ORAL ARGUMENT NOT YET SCHEDULED
No. 24-1120 (and consolidated cases)

IN THE UNITED STATES COURT OF APPEALS
FOR THE DISTRICT OF COLUMBIA CIRCUIT

STATE OF WEST VIRGINIA ET AL.,

Petitioners,

v.

U.S. ENVIRONMENTAL PROTECTION AGENCY ET AL.,

Respondents.

On Petitions for Review of Final Agency Action of the
United States Environmental Protection Agency
89 Fed. Reg. 39,798 (May 9, 2024)

BRIEF FOR *AMICI CURIAE* CARBON CAPTURE AND STORAGE SCIENTISTS AND ENGINEERS IN SUPPORT OF RESPONDENTS

MICHAEL BURGER
ROMANY WEBB
Counsel for Amici Curiae
Columbia Law School
Sabin Center for Climate Change Law
435 West 116th Street
New York, NY 10027
Tel: (212) 854-2372
mburger@law.columbia.edu

CERTIFICATE AS TO PARTIES, RULINGS, AND RELATED CASES

Pursuant to D.C. Circuit Rule 28(a)(1)(A), counsel certifies as follows:

A. Parties and *Amici*

Except for the following, all parties, intervenors, and *amici* appearing in this Court are, to the best of my knowledge, listed in the Brief for Respondents: *Amici Curiae* Carbon Capture and Storage Scientists and Engineers; National League of Cities, the U.S. Conference of Mayors, and Cities, Towns, Counties, and Mayors; and the Institute for Policy Integrity in support of Respondents.

B. Rulings Under Review

References to the rulings at issue appear in the Brief for Respondents.

C. Related Cases

References to related cases appear in the Brief for Respondents.

RULE 29 STATEMENTS

The following parties have indicated their consent to the filing of this brief: Petitioner States;[1] Respondent U.S. Environmental Protection Agency; and Respondent-Intervenors American Lung Association, American Public Health Association, Clean Air Council, Clean Wisconsin, Natural Resources Defense Council, Power Companies Climate Coalition, and States and Municipalities.[2] All remaining parties do not oppose or take no position on the filing of this brief.

Pursuant to Federal Rule of Appellate Procedure 29(c)(5), *amici* state that no party or party's counsel authored this brief in whole or in part, and that no other person besides *amici* or their counsel contributed money that was intended to fund preparing or submitting the brief.

---

[1] State Petitioners include: State of Alabama, State of Alaska, State of Arkansas, State of Florida, State of Georgia, State of Idaho, State of Indiana, State of Iowa, State of Kansas, State of Kentucky, State of Louisiana, State of Mississippi, State of Missouri, State of Montana, State of Nebraska, State of New Hampshire, State of North Dakota, State of Ohio, State of Oklahoma, State of South Carolina, State of South Dakota, State of Tennessee, and State of West Virginia.

[2] State and Municipal Respondent-Intervenors include: State of Arizona, State of Colorado, State of Connecticut, District of Columbia, State of Delaware, State of Illinois, State of Hawai‘i, State of Maryland, State of Maine, State of Michigan, State of Massachusetts, State of Minnesota, State of New Mexico, State of North Carolina, State of New York, State of Oregon, State of Pennsylvania, State of Rhode Island, State of Vermont, State of Washington, State of Wisconsin, City of Boulder, City of Chicago, City and County of Denver, City of New York, and California Air Resources Board.

Pursuant to D.C. Circuit Rule 29(d), *amici* state that a separate brief is necessary for their presentation to this Court due to their distinct expertise and interests. *Amici* are scientists and engineers with expertise in carbon capture, utilization, and storage technologies. They have a unique capacity to aid the Court in understanding the extent to which these technologies are adequately demonstrated and available for installation at coal-fired and natural gas-fired power plants. No other *amici* of which we are aware share this perspective or address these specific issues. Accordingly, the *amici*, through counsel, certify that filing a joint brief would not be practicable.

/s/ Michael Burger
Michael Burger

TABLE OF CONTENTS

TABLE OF AUTHORITIES

Cases

Statutes

Rules

Other Authorities

GLOSSARY OF ABBREVIATIONS

BSER	Best System of Emission Reduction
CAA	Clean Air Act
CCS	Carbon Capture and Storage
CO_2	Carbon Dioxide
DOE	United States Department of Energy
DOT	United States Department of Transportation
EOR	Enhanced Oil Recovery
EPA	United States Environmental Protection Agency
IEA	International Energy Agency
MMT	Million Metric Tons
MW	Megawatt
NSPS	New Source Performance Standard
RD&D	Research, Development, and Demonstration

IDENTITY AND INTERESTS OF *AMICI CURIAE*

Amici curiae are six scientists and engineers, all of whom are experts in various aspects of carbon capture and storage ("CCS") technologies. As such, they are uniquely well-suited to inform the Court about the technical viability and advanced status of CCS technologies. Their names and affiliations are listed below. Additional information about their experience and credentials is available in the *Motion for Leave to Participate as* Amici Curiae.

- David Goldberg (Columbia University)
- Susan Hovorka (University of Texas, Austin)
- Ah-Hyung Alissa Park (University of California, Los Angeles)
- Gary Rochelle (University of Texas, Austin)
- Edward Rubin (Carnegie Mellon University)
- Jennifer Wilcox (University of Pennsylvania)

ARGUMENT

The Clean Air Act ("CAA") requires the U.S. Environmental Protection Agency ("EPA") to set new source performance standards ("NSPS") based on the "degree of emissions limitation achievable through the application of the best system of emission reduction ["BSER"] which . . . the Administrator determines has been adequately demonstrated." 42 U.S.C. § 7411(a)(1). The CAA also requires EPA to set performance standards for existing sources of certain pollutants. *Id.* § 7411(d). EPA has established NSPS for carbon dioxide ("CO_2") emissions from new base load natural gas-fired combustion turbines, and performance standards for existing coal-fired boilers, based on its determination that the BSER for these plants includes CCS with a ninety percent capture rate. 89 Fed. Reg. 39,798 (May 9, 2024). *Amici curiae*, who are experts in CCS science and technology, agree with EPA's determination that the technologies required to implement CCS with a ninety percent capture rate are adequately demonstrated and achievable.

EPA established separate NSPS for three sub-categories of natural gas-fired combustion turbines: (1) base load, (2) intermediate load, and (3) low load. EPA established a two-phase NSPS for base load facilities. For the second phase, base load facilities must limit their CO_2 emissions to 100 pounds CO_2/megawatt-hour. This emission rate is based on the degree of emission limitation achievable through "the use of CCS with a ninety percent capture rate." *Id.* at 39,902–03, 39,947–48. EPA has also applied this BSER to set emissions limitations for existing coal-fired power plants which intend to operate after January 1, 2039. *Id.* at 39,801. Both have a compliance date of January 1, 2032.

EPA based the standards on a CCS system involving post-combustion capture of CO_2. The basic process of post-combustion CO_2 capture is straightforward and akin to the process for removing other pollutants from the exhaust or "flue gas" produced by certain power plants and other industrial facilities as a byproduct of their operations. To capture the CO_2, that flue gas is pumped through a duct into a carbon scrubber rather than being released directly into the air. Most commonly, the carbon scrubber uses a chemical solution to separate the CO_2 from the rest of the flue gas. From there, the CO_2-depleted flue gas is vented into the air and the captured CO_2 is moved to a compressor, where it is compressed for transportation and then delivered to a storage site or utilization facility. *See generally Carbon Capture*, MIT, https://climate.mit.edu/explainers/carbon-capture. The process is essentially the same regardless of whether the flue gas is generated by an industrial plant or a power plant. It is also similar to the process of removing other noxious gases, such as sulfur dioxide, from power plant emissions. For example, sulfur dioxide scrubbers are installed at emitting units within power plants to process flue gas.

CCS technologies have been successfully implemented at scores of facilities worldwide, including multiple power plants, such as the Petra Nova facility in Texas and Boundary Dam facility in Canada. These and other "at scale" commercial projects establish that ninety percent CO_2 capture is achievable. Although the projects have not continuously captured ninety percent of CO_2 emissions on a facility-wide basis, that is by design and not due to some flaw in the capture technology. The projects were intended to, and did, validate the capture technology at scale and establish that it is feasible, reliable, and cost effective in achieving ninety percent emission reductions. With that established, the technology is now being deployed more broadly, with several larger projects currently in development.

The experience gained from Boundary Dam, Petra Nova, and other projects has also enabled CCS cost reductions. Thus, although the performance standards are already attainable taking into account cost, continued technological improvements and cost declines will make compliance with the standard even easier in the near future. The history of other power plant emission control technologies, such as the flue gas desulfurization systems implemented in response to past performance standards, provides compelling evidence that "learning by doing" dramatically reduces costs over time. *Amici* agree the CO_2 performance standards are readily achievable based on CCS systems that have been demonstrated by real-world applications.

I. CCS Systems that Capture Ninety Percent of CO_2 Are Available and Being Deployed

The Court of Appeals for the D.C. Circuit has described an "adequately demonstrated" system as one which has been "shown to be reasonably reliable, reasonably efficient, and which can reasonably be expected to serve the interests of pollution control without becoming exorbitantly costly." *Essex Chem. Corp. v. Ruckelshaus*, 486 F.2d 427, 433 (D.C. Cir. 1973). Given these legal parameters, EPA's determination that CCS with a ninety percent capture rate is adequately demonstrated is scientifically sound.

There is ample evidence to support EPA's determination. CCS technologies have been developed, deployed, and improved over decades in the industrial context and, more recently, in the power sector. The number of large-scale CCS projects in operation has grown over time, and that trend is continuing with several new projects currently under development.

This section details the development of CCS component technologies and their successful combination in large-scale integrated systems. The section then explains, consistent with EPA's determination, that the technology required to achieve CCS with a ninety percent capture rate is available and already being deployed. Finally, the section explains that use of this technology can be rapidly implemented across power plants before the January 2032 compliance date.

A. CCS Technologies Have Been Successfully Deployed and Scaled Up

There are three components to CCS technology: CO_2 capture, CO_2 transport, and CO_2 storage. The specific technologies comprising the BSER include (1) post-combustion capture using a chemical absorption process; (2) transportation via short (approximately sixty-two miles or less), lateral CO_2 pipelines; and (3) permanent geologic storage, especially in deep saline reservoirs. 89 Fed. Reg. at 39,846, 39,855. All three components have been adequately demonstrated, both individually and in combination. CCS components are highly modular and easily linked, as demonstrated by at least thirty-four commercial-scale integrated CCS projects currently in operation.[3]

While we have the most experience with CCS at industrial facilities, the same technologies that have been proven there can also be used at power plants. Berend Smit et al., *The Grand Challenges in Carbon Capture, Utilization, and Storage*, 2 Front. Energy Res. 1 (2014). This has already occurred at several facilities including, but not limited to, Petra Nova, Boundary Dam, Plant Barry, and Bellingham, all of which have demonstrated that a ninety percent capture rate is reliably achievable.

1. CCS Component Technologies Are Available

CO_2 Capture. Carbon capture technologies were first developed in the 1930s to remove CO_2 from raw natural gas using a process called chemical absorption. The process uses chemical solvents, most commonly amines, to separate CO_2 from other gases. Anand Rao & Edward Rubin, *A Technical, Economic, and Environmental Assessment of Amine-Based CO_2 Capture Technology for Power Plant GHG Control*, 36 Env't Sci. Tech. 4,467, 4,468 (2002). Industrial facilities began implementing this process in the 1970s to separate CO_2 from flue gas streams for sale to enhanced oil recovery ("EOR") operations and for other

[3] *See* Table 1, *infra* page 16.

industrial applications. *Id*. Since then, the chemical absorption process has been refined and other carbon capture methods have been developed, including physical absorption, membrane separation, adsorption, and cryogenic separation. *See id*. These processes can be implemented in three types of capture systems at power plants: post-combustion, pre-combustion, or oxy-combustion systems. Heleen de Coninck & Sally Benson, *Carbon Dioxide Capture and Storage: Issues and Prospects*, 39 Ann. Rev. Env't Res. 243, 248 (2014); Jennifer Wilcox, *Carbon Capture* (2012).

The BSER determined by EPA incorporates post-combustion capture with chemical absorption. This is the most "mature" carbon capture technology, having been used for fifty-plus years. Cong Chao et al., *Post-Combustion Carbon Capture*, 138 Renewable and Sustainable Energy Rev. 1 (2021); Rao & Rubin, *supra*; 89 Fed. Reg. at 39,846. Post-combustion capture with amine-based solvents has long been "the technology of choice for" power plants with CCS. Eva Sanchez Fernandez et al., *Operational Flexibility Options in Power Plants with Integrated Post-Combustion Capture*, 48 Int'l J. Greenhouse Gas Control 275, 275 (2016). Amine-based absorption systems designed specifically for large-scale post-combustion capture at power plants are commercially available.[4] Suppliers

[4] Products include: Fluor Econamine FG Plus, Mitsubishi Heavy Industries KM-CDR Process, BASF/Linde OASE Blue, and Shell CANSOLV. EPA, *Technical Support Document: Literature Survey of Carbon Capture Technology*, EPA-HQ-

continue to refine their amine-based capture systems to enhance performance and reduce costs.[5]

Pre-combustion and oxy-combustion systems are not contemplated by the BSER but can also be used to meet the performance standards. Although post-combustion systems have been much more prominent in the power sector, studies suggest that pre-combustion and oxy-combustion methods could prove increasingly viable for carbon capture in the future in some applications. *See, e.g.*, Xiang Yun Debbie Soo et al., *Advancements in CO_2 Capture by Absorption and Adsorption: A Comprehensive Review*, 81 J. CO_2 Utilization 1 (2024); Zhongde Dai & Liyuan Deng, *Membranes for CO_2 Capture and Separation*, 335 Separation and Purification Tech. 1 (2024). There have been demonstration projects with pre-combustion and oxy-combustion systems at power plants and commercial use of pre-combustion capture in industrial applications. *See* Wai Lip Theo et al., *Review of Pre-Combustion Capture and Ionic Liquid in Carbon Capture and Storage*, 183 Applied Energy 1,633 (2016).

OAR-2013-0495-11773, at 10–11 (2015). *See also* Global CCS Institute, *State of the Art: CCS Technologies 2023* (2023), https://www.globalccsinstitute.com/wp-content/uploads/2023/08/State-of-the-Art-CCS-Technologies-2023-Global-CCS-Institute.pdf (listing additional CCS vendors).

[5] Companies include Mitsubishi, General Electric, Babcock and Wilcox, Aker Clean Carbon, HTC, and Huaneng.

CO_2 Transport. Just as capture technology has a long history of use, CO_2 transport via pipeline has occurred at a large scale for decades. Accordingly, the U.S. already has CO_2 pipeline infrastructure that connects entire regions via large, interstate systems. Cong. Rsch. Serv., *Carbon Capture and Sequestration (CCS) in the United States* 8 (2022), https://sgp.fas.org/crs/misc/R44902.pdf. As of 2023, there were approximately 5,340 miles of operational CO_2 pipelines in the U.S., transporting over sixty-six million metric tons ("MMT") of CO_2 annually. *Id.* at 8; DOT, *Annual Report Mileage for Hazardous Liquid or Carbon Dioxide Systems*, https://www.phmsa.dot.gov/data-and-statistics/pipeline/annual-report-mileage-hazardous-liquid-or-carbon-dioxide-systems; 89 Fed. Reg. at 39,855.

Pipelines are a cost-effective, reliable means of transporting CO_2 and can be expanded quickly. Between 2011 and 2022, the number of pipeline miles increased by fourteen percent. *Id.* at 39,855, n.381. Additional CO_2 pipeline projects are currently under development, including the Midwest Carbon Express line, which will extend approximately 2,000 miles across five states. Cong. Rsch. Serv., *Carbon Dioxide (CO_2) Pipeline Development: Federal Initiatives* 1 (2023), https://crsreports.congress.gov/product/pdf/IN/IN12169. There are also plans to convert part of the existing 300,000 mile long natural gas transmission system to carry CO_2. Cong. Rsch. Serv., *Siting Challenges for Carbon Dioxide (CO_2) Pipelines* 2 (2023), https://crsreports.congress.gov/product/pdf/IN/IN12269.

Importantly, though, EPA's BSER does not require the expansion of interstate CO_2 pipelines. Rather, it is based on the use of short, lateral pipelines connecting emitting facilities to the nearest CO_2 storage reservoir. 89 Fed. Reg. at 39,855. This is viable because of the widespread availability of permanent storage sites. Approximately eighty percent of emitting facilities in the U.S. are located within sixty-two miles of potential storage sites and seventy-five percent are within thirty-one miles. IEA, *Special Report on Carbon Capture Utilisation and Storage: CCUS in Clean Energy Transitions* 131–32 (2020), https://iea.blob.core.windows.net/assets/181b48b4-323f-454d-96fb-0bb1889d96a9/CCUS_in_clean_energy_transitions.pdf; 89 Fed. Reg. at 39,855–62. Construction of short, lateral pipelines is thus a feasible near-term option.

Further, new plants can be sited close to storage reservoirs, reducing transportation needs and associated costs. For example, the Illinois Basin Decatur Project was designed to, and did, capture CO_2 from biofuel production and transport it via above-ground pipeline a mere 1.2 miles to saline storage. Nat'l Energy Tech. Lab'y, *Carbon Storage Atlas: Midwest Geological Sequestration Consortium*, https://netl.doe.gov/coal/carbon-storage/atlas/mgsc/phase-III/ibdp; 89 Fed. Reg. at 39,859. CO_2 can also be transported economically by truck, rail, or barge over short distances. *Id.* at 39,880; Corey Myers et al., *The Cost of CO_2*

Transport by Truck and Rail in the United States, 134 Int'l J. Greenhouse Gas Control 1 (2024).

In the longer term, building CO_2 collection pipelines and hubs that serve multiple users can reduce costs. *See* Wan Yun Hong, *A Techno-Economic Review on Carbon Capture, Utilisation and Storage Systems for Achieving a Net-Zero CO_2 Emissions Future*, 3 Carbon Capture Sci. & Techn. 1 (2022); *see also, e.g.*, 89 Fed. Reg. at 39,934; 42 U.S.C. § 16298d(j) (creating a "Regional direct air capture hubs" program, which will support development of CCS hubs that stationary sources can share).

CO_2 Storage. Permanent geologic CO_2 storage has been occurring in the U.S. for decades. The technology was first developed in the 1970s for the purposes of EOR, which is now widespread within the oil industry, and results in significant CO_2 storage. While EOR storage is an option for meeting the performance standards, the BSER also accounts for storage in deep saline reservoirs, which are ideal storage sites because they are found throughout the U.S. and have enormous storage capacity. 89 Fed. Reg. at 39,855; *see also* Michael Szulczewski et al., *Lifetime of Carbon Capture and Storage as a Climate-Change Mitigation Technology*, 109 PNAS 5185 (2012). The International Energy Agency ("IEA") has concluded that deep saline storage is a proven method for permanent CO_2 sequestration. IEA, *CO_2 Capture and Storage: A Key Carbon Abatement Option* 81

(2008), https://iea.blob.core.windows.net/assets/7a2e4c6f-6cb3-4e40-9623-e1d61843c8ba/CCS_2008.pdf.

The longest-running deep saline storage operation globally is the Sleipner project in Norway, which began in 1996 and injects CO_2 at a rate of 1 MMT per year. Kai Zhang et al., *Extension of CO_2 Storage Life in the Sleipner CCS Project by Reservoir Pressure Management*, 108 J. Nat. Gas Sci. & Eng'g 1 (2022). Other large deep saline storage operations include the Snøhvit project, also in Norway, which injects CO_2 at a rate of 0.7 MMT per year and Quest CCS in Canada which began operating in 2015 and stored 5 MMT of CO_2 within its first five years at a cost thirty-five percent lower than anticipated. 89 Fed. Reg. at 39,865; *Quest CCS Facility Captures and Stores Five Million Tonnes of CO2 Ahead of Fifth Anniversary*, Shell (July 9, 2020), https://www.shell.ca/en_ca/media/news-and-media-releases/news-releases-2020/quest-ccs-facility-captures-and-stores-five-million-tonnes.html. These Norwegian and Canadian projects were put in place in response to governmental policies to reduce industrial carbon emissions.

In addition to deep saline reservoirs, there are a number of alternative storage options, including through EOR and in basalt rock formations. 89 Fed. Reg. at 39,855. EOR is an attractive storage option because it provides a "readily available pathway to large volume storage," and selling CO_2 for EOR can help offset the costs of a CCS system. Bruce Hill et al., *Geologic Carbon Storage*

Through Enhanced Oil Recovery, 37 Energy Procedia 6808, 6808–09 (2013). The EOR industry has "a proven track record of safely injecting CO_2 into geologic formations" for permanent storage. Nat'l Energy Tech. Lab'y, *Carbon Dioxide Enhanced Oil Recovery* 17 (2010), https://www.netl.doe.gov/sites/default/files/netl-file/co2_eor_primer.pdf.

Storage in basalt has also proven highly successful. Basalt storage relies on the process of carbon mineralization, whereby CO_2 injected into basalt and certain other rock formations is rapidly converted into solid minerals. While not as prevalent as deep saline formations, basalt deposits can be found throughout the U.S. Arshad Raza et al., *Carbon Mineralization and Geological Storage of CO_2 in Basalt: Mechanisms and Technical Challenges*, 229 Earth-Sci. Rev. 1 (2022). Basalt storage has been demonstrated in the Wallula Project in the U.S. and at the Carbfix facility in Iceland, which has operated for a decade, and stored over 100,000 tons of CO_2 during that time. *Wallula Basalt Project*, Pac. Nw. Nat'l Lab'y, https://www.pnnl.gov/projects/carbon-storage/wallula-basalt-project; Carbfix, *Turning CO_2 into Stone* 3 (2022), https://usea.org/sites/default/files/event-/Carbfix_Intro_US_DOE_2022_OJ.pdf.

Using a combination of geologic storage methods, the U.S. had stored over 7.2 MMT of CO_2 successfully by 2014. Rubaya Tasnin Mim et al., *Minireview on CO_2 Storage in Deep Saline Aquifers: Methods, Opportunities, Challenges, and*

Perspectives, 37 Energy Fuels 18467, 18,467 (2023). Globally, 28 projects were storing 41 MMT of CO_2 per year by 2020. Zhang et al., *supra*.

Petitioners allege that CO_2 storage technology is not adequately demonstrated because currently operating projects cannot accommodate the amount of CO_2 that will need to be stored. *See* Pet'rs' Br. 69. However, there are multiple new, large-scale sequestration facilities currently under development and vast potential for additional storage sites which can be ready to receive CO_2 injections by 2032. The U.S. Department of Energy ("DOE") estimates that geologic formations in the U.S. have the capacity to store up to twenty-two trillion tons of CO_2. DOE, *Carbon Storage Atlas* 3 (5th ed. 2015), https://www.netl.doe.gov/sites/default/files/2018-10/ATLAS-V-2015.pdf. This is orders of magnitude larger than the amount of CO_2 that EPA estimates will need to be stored under the new standards (i.e., 1.3 to 1.4 billion tons between 2028 and 2047). 89 Fed. Reg. at 39,863. Building on the success of existing CO_2 storage operations, and spurred by various government policies including grant programs and tax credits, a number of new storage projects are currently in development in the U.S. Cong. Rsch. Serv., *Carbon Capture and Sequestration*, *supra*, at 16; *see, e.g.*, 26 U.S.C. § 45Q. Examples include the River Bend CCS project in Louisiana, which has storage capacity of over 620 MMT CO_2 and is expected to make its first injection in 2026, and the Bayou Bend CCS project in Texas, which has over 1 billion tons of CO_2 storage capacity and is expected to make its first injection in early 2027.

As further evidence that storage operations are expanding, EPA is currently reviewing over 150 applications for permits for geologic carbon sequestration wells under its Underground Injection Control Permit program. *Underground Injection Control (UIC) Class VI Permit Tracker*, EPA (Sept. 27, 2024), https://awsedap.epa.gov/public/single/?appid=8c074297-7f9e-4217-82f0-fb05f54f28e7&sheet=51312158-636f-48d5-8fe6-a21703ca33a9&theme=horizon&bookmark=6218ffed-bb6e-42e4-a4f1-52d87e036a1b&opt=ctxmenu.

Between the success of existing operations, the numerous projects in development, and the U.S.'s ample storage capacity, it is clear that CCS is a demonstrated, effective, and reliable technology for reducing CO_2 emissions.

2. Integrated CCS Systems Are Available

There are at least thirty-four commercial-scale integrated CCS projects operating around the world, including power sector projects at Petra Nova (U.S.), Boundary Dam (Canada), Taizhou (China), and Jinjie (China). *See* Table 1. Thirteen of the projects have come online within the last five years. A number of projects have undergone upgrades to increase their capture capacity. *See, e.g.*, Nat'l Petroleum Council, *Meeting the Dual Challenge* C-3–C-4 (2021), https://dualchallenge.npc.org/files/CCUS-Appendix_C-030521.pdf. These projects demonstrate that the three CCS components can be successfully integrated at scale.

Table 1: Commercial-Scale Integrated CCS Systems Operating in 2023[6]

Project	Operation Date	CO_2 Source	Capture	Pipeline km	Storage	Rate MMT/year
Taizhou (China)	2023	Power generation	Chemical absorption	N/A (under construction)	EOR	0.5
Qilu-Shengli (China)	2022	Chemical	Chemical absorption	115	EOR	1
Yulin CO_2-EOR (China)	2022	Chemical	Chemical absorption	N/A (truck)	EOR	0.3
Glacier (Canada)	2022	Natural gas processing	Physical absorption	Not public	Geologic storage	0.2
Richardton (U.S.)	2022	Ethanol production	Compression	3	Deep saline	0.18
Jinjie (China)	2021	Power generation	Chemical absorption	N/A (truck)	Deep saline	0.15
Yan'an CO_2-EOR (China)	2021	Chemical	Physical absorption	25	EOR	0.1
Sturgeon Refinery (Canada)	2020	Bitumen refining	Physical separation	240	EOR	1.6
Nutrien (Canada)	2020	Hydrogen production	Chemical absorption	240	EOR	0.3
Gorgon (Australia)	2019	Natural gas processing	Chemical absorption	7	Deep saline	4

[6] Global CCS Institute, *Global Status of CCS 2023*, at 77–78 (2023), https://www.globalccsinstitute.com/wp-content/uploads/2024/01/Global-Status-of-CCS-Report-1.pdf; Nat'l Energy Tech. Lab'y, *Carbon Capture and Storage Database* (2023), https://netl.doe.gov/carbon-management/carbon-storage/worldwide-ccs-database; Nat'l Petroleum Council, *supra*, at App. C; *SCCS Projects Home*, Scottish Carbon Capture & Storage, https://www.geos.ed.ac.uk/sccs/; *Geoengineering Map*, Geoengineering Monitor, https://map.geoengineeringmonitor.org/; *Facilities Database*, Global CCS Institute, https://co2re.co/FacilityData.

Jilin Oilfield (China)	2018	Natural gas processing	Chemical absorption	50	EOR	0.6
Petra Nova (U.S.)	2017	Power generation	Chemical absorption	129	EOR	1.4
ADM Decatur (U.S.)	2017	Ethanol production	Compression and drying	3	Deep saline	1.1
Abu Dhabi (U.A.E.)	2016	Iron and steel production	Chemical absorption	43	EOR	0.8
Quest (Canada)	2015	Hydrogen production	Chemical absorption	64	Deep saline	1.3
Uthmaniyah (Saudi Arabia)	2015	Natural gas processing	Chemical absorption	85	EOR	0.8
Karamay Dunhua (China)	2015	Chemical	Chemical absorption	N/A (truck)	EOR	0.1
Boundary Dam (Canada)	2014	Power generation	Chemical absorption	66	EOR/ Deep saline	1
Petrobras Santos Basin (Brasil)	2013	Natural gas processing	Membrane separation	Not public	EOR	10.6
Coffeyville Fertilizer (U.S.)	2013	Fertilizer production	Adsorption	109	EOR	1
Air Products (U.S.)	2013	Hydrogen production	Adsorption	21	EOR	1
Lost Cabin Gas (U.S.)	2013	Natural gas processing	Physical absorption	373	EOR	0.9
Bonanza BioEnergy (U.S.)	2012	Ethanol production	Compression	23	EOR	0.1
Yanchang Demonstration (China)	2012	Chemical	Physical absorption	100	EOR	0.05
Century Plant (U.S.)	2010	Natural gas processing	Physical absorption	161	EOR	8.4
Shute Creek (U.S.)	2010	Natural gas processing	Cryogenic separation	229	EOR	7
Arkalon (U.S.)	2009	Ethanol production	Compression	50	EOR	0.5
Snøhvit (Norway)	2008	Natural gas processing	Chemical absorption	143	Deep saline	0.7
South Chester (U.S.)	2003	Natural gas processing	Chemical absorption	15	EOR	0.35

Great Plains Synfuels (U.S.)	2000	Coal gasification	Physical absorption	330	EOR	3
Sleipner (Norway)	1996	Natural gas processing	Chemical absorption	240	Deep saline	1
Szank Field (Hungary)	1992	Natural gas processing	Chemical absorption	Not public	EOR	0.16
Enid Fertilizer (U.S.)	1982	Fertilizer production	Chemical absorption	193	EOR	0.7
Terrell (U.S.)	1972	Natural gas processing	Physical absorption	354	EOR	0.5

Scores more CCS facilities are currently under development, with 105 integrated or component facilities scheduled to begin operation within the next two years. Global CCS Institute, *Global Status of CCS 2023*, at 77–92 (2023), https://www.globalccsinstitute.com/wp-content/uploads/2024/01/Global-Status-of-CCS-Report-1.pdf.

B. CCS Systems with Ninety Percent Capture Have Been Developed over Decades and Deployed At Scale

This section explains the history of development of ninety percent capture technology from laboratory-scale experiments through successful commercial demonstrations and details the technology scaling process.

1. Development of Capture Technology to Achieve a Ninety Percent Capture Rate

Capture rates of ninety percent or more have been researched and observed in laboratory settings going back as far as the 1970s, when CCS technology was still in its infancy, and have been a continued focus of research since then. *See, e.g.*, C. Mustacchi et al., *Carbon Dioxide Disposal in the Ocean*, *in Carbon*

Dioxide, Climate and Society 286 (Jill Williams ed., 1978); Angelo Basile et al., *Membrane Technology for Carbon Dioxide (CO_2) Capture in Power Plants*, *in Advanced Membrane Science and Technology for Sustainable Energy and Environmental Applications* 121 (Angelo Basile & Suzana Pereira Nunes eds., 2011). After decades of technological advances, the achievability of a ninety percent capture rate is widely accepted in the scientific literature, and indeed is often assumed in CCS studies. *See* Patrick Brandl et al., *Beyond 90% Capture: Possible, But at What Cost?*, 105 Int'l J. Greenhouse Gas Control 1, 1 (2021) ("a 90% CO_2 capture rate has become ubiquitous in the literature"). In fact, as the technology has matured, "state of the art" applications of CCS at power plants and other industrial facilities have been designed to achieve emission reductions well in excess of ninety percent. Yang Du et al., *Zero- and Negative-Emissions Fossil-Fired Power Plants UsingCO₂ Capture by Conventional Aqueous Amines*, 111 Int'l J. Greenhouse Gas Control 1 (2021); Haibo Zhai & Edward Rubin, *It Is Time to Invest in 99% CO_2 Capture*, 56 Env't Sci. Tech. 9829 (2022).

Larger scale testing outside the laboratory has further confirmed the technical feasibility of capture rates of ninety percent or more. For example, The Technology Centre Mongstad in Norway has tested various solvents in post-combustion systems treating flue gas from natural gas combined cycle plants and achieved capture rates of ninety-eight percent. *Point Source Carbon Capture from*

Power Generation Sources, Nat'l Energy Tech. Lab'y, https://netl.doe.gov/carbon-capture/power-generation; *We Test Technologies*, Technology Centre Mongstad, https://tcmda.com/technology-testing. This and other research indicate that achieving capture rates higher than ninety percent is technically and economically feasible. Brandl et al., *supra*, at 9–10 ("higher capture rates . . . are economically feasible at low marginal costs . . . Thus, claims of capture rates higher than 90% are both technically feasible and economically reasonable in reaching GHG emissions reduction targets with negligible increase to the overall system costs.").

Although the BSER is based on a post-combustion system, scientific studies and "real world" deployments show that pre-combustion and oxy-combustion systems can also achieve ninety percent capture. Basile et al., *supra*, at 120 ("The benefits of [the pre-combustion] process are . . . 90–95% of CO_2 emissions capture"); *id.* (describing a "promising [oxy-combustion] technology" called "chemical looping combustion" which "has a potential for 100% CO_2 capture").

2. Demonstrations of Ninety Percent Capture Rates in Existing Facilities

As explained above, a large body of scientific work demonstrates that CCS with a capture rate of ninety percent or higher is feasible, reliable, and efficient. This has also been proven through deployment of the technology at multiple large-scale power plants, including the coal-fired Boundary Dam, Petra Nova, and Plant Barry projects and the natural gas-fired Bellingham Cogeneration Facility.

SaskPower's Boundary Dam in Canada was the first coal-fired power plant globally to be retrofitted with CCS using an amine-based post-combustion capture system designed to achieve ninety percent CO_2 capture at a commercial scale. EPA, *Technical Support Document: Greenhouse Gas Mitigation Measures for Steam Generating Units*, EPA-HQ-OAR-2023-0072, at 25 (2024). The integrated system includes a fifty kilometer pipeline which delivers a portion of the CO_2 to nearby oil fields for use in EOR and a second two kilometer pipeline which delivers CO_2 to the Aquistore Storage Project where it is injected for deep saline storage. The capture system at Boundary Dam was installed at the 115 megawatt ("MW") Power Unit 3, came online in 2014, and "completed a 72-hour demonstration nameplate test of its design capacity [where] the plant was able to capture . . . 99.7% of the design capacity [89.7% CO_2 capture]." SaskPower, *SaskPower 2015–16 Annual Report* 59 (2016), https://www.saskpower.com/about-us/our-company/~/link.aspx?_id=29E795C8C20D48398EAB5E3273C256AD&_z=z. In total, since coming online, the system has captured over 5.7 MMT of CO_2. *BD3 Status Update: Q4 2023*, SaskPower (Jan. 16, 2024), https://www.saskpower.com/about-us/our-company/blog/2024/bd3-status-update-q4-2023. Since the project was designed to demonstrate the technology and tailored to capture an amount of CO_2 in demand by the plant's EOR off-takers, SaskPower has not consistently run all flue gas from the unit through the capture system. 89 Fed. Reg. at 39,848. Nevertheless, the project clearly establishes that ninety percent capture is achievable and feasible at scale.

This has also been demonstrated at several other facilities. For example, the Petra Nova facility in Texas was the first CCS retrofit project to a coal-fired plant in the U.S. This at-scale demonstration employed a post-combustion system using a proprietary, amine solvent from Mitsubishi Heavy Industries. EPA, EPA-HQ-OAR-2023-0072, *supra*, at 28. The project aimed to demonstrate a ninety percent capture rate at a scale of up to 250 MW-electric and successfully captured 92.4% of CO_2 from the processed slipstream. Nat'l Energy Tech. Lab'y, *W.A. Parish Post-Combustion CO_2 Capture and Sequestration Demonstration Project* 6 (2020), https://www.osti.gov/servlets/purl/1608572.

The same technology has also been implemented at smaller scale at coal plants. Plant Barry is a coal-fired power plant in Alabama, which launched an integrated CCS demonstration project in 2011 treating a 25 MW portion of the plant's flue gas stream. It operated stably, capturing ninety percent CO_2 under full load conditions. Mitsubishi Heavy Industries, *Plant Barry CO_2 Capture Project* 11 (2015), https://fossil.energy.gov/archives/cslf/sites/default/files/documents/tokyo2016/Kamijo-PlantBarryProject-Workshop-Session2-Tokyo1016.pdf.

The Bellingham Cogeneration Facility in Massachusetts demonstrated ninety percent CO_2 capture at a combined cycle natural gas-plant. An amine-based post-combustion capture system operated on a 40 MW slipstream from 1991 to 2006. 89 Fed. Reg. at 39,926. It consistently captured 85 to 95% of CO_2 emissions. DOE, *Carbon Capture Opportunities for Natural Gas Fired Power Systems* 2, https://www.energy.gov/fecm/articles/carbon-capture-opportunities-natural-gas-fired-power-systems. CCS technologies are the same for coal- and natural gas-fired plants, and EPA correctly concluded that the technology used at coal plants will actually be easier to implement at natural gas plants because natural gas lacks impurities that naturally occur in coal and affect the efficiency of capture systems. 89 Fed. Reg. at 39,927.

C. Ninety Percent Capture Technology is Readily Scalable

Multiple successful at-scale demonstration projects have clearly established that ninety percent CCS technology is achievable and feasible. Following those demonstrations, the technology is now being scaled-up and deployed more widely.

The Petitioners' central argument is that EPA has not adequately demonstrated the technology because its example projects do not consistently capture ninety percent of CO_2 emissions on a facility-wide basis and thus do not currently meet the performance standards. *See, e.g.*, Pet'rs' Br. 46, 49–50, 54. This argument fails for two reasons: (1) the same technologies that have been proven to capture ninety percent or more of CO_2 at individual slipstreams can be deployed on a facility-wide basis; and (2) the previous projects reflect a phased approach to implementing CCS in which capture systems were intentionally installed on single slipstreams. This is not due to any flaw in the technology but, rather, to demonstrate that they work before incurring the costs of full deployment and to tailor capture systems to the amount of CO_2 the facilities have agreed to sell. Now that the systems efficacy has been established, additional, larger projects are being developed and the stage is set for rapid deployment between now and 2032 in response to the new standards.

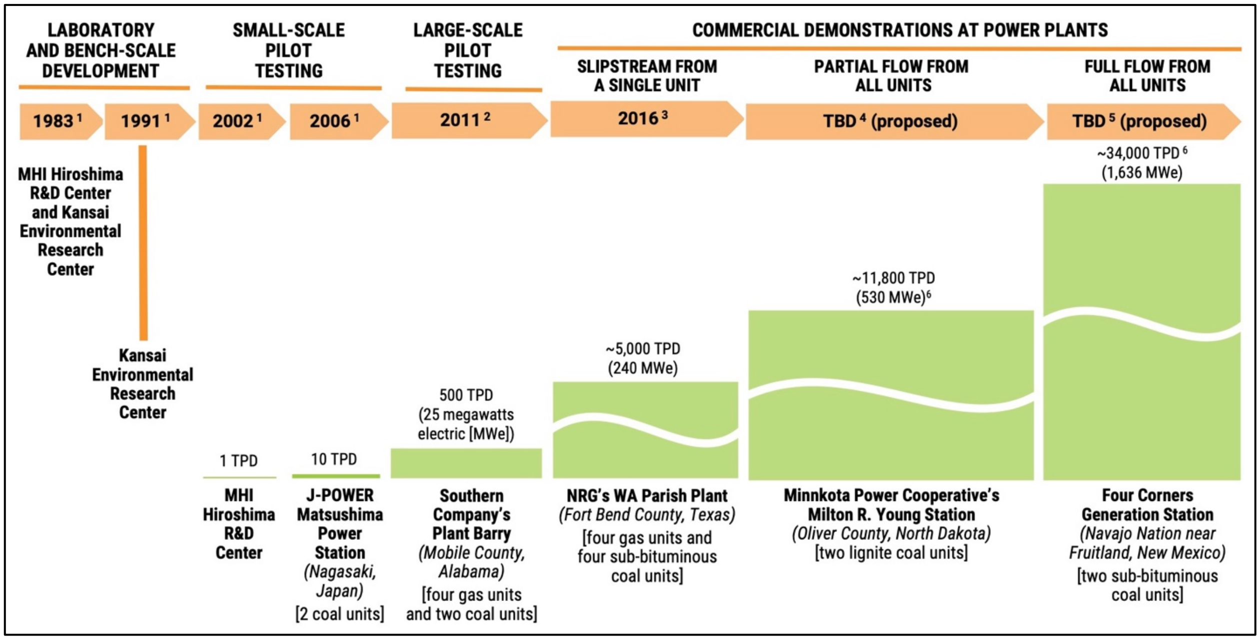
First, the process of scaling CO_2 capture in a facility from slipstream capture to facility-wide capture does not require different technology. It requires expanding the technology's capacity, either by building bigger capture systems or by building multiple process trains. Capture projects performed on a slipstream are foundational for commercial deployment and are viewed as an adequate demonstration of the technology to be implemented more widely. *See Illinois Utility Working with University of Illinois on DOE Funded Carbon Capture Research Project*, Mining Connection (May 21, 2021), https://miningconnection.com/news/article/illinois_utility_working_with_university_of_illinois_on_doe_funded_carbon_c ("The successful construction and operation of [a CCS project on a 10 MW slipstream of flue gas at a larger] plant will provide a means to demonstrate an economically attractive and transformational capture technology. The approach used to design, construct, and commission the design . . . will help enable the commercialization process").

For example, the Boundary Dam system can treat the entire flue gas from a single 115 MW unit. SaskPower, *supra*, at 59. Although this is not facility-wide capture because Boundary Dam has other coal-fired units, it is consistent with how CCS systems are expected to be implemented at full facilities. That is on a unit-by-unit basis, which is feasible because CCS technologies are modular. For instance, if a new base load natural gas-fired unit was constructed at a multi-unit facility, a CCS system capable of ninety percent capture would be applied to the single new unit with its own stack. Therefore, Boundary Dam Unit 3 demonstrates the CCS technology on a full unit in the same manner that power plants will likely deploy CCS systems one unit at a time to meet facility-wide performance standards.

Second, Petitioners' argument reflects a misunderstanding of the CCS research, development, and demonstration ("RD&D") process. When developing CCS technologies for point sources, "[t]o cost-effectively meet the research objectives of a pilot-scale test, a project is usually sized such that only a small fraction of the plant's gas stream emissions is used." Nat'l Energy Tech. Lab'y, *Understanding Scales and Capture Rates for Point-Source Carbon Capture Technology Development* 1 (2024), https://netl.doe.gov/sites/default/files/publication/R-D239%20-%20Scales%20and%20Capture%20Rates%20for%20Point-Source.pdf. Thus, "at a fossil-fuel power plant with multiple combustion units, the volume of flue gas from a single unit will typically exceed what is needed by a pilot project to validate the technology's maximum steady-state gross carbon capture efficiency, typically 95+%." *Id*. In other words, the fact that ninety percent CO_2 capture systems have been deployed on only single slipstreams or single units within larger-scale facilities is not, as Petitioners allege, evidence that the technology is infeasible. Rather, projects like Petra Nova are sized to capture the amount of CO_2 that the facility contracts to sell and need not capture from full units in the absence of a regulatory requirement to do so. Still, having served an important purpose of validating the technologies in the RD&D process, their systems are now being scaled-up and implemented more broadly. The RD&D cycle for Petra Nova (see Figure 1) illustrates this process.

As described in Figure 1, Mitsubishi Heavy Industries' capture system has been though a number of development phases: laboratory- and bench-scale research in Japan, small-scale pilot testing in Japan, large-scale pilot testing at Plant Barry in the U.S., and commercial demonstration at Petra Nova using a single unit's slipstream. The technology is now ready to be deployed in commercial projects which involve all emitting units in a facility. And that is already happening.

Figure 1: Development of the Kansai Mitsubishi Carbon Dioxide Recovery (KM-CDR) Process for Coal-Fired Power Plants[7]



Additional facilities are now deploying ninety percent capture technology based on the success of the prior demonstration projects. For example, two proposed projects have followed from Petra Nova and will deploy Mitsubishi's capture technology at all emitting units: (1) the Milton R. Young Station in North Dakota and (2) the Four Corners Generation Station in Navajo Nation. *See* Figure 1; 89 Fed. Reg. at 39,840. Both projects are designed to capture ninety-five percent or more CO_2.

[7] Nat'l Energy Tech. Lab'y, *Understanding Scales and Capture Rates*, *supra*.

Similarly, building on the success of Boundary Dam Unit 3, SaskPower is planning another CCS project at the coal-fired Shand Power Station. *See* Int'l CCS Knowledge Centre, *The Shand CCS Feasibility Study: Public Report* (2018), https://ccsknowledge.com/pub/Publications/Shand_CCS_Feasibility_Study_Public_Report_Nov2018_(2021-05-12).pdf. Drawing on the lessons learned from Boundary Dam Unit 3, SaskPower has concluded that Shand can achieve a capture rate of *at least* ninety percent when the plant is at full load, or up to ninety-seven percent at a reduced load with integration of renewable energy sources. *Id.* at iii, x.

Understanding how this scaling process will continue to unfold, EPA appropriately set a compliance date of January 1, 2032 to allow power plants sufficient lead time to deploy the technology. The Petitioners argue that EPA's compliance timeline is unrealistic. Pet'rs' Br. 70–75. However, 7.5 years is within the range of time required to develop CCS projects. *See, e.g.*, Emily J. Moore et al., *Expert Elicitation of the Timing and Uncertainty to Establish a Geologic Sequestration Well for CO_2 in the United States*, 121 PNAS 1 (2023). In fact, Petra Nova took only two and a half years to design, procure, construct, and commission the fully integrated CCS system. DOE, *Final Scientific/Technical Report: Petra Nova* 17 (2020), https://www.osti.gov/servlets/purl/1608572.

II. CCS Costs Are Reasonable and Will Decline with Operational Experience and Technological Innovation

Amici expect that the costs of CCS systems will decline as the adoption of CCS becomes more widespread. Studies show "economies of scale [have] an observable effect on the cost of CO_2 capture." Brandl et al., *supra*, at 9. Already we are seeing cost reductions associated with lessons learned from past projects. For example, SaskPower's feasibility study for the Shand Power Station found that the capital costs of retrofitting Shand with ninety percent capture technology would be sixty-seven percent less than they were for Boundary Dam Unit 3, in large part due to SaskPower's experience implementing the technology at Unit 3. Int'l CCS Knowledge Centre, *supra*, at x.

The same trend has been observed in China: after China Energy began CCS operations at the Yulin Jinjie power plant in 2021, it quickly implemented CCS at a significantly larger power plant in Taizhou, Jiangsu province in 2023. Both plants' post-combustion systems have a ninety percent capture rate but the second project's total costs per ton of CO_2 were nearly thirty percent lower than the first project's. Tao Wang, Professor, Zhejiang University, Presentation at DOE Nat'l Energy Tech. Lab'y Carbon Management Research Project Review Meeting 9 (Aug. 30, 2023), https://netl.doe.gov/sites/default/files/netl-file/23CM_GP_Tao.pdf.

Technological development and further scaling could also yield cost reductions in the coming years. A number of new capture approaches, including systems using novel solvents and improved membrane-based systems, are currently in development, as are novel carbon storage methods, including ex situ mineralization (allowing CO_2 to be converted into construction materials) and polymerization (allowing CO_2 to be converted into plastics). Commercial and industrial demand for CO_2 is growing as new uses emerge, including some that involve durable storage (e.g., in the production of building materials), which generates new revenue streams for entities capturing CO_2. IEA, *Putting CO_2 to Use: Creating Value from Emissions* 1 (2019), https://iea.blob.core.windows.net/assets/50652405-26db-4c41-82dc-c23657893059/Putting_CO2_to_Use.pdf. There is also significant government support for CCS. The Inflation Reduction Act of 2022 expanded tax credits for geologic storage of CO_2 captured at power plants and made funding available to support CCS projects. 26 U.S.C. § 45Q; *see, e.g.*, 7 U.S.C. § 8103(j)(1).

These expectations for significant and sustained cost reductions for CCS build on a rich and well-documented history of cost reductions for other power plant technologies and emissions control systems. Edward Rubin et al., *A Review of Learning Rates for Electricity Supply Technologies*, 86 Energy Pol'y 198 (2015). Thus, while the performance standards are "cost reasonable," compliance will become even easier in the near future due to cost declines and technological improvements.

CONCLUSION

CCS systems that capture ninety percent of CO_2 emissions are technically viable and capable of delivering the emissions reductions necessary to meet the performance standards for power plants. Large-scale demonstrations leave no question that these systems are ready to be implemented now and can be designed, permitted, and installed within the next seven years. Advances in existing and emerging technologies, plus lessons learned from past experience, will further drive down costs and improve the performance of CCS systems. For these reasons, *amici* support EPA's determination that the BSER for existing coal-fired power plants and new natural gas-fired power plants should include ninety percent CCS.

Respectfully submitted,

/s/ Michael Burger

MICHAEL BURGER
ROMANY WEBB
Columbia Law School
Sabin Center for Climate Change Law
435 West 116th Street
New York, NY 10027
Tel: (212) 854-2372
mburger@law.columbia.edu

October 18, 2024

CERTIFICATE OF COMPLIANCE

I hereby certify that the foregoing brief complies with the type-volume limitations set forth in D.C. Circuit Rule 32(e)(3) and Federal Rules of Appellate Procedure 32(a)(7)(B)(i) and 29(a)(5) because this brief contains 6,486 words, excluding the parts of the brief exempted by Federal Rule of Appellate Procedure 32(f) and D.C. Circuit Rule 32(e)(1). The foregoing brief complies with the typeface requirements of Federal Rule of Appellate Procedure 32(a)(5) and the type style requirements of Federal Rule of Appellate Procedure 32(a)(6) because this brief has been prepared in a proportionally spaced typeface using Microsoft Office Word 2010 in 14-point Times New Roman font.

Respectfully submitted,

/s/ Michael Burger
Michael Burger

October 18, 2024

CERTIFICATE OF SERVICE

I hereby certify that I electronically filed the foregoing with the Clerk of the Court for the United States Court of Appeals for the District of Columbia Circuit using the Court's CM/ECF system on October 18, 2024, which will send notice of such filing to all counsel who are CM/ECF registered users.

Respectfully submitted,

/s/ Michael Burger
Michael Burger

October 18, 2024