ORAL ARGUMENT SCHEDULED FOR April 17, 2017
No. 15-01381 (and consolidated cases)

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

STATE OF NORTH DAKOTA, ET AL.,

Petitioners,

v.

U.S. ENVIRONMENTAL PROTECTION AGENCY, ET AL.,

Respondents.

On Petitions for Review of a Final Action of the
United States Environmental Protection Agency

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

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December 21, 2016

CERTIFICATE AS TO PARTIES, RULINGS, AND RELATED CASES

A. Parties and *Amici*

All parties, intervenors, and *amici* appearing before this court are listed in the Respondent EPA's Initial Brief.

B. Rulings Under Review

References to the rulings at issue in this case appear in the Respondent EPA's Initial Brief.

C. Related Cases

References to related cases appear in the Respondent EPA's Initial Brief.

RULE 29 STATEMENTS

The following parties have indicated their consent to the filing of this brief: American Lung Association; Calpine Corporation; the City of Austin d/b/a Austin Energy; the City of Los Angeles, by and through its Department of Water and Power; the City of Seattle, by and through its City Light Department; Clean Air Council; Clean Wisconsin; Conservation Law Foundation; Environmental Defense Fund; National Grid Generation, LLC; New York Power Authority; Ohio Environmental Council; Pacific Gas and Electric Company; Sacramento Municipal Utility District; Sierra Club; and State of Missouri. All remaining parties do not oppose or take no position on the filing of this brief.

Pursuant to Fed. R. App. P. 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.

Pursuant to D.C. Cir. R. 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 with expertise in the 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 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

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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
EOR	Enhanced Oil Recovery
EPA	United States Environmental Protection Agency
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
MIT	Massachusetts Institute of Technology
MMT	Million Metric Tons
MT	Metric Tons
MW	Megawatt
MWh	Megawatt-Hour
NSPS	New Source Performance Standard
SCPC	Supercritical Pulverized Coal

IDENTITY AND INTERESTS OF *AMICI CURIAE*

Amici curiae are eleven scientists, 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*.

- Roger Aines (Lawrence Livermore National Laboratory)
- Sally Benson (Stanford University)
- S. Julio Friedmann (Lawrence Livermore National Laboratory)
- Jon Gibbins (United Kingdom CCS Research Centre)
- Raghubir Gupta (RTI International)
- Howard Herzog (Massachusetts Institute of Technology)
- Susan Hovorka (University of Texas at Austin)
- Meagan Mauter (Carnegie Mellon University)
- Ah-Hyung (Alissa) Park (Columbia University)
- Gary Rochelle (University of Texas at Austin)
- Jennifer Wilcox (Colorado School of Mines)

ARGUMENT

The Clean Air Act ("CAA") requires the U.S. Environmental Protection Agency ("EPA") to establish new source performance standards ("NSPS") that reflect the "degree of emission 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). EPA has established an NSPS for carbon dioxide ("CO_2") emissions from newly constructed coal-fired power plants based on its determination that the BSER for these plants includes partial carbon capture and storage ("CCS"). 80 Fed. Reg. 64510 (Oct. 23, 2015). *Amici curiae* experts in CCS science and technology agree with EPA's determination that the NSPS should reflect the emissions reductions achievable through partial CCS.

The NSPS requires new coal-fired power plants to limit their CO_2 emissions to 1,400 lbs CO_2/MWh. 80 Fed. Reg. at 64513. This emission rate is based on the degree of emission limitation achievable by a highly efficient supercritical pulverized coal ("SCPC") utility boiler implementing post-combustion CCS to capture and store a portion of its CO_2 emissions (approximately 16% for bituminous coal, 23% for subbituminous or dried lignite). *Id*. To meet this standard through partial CCS, a new 500 MW SCPC unit would need to capture and store approximately 354,000 metric tons ("MT") CO_2 per year. *Id.* at 64574. [1]

In setting this standard, EPA rightly concluded that the technologies required to implement partial CCS are "adequately demonstrated" within the meaning of the CAA. As detailed in this brief, this standard is based on the deployment of well-established CCS technologies that have been successfully deployed in industrial applications for decades, are commercially available, and have been proven to be technically viable for power plants on the scale required for compliance with the rule.[2] In fact, there are many CCS systems in operation today that capture significantly more than 354,000 MT CO_2 per year. One notable example is the Boundary Dam project in Canada: a CCS retrofit to an existing lignite-fueled coal-fired power plant which successfully captured and stored 800,000 MT CO_2 in the past year. Another major power sector CCS project, Petra Nova, is now fully built and will begin operating in 2017. It is designed to capture approximately 1,400,000 MT CO_2 / year. Petra Nova and Boundary Dam demonstrate that the NSPS is attainable through the deployment of proven CCS technologies, specifically: post-combustion capture, pipeline transport, and geologic storage.

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[1] Since the rule does not mandate the use of any particular technology, a unit could also meet the standard by co-firing with natural gas.

[2] This brief focuses on technical viability. *See* Respondent EPA's Initial Brief at 65-74 for discussion of economic viability.

The experience gained from these projects will contribute to significant CCS cost reductions in the immediate future. In fact, the Boundary Dam operator expects a 30% cost reduction for its next CCS project due to experience gained from Boundary Dam. CCS costs will also decline due to improvements in existing technologies as well as emergent and transformational technologies that are currently being tested in laboratories and pilot projects. Point being: the NSPS is already attainable, but technological advances will make it even easier to meet this standard in the near future.

In light of these factors, *amici* CCS scientists believe that the NSPS reflects a conservative estimate of what can actually be achieved through the deployment of CCS systems at coal-fired power plants.

I. AN ADEQUATELY DEMONSTRATED SYSTEM MUST BE AVAILABLE FOR INSTALLATION, BUT NEED NOT BE WIDELY DEPLOYED IN THE REGULATED SECTOR

The D.C. Circuit has stated that an "adequately demonstrated" system is 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), *cert. denied,* 416 U.S. 969 (1974). The system does not need to "be in actual routine use somewhere." *Portland Cement Ass'n v. Ruckelshaus*, 486 F.2d 375, 391 (D.C. Cir. 1973). Rather, the "essential question" is "whether the technology would be available for installation in new plants." *Portland Cement*, 486 F.2d at 391.

EPA can determine that a system is "adequately demonstrated" for a source category based on "the reasonable extrapolation of a technology's performance in other industries." *Lignite Energy Council v. U.S. EPA*, 198 F.3d 930, 934 (D.C. Cir. 1999) (upholding EPA's determination that selective catalytic reduction was adequately demonstrated for coal-fired industrial boilers based on studies showing that this technology had been deployed at utility boilers).

EPA also has "authority to hold the industry to a standard of improved design and operational advances" when defining the BSER "so long as there is substantial evidence that such improvements are feasible." *Sierra Club v. Costle*, 657 F.2d 298, 364 (D.C. Cir. 1981) (upholding NSPS that assumed higher pollutant removal rates than had actually been achieved in practice by scrubbers). This is consistent with the technology-forcing goals of Section 111 and the CAA as a whole. *Id. See also Portland Cement*, 486 F.2d at 391 ("Section 111 looks toward what may fairly be projected for the regulated future, rather than the state of the art at present, since it is addressed to standards for new plants"). Accordingly, the D.C. Circuit has upheld EPA's authority to set a NSPS "at a level that is higher than has actually been demonstrated over the long term by currently operating [units employing the BSER].” *Sierra Club*, 657 F.2d at 364.[3]

II. CCS IS AN ADEQUATELY DEMONSTRATED SYSTEM FOR REDUCING CO_2 EMISSIONS FROM COAL-FIRED POWER PLANTS

There is ample evidence to support EPA’s determination that CCS is an adequately demonstrated system for reducing CO_2 emissions from coal-fired power plants. As detailed herein, CCS technologies have been proven through decades of experience in industrial applications and are now being successfully deployed on a large scale to capture and permanently store CO_2 emissions from power plants. Petitioners’ assertion that CCS component technologies “exist only in highly-subsidized, pilot-scale, or experimental form” is simply untrue. State Petitioners’ Brief at 4.

Petitioners also assert that CCS is not adequately demonstrated for power plants because there is no power plant that applies *all* of the components of the BSER, namely post-combustion capture, pipeline transport, and deep saline storage. Non-State Petitioners’ Brief at 49. But these components are highly modular and easily linked, and it is entirely appropriate to conclude that CCS is an

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[3] For more on the technology forcing elements of Section 111(b), *see* Brief for Amici Curiae Technological Innovation Experts in Support of Respondents.

adequately demonstrated system based on evidence that each component is adequately demonstrated. Moreover, as discussed below, there are a number of large-scale CCS systems in operation and under construction which prove that these components can be successfully integrated to meet the NSPS.

In support of these arguments, this section: (a) reviews how CCS technologies have been successfully developed and scaled-up in the industrial context; (B) explains how existing CCS technologies, including those developed in the industrial context, are applied to power plants; and (C) describes the many CCS systems that are currently installed at power plants and industrial boilers.

A. CCS Technologies Have Been Successfully Deployed and Scaled Up in Industrial Applications

CCS technologies have been successfully used in industrial applications for decades, often in commercial contexts, and many large-scale, integrated CCS projects are now in operation or under construction. After decades of experience and hundreds of CCS projects, we know a great deal about CCS technologies, and there are no technical barriers to implementing CCS. S. Julio Friedmann, *CO_2 Capture and Sequestration*, in *Fossil Energy: Selected Entries from the Encyclopedia of Sustainability Science and Technology* 597, 598 (2012).

1. Development of CCS Component Technologies

CO_2 capture technology was first invented in the 1930s to remove CO_2 from natural gas. The process used then (chemical absorption), which is still in use today, involves the use of chemical solvents, typically amines, to separate CO_2 from other gases. In the late 1970s and early 1980s, industrial sources began to use this process to separate CO_2 from flue gas streams so that it could be sold in enhanced oil recovery ("EOR") operations and other industrial applications.[4] Anand Rao & Edward Rubin, *A Technical, Economic, and Environmental Assessment of Amine-Based CO_2 Capture Technology for Power Plant GHG Control*, 36 Environ. Sci. Technol. 4467, 4468 (2002). Chemical absorption technologies have been refined over the past 40 years and are now routinely used in post-combustion capture at power plants.

The number and scale of CO_2 capture operations have grown considerably in the past decade. There are hundreds of capture systems in operation, including 15 large-scale integrated CCS projects with capture rates that significantly exceed

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[4] The longest running flue gas capture project is the Searles Valley Minerals soda ash plant in California, which has operated since 1978. It uses post-combustion amine-based chemical absorption (the same capture technology underpinning the NSPS) to capture approximately 270,000 MT CO_2 per year from the flue gas of a coal-fired boiler. The fact that the capture system is installed at an industrial boiler as opposed to a utility boiler has no bearing on the effectiveness of the technology. *Report of the Interagency Task Force on Carbon Capture and Storage*, 31 (2010), EPA-HQ-OAR-2013-0495-11416.

what would be required under the NSPS.[5] Capture technologies have expanded to include physical absorption, membrane separation, adsorption, and cryogenic separation as well as chemical absorption. All of these technologies can be used in power plants, but chemical absorption is the preferred method for post-combustion capture due to the advanced status of the technology. IEA, *20 Years of Carbon Capture and Storage: Accelerating Future Deployment* (2016).

CO_2 that is captured for use or storage is typically transported via pipeline to the end use or storage site. Operators have decades of experience in CO_2 pipeline transport, and there are now thousands of miles of CO_2 pipelines in the U.S.[6]

The development of permanent geologic CO_2 storage technologies began in the early 1970s, when captured CO_2 was first injected into oil wells to boost oil recovery in EOR operations. EOR operations have expanded significantly since then: worldwide, the number of CO_2 EOR projects has increased from 40 projects in 1984 to 142 projects in 2012. Bruce Hill, Susan Hovorka & Steve Melzer, *Geologic Carbon Storage Through Enhanced Oil Recovery*, 37 Energy Procedia 6808, 6811 (2013). Use of CO_2 in EOR has contributed to "rapid progress" in the evolution of both CO_2 transport and geologic storage technologies. Sally Benson,

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[5] *See* Table 1, *infra* page 11, for a list of these systems.
[6] *See* Section II(B)(2), *infra* page 17, for more information about U.S. CO_2 pipeline infrastructure.

Overview of Geologic Storage of CO_2, in *Carbon Dioxide Capture for Storage in Deep Geologic Formations*, 665 (2005). The CO_2 EOR industry now has "a proven track record of safely injecting CO_2 into geologic formations" for permanent storage. National Energy Technology Laboratory, *Carbon Dioxide Enhanced Oil Recovery*, 17 (2010).

In the 1990s, researchers began to experiment with other CO_2 storage methods. One of the best developed methods is deep saline storage, which relies on many of the same technologies used for EOR. There are now several large scale projects that have stored large quantities of CO_2 in deep saline reservoirs without any CO_2 leakage.[7] The IEA has concluded that deep saline storage, like EOR, is a proven method for permanent sequestration of CO_2. IEA, *CO_2 Capture and Storage: A Key Carbon Abatement Option*, 81 (2008).

2. Development of Large-Scale Integrated CCS Systems

There are now fifteen large-scale integrated CCS projects in operation around the world, including the power sector project at Boundary Dam (see Table 1, next page). Global CCS Institute, *The Global Status of CCS 2016* (2016). All of these projects have CO_2 capture rates that exceed what would be required for a 500

[7] These deep saline storage projects are further discussed in Section II(B)(3), *infra* page 19.

MW SCPC to achieve the NSPS. Roughly half of them use chemical absorption, demonstrating the viability of this capture technology.

Table 1: Large-Scale Integrated CCS Systems[8]

Project	Date	CO_2 Source	Capture	Pipeline	Storage	Rate MMT/yr*
Shute Creek (U.S.)	2010 – present	Natural gas processing	Cryogenic separation	460 km	EOR	6-7
Century Plant (U.S.)	2010 – Present	Natural gas processing	Physical absorption	43 km	EOR	5
Great Plains Synfuels (U.S.)	2000 – Present	Coal gasification	Physical absorption	315 km	EOR	3
Val Verde Plant (U.S.)	1998 – Present	Natural gas processing	Physical absorption	130 km	EOR	1.3
In Salah (Algeria)	2004 – 2011	Natural gas processing	Chemical absorption	14 km	Deep saline	1 – 1.2
Quest (Canada)	2015 – present	Hydrogen production	Chemical absorption	64 km	Deep saline	1
Air Products (U.S.)	2013 – present	Hydrogen production	Vacuum swing adsorption	158 km	EOR	1
Lost Cabin Gas (U.S.)	2013 – present	Natural gas processing	Physical absorption	374 km	EOR	0.9
Sleipner (Norway)	1996 – present	Natural gas processing	Chemical absorption	240 km	Deep saline	0.85

[8] Data: Global CCS Institute, *Large Scale CCS Projects*, https://www.globalccsinstitute.com/projects/large-scale-ccs-projects, EPA-HQ-OAR-2013-0495-11650; MIT CCS Technologies Program, *Project Database*, https://sequestration.mit.edu/tools/projects/index.html.

Boundary Dam (Canada)	2014 – present	Power generation	Chemical absorption	66 km	EOR / deep saline	0.8
Uthmaniyah (Saudi Arabia)	2015 – present	Natural gas processing	Chemical absorption	85 km	EOR	0.8
Abu Dhabi (United Arab Emirates)	2016 – present	Iron and steel production	Chemical absorption	43 km	EOR	0.8
Coffeyville Fertilizer (U.S.)	2013 – present	Fertilizer production	Physical absorption	112 km	EOR	0.7 – 0.8
Snøhvit (Norway)	2008 – present	Natural gas processing	Chemical absorption	143 km	Deep saline	0.7
Petrobas Santos Basin (Brazil)	2013 – present	Natural gas processing	Membrane separation	N/A - direct injection	EOR	0.7
Enid Fertilizer (U.S.)	1982 – present	Fertilizer production	Chemical absorption	225 km	EOR	0.7

* MMT = Million Metric Tons

There are also a number of smaller projects and projects under development that further demonstrate the feasibility of integrated CCS.[9] One notable example is the Archer Daniels Midland ("ADM") Illinois Industrial CCS Project. During the initial phase of this project (November 2011-2014), ADM captured 1 MMT CO_2 from its ethanol plant in Decatur, Illinois using a chemical absorption process. The CO_2 was transported via pipeline to a deep saline storage site 1.6 km away. ADM

[9] Power sector projects are discussed in Section II(C), *infra* page 24.

is now scaling up the system so that it will capture approximately 1 MMT per year, starting in early 2017. Global CCS Institute, *Illinois Industrial CCS Project*, https://www.globalccsinstitute.com/projects/illinois-industrial-carbon-capture-and-storage-project.

B. CCS Technologies Developed in Industrial Contexts Can Be Used at Coal-Fired Power Plants

Technologies that have been proven in the industrial sector can be used to capture, transport, and store CO_2 from coal-fired power plants. Berend Smit, Ah-Hyung (Alissa) Park, & Greeshma Gadikota, *The Grand Challenges in Carbon Capture, Utilization, and Storage*, 2(55) Front. Energy Res. 1 (2014). This section explains how each CCS component can be implemented at power plants.

1. CO_2 Capture

There are three types of systems that can be used to capture CO_2 from power plants: post-combustion systems, pre-combustion systems, and oxy-combustion systems. Heleen de Coninck & Sally M. Benson, *Carbon Dioxide Capture and Storage: Issues and Prospects*, 39 Annu. Rev. Environ. Resour. 243, 248 (2014); Jennifer Wilcox, *Introduction to Carbon Capture*, in *Carbon Capture* (2012). There are also different capture processes that can be deployed within these systems, the dominant ones being: chemical absorption, physical absorption, adsorption, and membrane separation.

The NSPS is based on the emissions reductions that could be achieved through a post-combustion capture system that captures a modest proportion of a plant's overall emissions.[10] In a post-combustion system, CO_2 is removed after the combustion of fuel at a power plant or industrial source, typically through chemical absorption with an amine-based solvent. Post-combustion capture based on amine scrubbing is a "mature technology" that has been proven in many projects and is "the technology of choice for the first fossil fuel power plants with CO_2 capture." Eva Sanchez Fernandez et al., *Operational Flexibility Options in Power Plants with Integrated Post-Combustion Capture*, 48 Intl. J. Greenhouse Gas Control 275, 275 (2016). *See also* Dennis Leung et al., *An Overview of Current Status of CO_2 Capture and Storage Technologies*, 39 Renewable & Sust. Energy Rev. 426 (2014) (finding that post-combustion capture is the most mature process for CO_2 capture for new and existing power plants). Vendors now offer technology products specifically developed for large-scale post-combustion capture at power plants (often accompanied by performance guarantees).[11]

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[10] As noted above, the NSPS does not mandate the use of any specific technology, and can be met by co-firing with natural gas or using a different CCS system.

[11] These products include: Fluor Daniel Econamine FG Plus, Mitsubishi Heavy Industries KM-CDR, BASF/Linde OASE Blue, and Shell Cansolv. EPA, *Technical Support Document: Literature Survey of Carbon Capture Technology*, 10-11 (2015), EPA-HQ-OAR-2013-0495-11773.

The maturity of post-combustion capture technologies is due in large part to extensive experience with amine solvents. As noted above, amine-based absorption was first developed in the 1930s, and is currently the dominant capture technology in both industrial and power sector applications. Friedmann, *supra*, at 602. The cost and effectiveness of absorption-based capture systems has improved considerably in recent years due to advances in amine-based solvents. de Coninck & Benson, *supra*, at 248. *See also* Xiaomei Wu, *The Advances of Post-Combustion CO_2 Capture with Chemical Solvents*, 63 Energy Procedia 1339 (2014); Paul-Emmanuel Just, *Advances in the Development of CO_2 Capture Solvents*, 37 Energy Procedia 314 (2013). Many companies continue to refine their amine-based capture systems to enhance performance and reduce costs.[12] Researchers are also experimenting with new types of liquid and solid solvents that could lead to breakthroughs in absorption-based capture.[13]

Pre-combustion and oxy-combustion systems are not part of EPA's BSER determination, but these systems can also be used to meet the NSPS. In pre-combustion systems, fossil fuel is partially oxidized in steam and oxygen under high temperature to produce hydrogen-rich syngas and then CO_2 is separated from

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[12] These companies include: Mitsubishi, General Electric, Babcock and Wilcox, Aker Clean Carbon, HTC, and Huaneng.
[13] *See* Section III, *infra* page 31.

the resulting syngas before it is burned to generate power. These systems are well-developed in the industrial applications such as coal-to-chemical facilities[14] but they can only be deployed at gasification plants. Yeung et al., *supra*, at 429. In oxy-combustion, fuel is burned in oxygen instead of air, and the resulting flue gas consists mainly of CO_2 and water vapor. The water vapor is then condensed and separated from CO_2 through cooling. Although these two technologies have not deployed into power markets as rapidly as post-combustion, many experts agree that pre-combustion and oxy-combustion could prove increasingly viable for carbon capture in the future.

There are also alternative capture processes, such as physical absorption, adsorption and membrane-based separation, which are not as mature as absorption and not yet considered an attractive option for large-scale CO_2 capture (and thus not part of the BSER).[15] But advances in these processes may make them more attractive and cost-effective for power plants in the near term.[16] This was

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[14] E.g., Eastman Chemical Company has successfully operated a pre-combustion system at its coal-to-chemicals facility in Kingsport, TN since 1984. The system captures approximately 200,000 MT CO_2 / year.

[15] Adsorption, which involves the use of solid sorbents to remove CO_2 from flue gas, is not yet considered an attractive option because the capacity and CO_2 selectivity of available adsorbents is low. Membrane-based capture, which involves the use of chemical membranes to separate CO_2 from flue gas, is not yet preferred due to the complexity of these systems.

[16] *See* Section III, *infra* 31.

highlighted recently by the US DOE in open stakeholder workshops that show many promising technologies for dramatic cost reductions. DOE, *2014 Transformational Carbon Capture Technology Workshop*, https://www.netl.doe.gov/research/coal/carbon-capture/workshop-2014.

2. CO_2 Transport

As noted above, large-scale CO_2 pipeline transport has been occurring for decades, primarily for the purpose of supplying CO_2 to EOR operations and other industrial applications. There are currently 5,195 miles of dedicated CO_2 pipelines in the U.S., which transport more than 68 million tons of CO_2 per year to industrial uses and storage sites. DOE, *A Review of the CO_2 Pipeline Infrastructure in the U.S.*, DOE/NETL-2014/1681 (2015); U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration, *Data & Statistics*, http://phmsa.dot.gov/pipeline/library/data-stats. The overall length and capacity of existing CO_2 pipeline infrastructure dwarfs what would be needed to transport the amount of CO_2 captured by plants complying with the NSPS.[17] Thus there is no question that CO_2 transport systems can be built on the scale necessary for compliance with the NSPS.

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[17] Existing capacity is equivalent to the capacity needed to transport CO_2 from nearly 200 new 500 MW plants, each capturing 354,000 MT CO_2 per year.

EPA used 100 km as a reference point for pipeline length when evaluating the technical and economic feasibility of the NSPS.[18] This figure does not reflect the maximum feasible distance for CO_2 transport. The length of CO_2 pipelines in North America ranges from 1.9 to 808 km. IEA, *CO_2 Pipeline Infrastructure*, Report no. 2013/18 (2014). Many of these pipelines are over 200 km. *Id.* The longest of these pipelines, the Cortez Pipeline (808 km) transports approximately 20 MMT CO_2 per year to an industry CO_2 hub at Denver City, Texas, where it is then distributed for use in EOR operations. *Id.*

Pipeline transportation represents a small proportion of CCS costs. To further reduce costs, plants could be sited close to storage sites or existing transport infrastructure (so as to tap into EOR markets and displace natural CO_2 sources).[19] Costs can also be reduced by building CO_2 collection pipelines and hubs that serve multiple users – an approach already taken by private companies in the development of EOR infrastructure. *See* de Coninck & Benson, *supra*, at 250 (noting that "[t]ransport of CO_2 by pipeline benefits from economies of scale and favors collaborative hub-and-spoke transport systems rather than point-point

[18] Petitioner EPA's Brief at 33-34, n. 16.
[19] Air Products is a good example: captured CO_2 from a steam methane reformer is transported via a dedicated 21 km CO_2 pipeline to the existing 515 km Denbury-Green pipeline for delivery to EOR operations, where it replaces natural CO_2 sources. The Kemper County Integrated Gasification Combined Cycle ("IGCC") CCS project will also connect to the Denbury-Green pipeline for delivery to EOR.

systems" and that "innovative financing schemes" can be used for multi-user pipelines).

3. CO_2 Storage

The mean estimate of geologic CO_2 storage capacity in the U.S. is 3,000 gigatons CO_2. USGS, *National Assessment of Geologic Carbon Dioxide Storage Sources* (2013), EPA-HQ-OAR-2013-0495-0044. This is enough to store the captured CO_2 from approximately 85,000 500 MW coal-fired plants operating for 100 years (each capturing 354,000 MT CO_2 / year).[20] There are a variety of geologic storage options located throughout the U.S., including: deep saline aquifers, EOR sites, and "deep" or "unmineable" coal seams. CO_2 can also be stored permanently through mineralization and conversion to usable materials.

EPA based the NSPS on the feasibility of deep saline storage, but has also stated that entities can comply with the standard through other storage approaches, including through EOR. 80 Fed. Reg. 64589. The availability of these other storage options will make it much easier and cheaper for some units to comply with the

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[20] As a point of reference, there are less than 1,000 coal-fired power plants in the U.S. (average capacity: 315 MW), and only a few planned units; thus, theoretical storage capacity is orders of magnitude larger than what would be needed to store CO_2 emissions from *both* planned and existing units. IEA, *Electricity*, https://www.eia.gov/electricity/data.cfm.

NSPS. EPA has thus taken a conservative approach in determining the technical viability and costs of CO_2 storage in the United States.

Deep saline storage is an excellent option for sequestering CO_2 emissions. Deep saline formations are found throughout the U.S. and have enormous CO_2 storage capacity. Michael Szulczewski et al., *Lifetime of Carbon Capture and Storage as a Climate-Change Mitigation Technology*, 109(14) PNAS 5185 (2012). As noted in the previous section, deep saline storage has been proven technically viable through decades of experience and many large-scale projects. These include Sleipner (Norway), which has stored 16.2 MMT CO_2 since 1996; Snøhvit (Norway), which has stored nearly 3 MMT CO_2 since 2008; In Salah (Algeria), which stored 3.8 MMT CO_2 from 2004 through 2011; Quest (Canada), which has stored 1 MMT since 2015; and the ADM Illinois Industrial Project. Global CCS Institute, *Projects*, https://www.globalccsinstitute.com/projects. There has been no CO_2 leakage reported from any of these projects.

Petitioners argue that the standard is invalid because deep saline storage has not been proven. In support of this argument, petitioners state that the three large-scale projects cited by EPA (In Salah, Sleipner and Snøhvit) are not integrated with carbon capture at steam units. The fact that these projects are not connected to steam units is irrelevant to the question of whether deep saline storage has been proven: the same technical considerations and costs would apply regardless of whether the CO_2 is sourced from a power plant or an industrial unit.

Petitioners also allege that two of the projects (In Salah and Snøhvit) have suffered "serious setbacks" which have caused them to "cease injection earlier than planned." Non-state Petitioners' Brief at 30. While it is true that In Salah suspended injection in 2011 due to pressure build-up and concerns about CO_2 migration, this project is still viewed as a success due to the large quantities of CO_2 that were successfully injected, the fact that the monitoring program served its purpose (identifying a risk of potential leaks before those leaks occurred), and the valuable lessons learned for future projects. As for Snøhvit, petitioners' claim that there were "serious setbacks" causing early cessation of injection is false: the operator detected a pressure build up in the formation, modified the injection well in 2011, and has continued injection without incident since then. Modifications and revisions of injection strategy after observation of reservoir response to injection are a normal part of any injection operation, and should not be considered setbacks.

As noted above, the rule also allows power plants to use other methods to store CO_2. EOR is an excellent alternative, as it provides a "readily available pathway to large volume storage" of captured CO_2, and selling CO_2 for EOR can help offset the costs of a CCS system. Hill, Hovorka & Melzer, *supra*, at 6809.

There is already abundant demand for CO_2 in U.S. EOR operations,[21] and many EOR "reservoir targets have not been flooded because of limited CO_2 supply." *Id.* at 6808.

EOR sites are ideal for sequestration because they: 1) contain reservoirs that have held hydrocarbons over geologic time, 2) have proven reservoir injectivity, 3) may offer "stacked storage" potential,[22] 4) are linked to existing CO_2 pipeline and injection infrastructure, 5) generate revenue for capturing companies, and 6) offer monitoring advantages due to available well infrastructure, experienced service company presence, and dense pre-injection data. *Id.* at 6808-09.

There are also other geologic storage sites, such as unmineable coal beds, that can be used to sequester carbon. To increase the diversity of options for geological CO_2 storage, researchers are currently evaluating the potential of CO_2 storage in basalt formation, which would rely on geochemical reactions between the CO_2 and basalt to mineralize the CO_2. De Conick & Benson, *supra*, at 252.

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[21] In 2010, the rate of CO_2 EOR injection was about 9 MMT per year. National Energy Technology Laboratory, *supra*, at 17.

[22] "Stacked storage potential" refers to the potential for combining EOR and deep saline storage. Many EOR sites have saline formations below the depleted producing zones. An EOR operator could contract with a power plant to provide storage for captured CO_2 in those saline formations. In this manner, "CO_2 EOR can prepare the way for continued and larger volume storage in underlying saline formations." Hill, Hovorka & Melzer, *supra*, at 6816.

Scientists have recently demonstrated that this form of "in situ" carbon mineralization is a viable storage option. Juerg Matter et al., *Rapid Carbon Mineralization for Permanent Disposal of Anthropogenic Carbon Dioxide Emissions*, 352 Science 1312 (2016). *See also* Jennifer Wilcox, *The Role of Mineral Carbonation in Carbon Capture*, in *Carbon Capture* (2012).

Finally, there are approaches currently under development to transform CO_2 into useable materials that could be sold to offset the costs of CCS systems.[23] These include: ex situ carbon mineralization (which would allow the mineralized carbon to be used as a material for construction or other applications), and using captured CO_2 as a chemical feedstock. Smit, Park, and Gadikota, *supra*, at 2. Using these approaches, scientists have successfully turned CO_2 into materials such as concrete and carbon monoxide (which can then be used to make a range of materials including fuels, plastics, and pharmaceuticals). *CO_2 Can Be Turned Into Sustainable Concrete*, The Chemical Engineer (Mar. 16, 2016); Song Lin et al., *Covalent Organic Frameworks Comprising Cobalt Porphyrins for Catalytic CO_2 Reduction in Water*, 349 Science 1208 (2015).

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[23] EPA will consider these alternate storage options on a case-by-case basis. 80 Fed. Reg. at 64581.

C. Many Power Generation CCS Systems are Operational or Under Development, Proving that CCS is Available for Installation at Coal-Fired Power Plants

CCS systems have now been installed at a number of coal- and natural gas-fired power plants and boilers, demonstrating that these systems can be scaled up and integrated to achieve the emission reductions required by the NSPS. Almost all of these projects rely on post-combustion capture using chemical absorption – the same technology that underpins the BSER – to capture large quantities of CO_2 emissions (in some cases, significantly more than 354,000 MT / year).

1. Post-Combustion Capture Projects

The **Boundary Dam Project** in Canada is the largest power sector CCS project in the world. It uses a post-combustion amine system to capture CO_2 from flue gas. The system commenced operations in the fall of 2014, and as of October 2016, it had captured a total of 1.27 MMT CO_2 (113,600 MT in 2014, 426,100 MT in 2015, and 686,600 MT in 2016). In the past twelve months, it captured 800,000 MT CO_2 (roughly 72% of the emissions from a 110 MW unit). Thus, the annual rate of capture at Boundary Dam (taking into account the fact that the system was only online for part of 2014) has exceeded the rate of capture required for a 500 MW facility under the NSPS (354,000 MT CO_2 per year, 16-23% of overall emissions). SaskPower anticipates that the annual capture rate will be approximately 1 MMT CO_2 per year (90% of emissions) once the facility has been operating for several years and initial operational issues have been resolved. Due to lessons learned from this project, SaskPower anticipates a 30% cost reduction for its next CCS project. Global CCS Institute, *The Future of Carbon Capture Will Focus on Cost Reduction* (Nov. 5, 2014).

Petitioners argue that the successful deployment of CCS at Boundary Dam does not show that CCS is "adequately demonstrated" for U.S. coal-fired power plants because the unit has a smaller capacity (110 MW) than the typical new coal-fired power plant in the U.S. (500 MW) and it burns lignite as opposed to bituminous or subbituminous fuels. Non-state Petitioners' Brief at 32. But contrary to the petitioners' assertion, both of these facts indicate that the CCS is viable on an even larger scale than what is required by the NSPS. The Boundary Dam unit has successfully captured *more* CO_2 than what would be required for a 500 MW plant to meet the NSPS, both in terms of CO_2 tonnage and percentage of overall emissions, thus proving that the NSPS is attainable. As for the type of coal used: as pointed out by petitioners, lignite coal actually produces more CO_2 than other types of coal. North Dakota Brief at 9. It should therefore be easier for a facility that uses bituminous or subbituminous coal to meet the NSPS.

Moreover, the fact that the Boundary Dam unit has successfully captured so much of its emissions while burning lignite coal directly contradicts petitioners' argument that the NSPS is unachievable for lignite-burning facilities. North Dakota Brief at 10; Lignite Organizations Brief at 21. It is true that a facility burning lignite will need to capture a greater percentage of its emissions (and thus the costs may be greater), but there are no serious technical obstacles to using CCS at a lignite-fueled facility.

Finally, Boundary Dam also demonstrates the feasibility of storing CO_2 via EOR and in deep saline formations. While most of the captured CO_2 has been used in EOR, the project manager recently announced that 100,000 tons of CO_2 have successfully been transported via pipeline and stored in deep saline as part of the Aquistore Project. Petroleum Technology Research Centre, *PRTC's Aquistore Project Surpasses 100,000 Tonnes of Stored CO_2* (Nov. 15, 2016). Thus, Boundary Dam demonstrates that all of the CCS components underpinning the BSER can be successfully integrated for the large-scale capture and storage of CO_2.

Another major project, **Petra Nova** (U.S.), is now fully constructed and slated to go online by the end of 2016. It will be the largest power sector CCS project in the world. Like Boundary Dam, Petra Nova will use a post-combustion amine system to capture CO_2 from an existing coal-fired power plant. Once operational, the system is expected to capture approximately 90% of the CO_2 from a 240-MW slipstream of flue gas (approximately 1.4 MMT CO_2 per year). The

CO_2 will be transported 82 miles (132 km) to be used in EOR operations, and the revenue from EOR will help pay for the system. Global CCS Institute, *Petra Nova Carbon Capture Project*, https://www.globalccsinstitute.com/projects/petra-nova-carbon-capture-project. The project is currently on schedule and on budget. DOE, *Petra Nova – W.A. Parish Project*, http://energy.gov/fe/petra-nova-wa-parish-project.

There are many power plants and industrial boilers with smaller but nonetheless substantial CCS systems, which capture approximately 20-75% of the emissions that would need to be captured from a 500 MW plant under the NSPS (see Table 2). The successful operation of these plants is further evidence that CCS systems can be deployed at the scale needed for compliance with the NSPS.

Table 2: Post-Combustion CCS at Power Plants and Industrial Boilers[24]

Project	**Facility type / size***	**Dates**	**Solvent**	**Capture rate** MT CO_2 / yr	**% NSPS ****	**Storage / Use**
Petra Nova (U.S.)	Coal-fired power plant (240 MW)	TBD	Amines	1,400,000	395%	EOR
Boundary Dam (Canada)	Coal-fired power plant (110 MW)	2014-present	Amines	800,000	226%	EOR / Deep Saline

[24] Data: Global CCS Institute, *Projects, supra*; *Report of the Interagency Task Force on Carbon Capture and Storage, supra*.

Searles Valley Minerals (U.S.)	Industrial coal-fired boiler	1978-present	Amines	270,000	75%	Carbonate brine for soda ash
Southern Company Plant Barry (U.S.)	Coal-fired power plant (25 MW)	2011 - present	Amines	165,000	47%	Deep saline
Shidongkou (China)	Coal-fired power plant (36 MW)	2009 - present	Amines	100,000 - 120,000	30 - 34 %	Beverage industry
AES Warrior Run (U.S.)	Coal-fired power plant (180 MW)	2000 - present	Amines	110,000	30%	Food industry
AEP / Alstom Mountaineer (U.S.)	Coal-fired power plant (20 MW)	2009-2011 ***	Chilled ammonia	100,000	28%	Deep saline
Fluor Corp. Bellingham (U.S.)	Natural gas-fired power plant	1991-2005	Amines	100,000	28%	Beverage industry
AES Shady Point (U.S.)	Coal-fired power plant (320 MW)	1991 - present	Amines	66,000	20%	Food industry

* Size refers to the size of the unit or slipstream from which CO_2 is captured.

** The percentages in this column are a comparison between the amount of CO_2 captured by the facility and the amount of CO_2 that a 500 MW unit would need to capture for compliance with the NSPS (356,000 MT CO_2 / year)

*** AEP/Alstom Mountaineer was cancelled *not* because of technical problems, but because the company did not believe state regulators would allow it to recover its costs from ratepayers in the absence of any federal climate policy calling or CO_2 emission reductions from power plants. Howard Herzog, *Lessons Learned from CCS Demonstration and Large Pilot Projects*, 11 (MIT 2016).

2. Pre-Combustion Capture Projects

While pre-combustion capture is not the technology underpinning the BSER, EPA has correctly concluded that this could provide an alternative compliance pathway for attaining the NSPS. There have been several successful pilot projects using pre-combustion capture at coal gasification plants. One example is RTI International's project at Tampa Electric's Polk Power coal-fired IGCC, which ran from 2014 through 2016 and captured approximately 1000 MT CO_2 / day. RTI is using the experience gained from that pilot project to develop commercial gasification and pre-combustion technology for power plants.

There is also a large-scale pre-combustion project at the Kemper County IGCC Plant which is now fully constructed and scheduled to commence operation in early 2017. This is a new 582 MW IGCC plant that turns lignite coal into syngas and then separates out the CO_2 before the fuel is burned. The captured CO_2 is then transported via a 61 mile (98 km) pipeline to the Denbury-Green pipeline and used for EOR. Global CCS Institute, *Kemper County Energy Facility*, https://www.globalccsinstitute.com/projects/kemper-county-energy-facility.

As noted by petitioners, the Kemper plant experienced some cost increases and delays during construction. State Petitioners' Brief at 33. This is true, but any problems at Kemper are not indicative of problems with the BSER (*post-combustion* capture at a SCPC unit), since Kemper uses a different technological configuration (*pre-combustion* capture at an IGCC unit). Moreover, to the extent that there were technical challenges, these were likely due to the fact that Kemper is demonstrating a novel gasification technology (a first-of-a-kind scale-up of a pressurized transport gasifier). The capture system (Selexol) is a conventional solvent-based capture technology that is widely used in industrial applications, and *amici* are not aware of any technical problems arising from the use of this technology at Kemper.

III. CCS COSTS WILL DECLINE WITH OPERATIONAL EXPERIENCE AND TECHNOLOGICAL INNOVATION

Other parties to this case have noted that the costs of CCS systems will decline as the adoption of CCS becomes more widespread, and this technological diffusion will be driven by the NSPS and other CO_2 regulations.[25] *Amici* agree with this assessment, and provide the following observations to support and supplement the statements made by other parties:

Near-term cost reductions will likely come from operational lessons learned from existing facilities like Boundary Dam and advances in existing technologies –

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[25] Considerable cost reductions have been observed in pollution abatement technologies following the promulgation of CAA standards (e.g., flue gas desulfurization scrubbers). The same can be expected for CCS technologies due to the promulgation of the NSPS and other CO_2 emissions standards. *See* Brief for Amici Curiae Technological Innovation Experts in Support of Respondents.

for example, improvements in the efficiency of amines and other chemical solvents used in post-combustion capture. As noted above, SaskPower is anticipating a 30% cost reduction due for its next CCS project based on lessons learned from Boundary Dam. Emergent and transformational technologies could also yield considerable cost reductions in years to come. For example, emergent technologies being developed by GE and Alstom could deliver a 30-50% cost reduction in 5-10 years, and transformation technologies like NetPower and Chemical Looping, could deliver a 70-100% cost reduction in the coming decades.[26]

Some of promising technologies to enhance the performance and decrease costs of CO_2 capture include:

- Novel solvents, including advanced amines, chilled ammonia, ionic liquids, and solvents that are optimized at molecular level for CO_2 removal;[27]
- Solid sorbent systems for post-combustion capture;[28]

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[26] A 100% cost reduction would mean zero additional cost for CO_2 capture.
[27] *See, e.g.*, P.D. Mobley et al., *Non-Aqueous Solvent (NAS) CO_2 Capture Process*, 13th International Conference on Greenhouse Gas Control Technologies, GHGT-13 (2016) (non-aqueous solvent in development could reduce energy demands for solvent-based CO_2 capture to 50% of conventional amine separation technology).
[28] *See* Thomas Nelson et al., *RTI's Solid Sorbent-Based CO_2 Capture Process: Technical and Economic Lessons Learned for Application in Coal-fired, NGCC, and Cement Plants*, 13th International Conference on Greenhouse Gas Control Technologies, GHGT-13 (2016) (RTI's physical absorption technology offers significant economic advantages over conventional amine scrubbing).

- Improved membrane-based capture systems;[29]
- Metal-organic frameworks to capture CO_2;
- Modular capture systems;
- Phase-change CO_2 separation;
- Supersonic expansion;
- Electrochemical processes;
- Cryogenic carbon capture;
- Hybrid capture systems;
- Chemical looping combustion; and
- Allam-cycle and other developments using supercritical CO_2 cycles.

There are also some promising technologies for reducing the costs of CO_2 storage that are currently being developed:

- Ex-situ carbon mineralization, which will allow CO_2 to be converted into materials for construction and other applications; and
- Polymerization of CO_2 (converting CO_2 into plastic); and
- Using CO_2 as a chemical feedstock for manufacturing other materials.

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[29] *See* Lora Toy, Atish Kataria & Raghubir Gupta, *CO_2 Capture Membrane Process for Power Plant Flue Gas: Final Technical Report* (2012) (an advanced membrane process could be retrofitted into current coal-fired power plants to capture at least 90% of CO_2 from plant flue gas with 95% captured CO_2 purity).

CONCLUSION

CCS systems are technically viable and capable of delivering large-scale emission reductions from power plants. There is no question that such systems can be readily deployed at new coal fired power plants to capture and store the amount of emissions required under the NSPS. Going forward, advances in both existing and emerging technologies could significantly reduce the costs and improve the performance of CCS systems. For these reasons, we support EPA's determination that the BSER for new coal-fired power plants should include partial CCS.

Respectfully submitted,

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December 21, 2016

CERTIFICATE OF COMPLIANCE

I hereby certify that the foregoing brief complies with the type-volume limitations set forth in D.C. Cir. R. 32(e)(3) and Fed. R. App. P. 29(d) because this brief contains 6,980 words, excluding the parts of the brief exempted by Fed. R. App. P. 32(a)(7)(B)(iii) and D.C. Cir. R. 32(e)(1). The foregoing brief complies with the typeface requirements of Fed. R. App. P. 32(a)(5) and the type style requirements of Fed. R. App. P. 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

December 21, 2016

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 December 21, 2016, which will send notice of such filing to all counsel who are CM/ECF registered users. I also caused the foregoing to be served via first-class mail on counsel for the following parties at the following addresses:

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