbon Matchmaker is an online information resource to connect users across the carbon capture, utilization, and storage (CCUS) and carbon dioxide removal (CDR) supply chains.

45Q Tax Credit Information: This pamphlet outlines which US carbon capture projects are eligible for which tax credits according to the 45Q tax credit program and the Inflation Reduction Act.

National Carbon Capture Center: This is the primary pilot testing center for carbon capture technologies in the US, operated by the Department of Energy and located in Wilsonville, AL.

REGIONAL NATURAL GAS TRADE ASSOCIATIONS:

Energy Association of Pennsylvania: The Energy Association of Pennsylvania (EAP) is a trade association that represents and promotes the interests of regulated electric and natural gas distribution companies operating in Pennsylvania.

Ohio Oil & Gas Association: The Ohio Oil & Gas Association is a trade association with members representing the people and companies directly responsible for the production of crude oil, natural gas, and associated products in Ohio.

Gas & Oil Association of West Virginia: GO-WV's mission is to support and advocate for their 500 member companies and their thousands of employees as they contribute to the growth and prosperity of West Virginia by safely providing reliable clean energy.

Maps of U.S. Natural Gas, Carbon Capture and CO_2 Storage

MAP OF NATURAL GAS CARBON CAPTURE PROJECTS FUNDED BY DEPARTMENT OF ENERGY

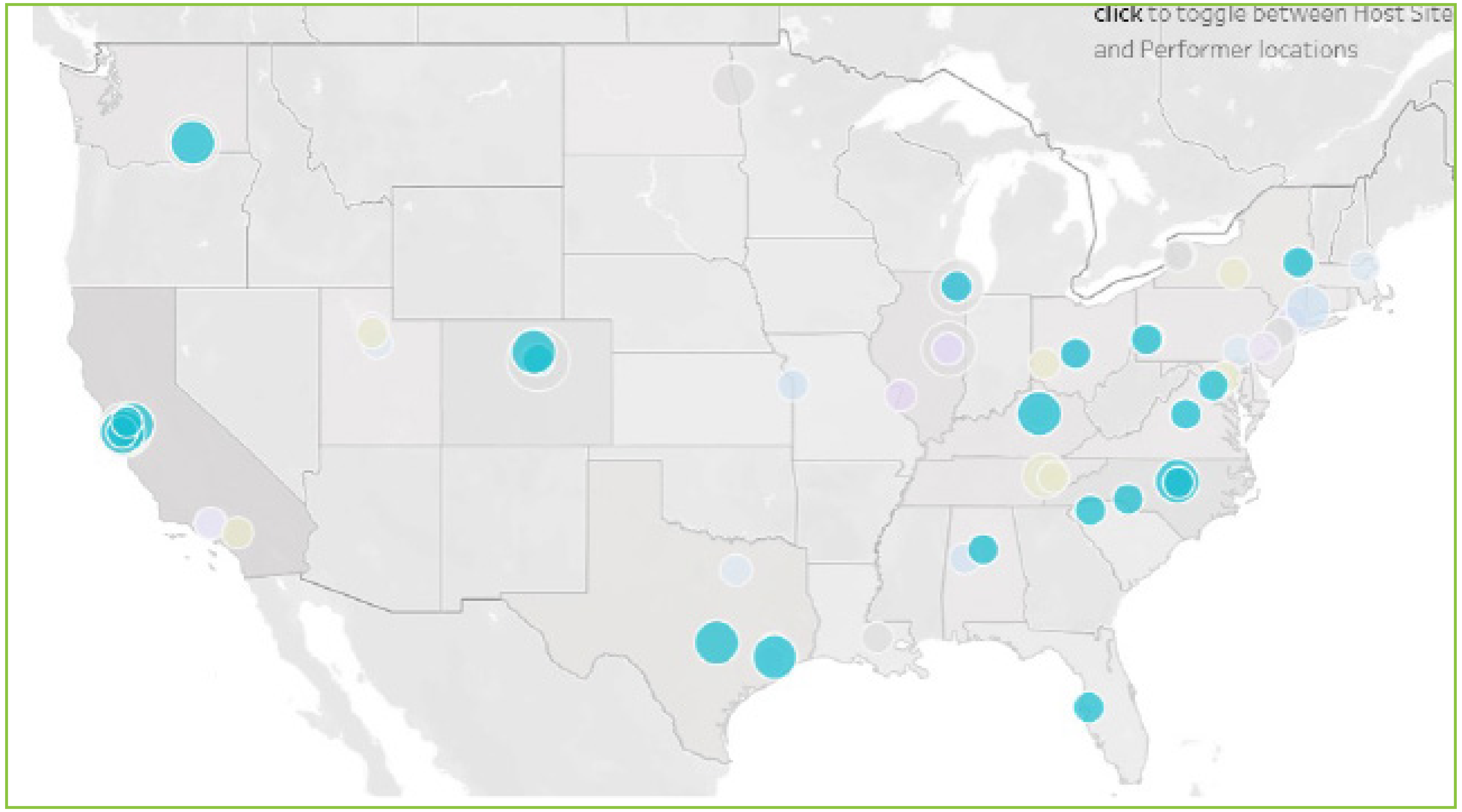

Figure 3. Map of all active and inactive projects for natural gas carbon capture that have been funded by the Department of Energy's Point Source Carbon Capture program [9].

ENERGY & MANUFACTURING in Appalachia

MAP OF U.S. CO_2 STORAGE CAPACITY

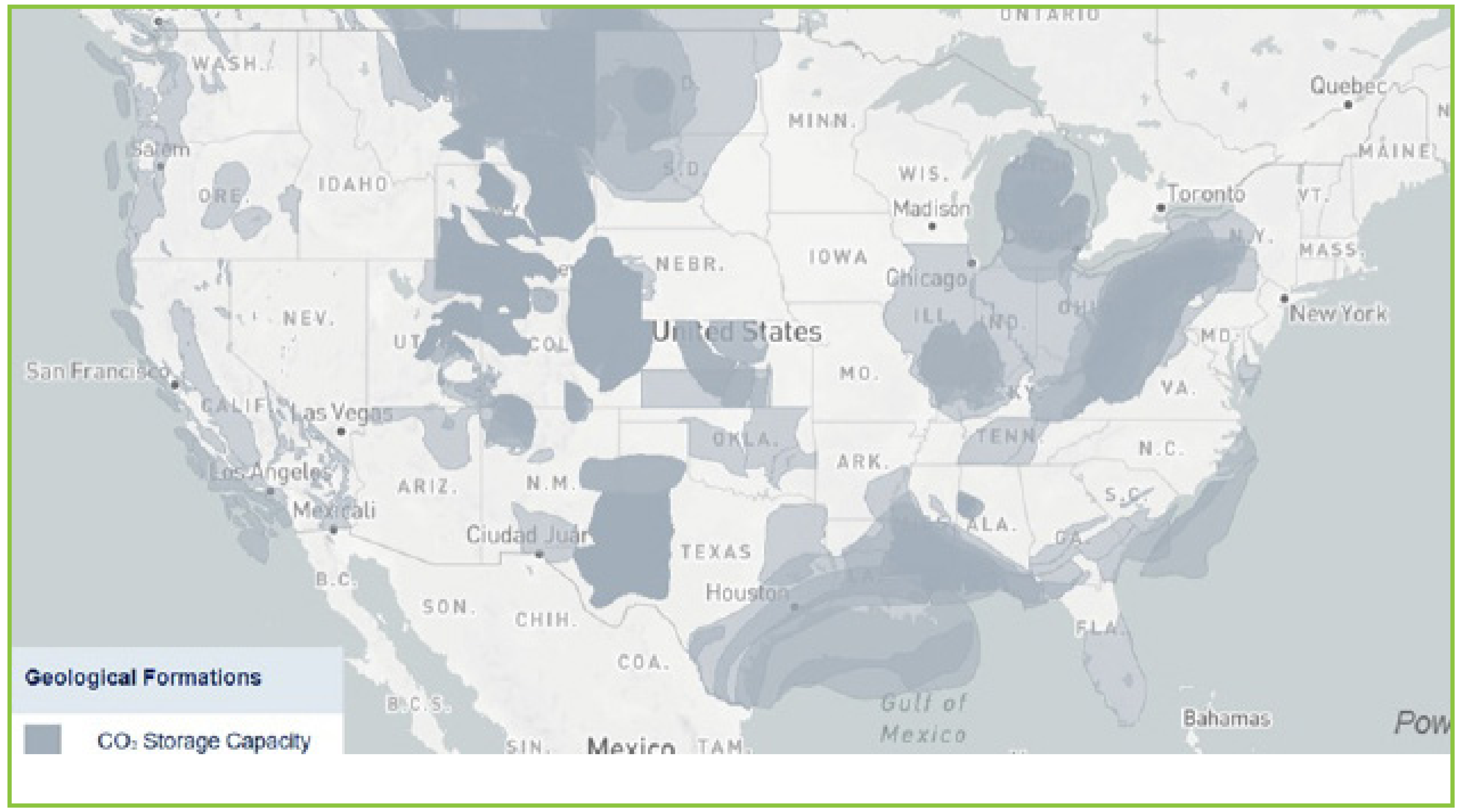

Figure 4. U.S. Underground CO2 Storage Capacity Map [10].

MAP OF U.S. NATURAL GAS POWER PLANTS

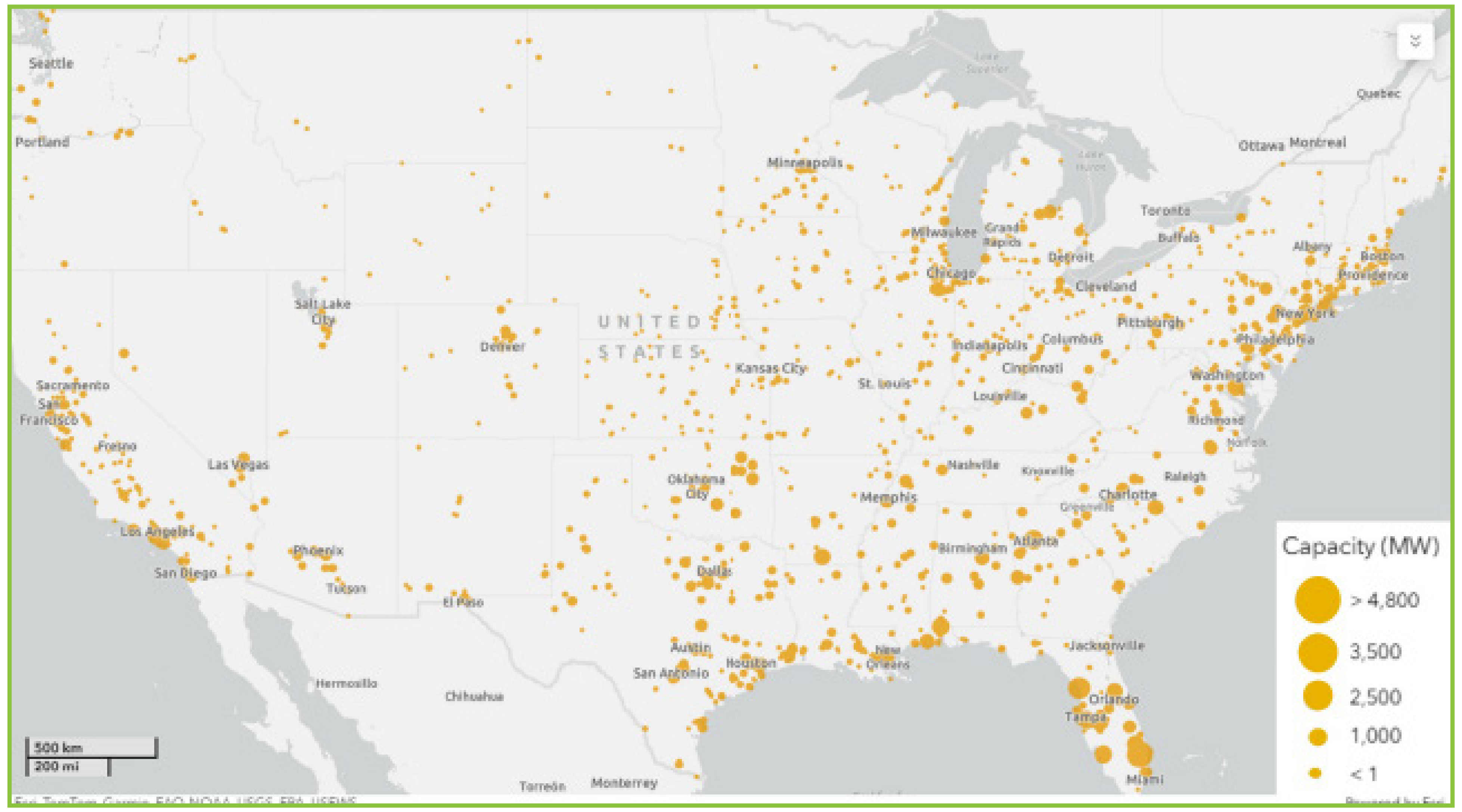

Figure 5. Map of natural gas power plants in the U.S. [8].

ENERGY & MANUFACTURING in Appalachia

References

[1] U.S. Energy Information Administration, "Use of natural gas-fired generation differs in the United States by technology and region," 12 March 2025. [Online]. Available: https://www.eia.gov/todayinenergy/detail.php?id=61444#.

[2] U.S. Energy Information Administration, "Electricity Data Browser," [Online]. Available: https://www.eia.gov/electricity/data/browser/. [Accessed 13 03 2025].

[3] National Energy Technology Laboratory, "Carbon Capture, Transport & Storage," 24 02 2022. [Online]. Available: https://www.energy.gov/sites/default/files/2022-02/Carbon%20Capture%20Supply%20Chain%20Report%20-%20Final.pdf. [Accessed 19 04 2025].

[4] S. Manhart, "Carbon Removal Policy in Trump's Second Term: What to Expect," Carbonfuture, 13 01 2025. [Online]. Available: https://www.carbonfuture.earth/magazine/carbon-removal-policy-in-trumps-second-term-what-to-expect. [Accessed 14 03 2025].

[5] Energy.gov, "Biden-Harris Administration Announces Over $2.3 Billion Investment To Cut U.S. Carbon Pollution," 05 May 2022. [Online]. Available: https://www.energy.gov/articles/biden-harris-administration-announces-over-23-billion-investment-cut-us-carbon-pollution. [Accessed 17 03 2025].

[6] T. Schmitt, S. Leptinsky, M. Turner, A. Zoelle, M. Woods, T. Shultz and a. R. James, "Fossil Energy Baseline Revision 4a," National Energy Technology Laboratory, Pittsburgh, PA, 2022.

[7] Shell Catalysts & Technologies, "A leading post-combustion CO_2 removal technology," [Online]. Available: https://catalysts.shell.com/en/Cansolv-co$_2$-fact-sheet. [Accessed 31 03 2025].

[8] Synapse Energy Economics, Inc., "Interactive Map of U.S. Power Plants," [Online]. Available: https://experience.arcgis.com/experience/bb8c905b75f84d908ab83f579498d085/page/Page. [Accessed 01 04 2025].

[9] National Energy Technology Laboratory, "Carbon CapInteractive Project Map," [Online]. Available: https://netl.doe.gov/carbon-management/carbon-capture/psc-map. [Accessed 19 04 2025].

[10] Clean Air Task Force, "U.S. Carbon Capture Activity and ProjMap," [Online]. Available: https://www.catf.us/ccsmapus/. [Accessed 13 03 2025].

Energy & Manufacturing in Appalacia Program

This energy overview research and report was created under the Energy & Manufacturing in Appalachia (EMA) program made possible with grant funding from the Appalachian Regional Commission. EMA provides technical assistance and business support to small and medium manufacturers and enterprises seeking to expand business, production and jobs in the energy supply chains. Energy is a big expense for manufacturing companies. EMA helps companies save money with energy efficiency and emissions reductions.

The EMA program supports Appalachia in 156 counties of Maryland, New York, Ohio, Pennsylvania, and West Virginia. This program was established to help small and medium manufacturers be a part of this Energy Economy. This program is managed by Manufacturing Extension Partnership (MEP) organizations from five Appalachian states. The activities and intended outcomes of EMA align with the National Institute of Standards and Technology (NIST) MEP and its mission to enhance the productivity and technological performance of U.S. manufacturing.

This Natural Gas: Carbon Capture energy overview was drafted by Dr. Katherine Hornbostel, who pulled together by a variety of information sources referenced within the document. Dr. Hornbostel serves as the department chair and an associate professor in the Mechanical Engineering department at Duquesne University. She can be contacted on **LinkedIn** or through email at **hornbostelk@duq.edu.**

Learn more about the Energy & Manufacturing in Appalachia program by visiting: **https://www.wemakeithere.org/energy/** and join the **EMA LinkedIn group**.

Contact EMA Program Manager, Tom Reed, directly at **Tom@WeMakeItHere.org** and (412) 918-4269 with any questions or assistance.

ENERGY & MANUFACTURING in Appalachia