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Cleaning up America's Coal: An Analysis of States' Potentials for Carbon Capture and Storage

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Abstract

Coal-fired power plants across the United States, though affordable and reliable providers of approximately 39% of the nation's power, emit approximately 25% of total greenhouse gas emissions in the country. Therefore, in moving forward with legislation to reduce the amount of emissions, coal-fired power plants are among the first emitters to be targeted. This research examined individual power plants and states across the country, and after determining the energy profile and amount of coal emissions for each state and analyzing the unique characteristics of each power plant, an analysis was conducted to determine which power plants would benefit most from a Carbon Capture and Storage (CCS) retrofit. CCS, which captures carbon and prevents it from being released into the atmosphere, provides a unique solution for coal-fired power plants in that it allows them to continue their normal use while reducing emissions. In the framework of the Environmental Protection Agency's regulations for coal-fired power plants through the Clean Power Plan, several states were ranked based on their energy profiles, emission amounts, and CCS retrofit value. With this research, a quantitative outreach strategy was designed for the Department of Energy to implement CCS technology in a select group of states, focusing on cost-effectiveness and efficiency of CCS in each state. The states that were identified as ideal candidates for CCS retrofits included: Illinois, Missouri, North Dakota, and West Virginia.

Introduction and Background

Coal has served as a staple for the world's energy needs for thousands of years and continues to serve a pivotal role in the energy balance of the planet. An abundant resource across most of the world, coal has provided a large percentage of the world's energy for a competitive price. In 2014, coal comprised 32% of all electricity generation in OECD countries[1], with other fossil fuel sources comprising an additional 27% of generation (International Energy Agency, 2015). The United States is no exception: approximately 39% of the nation's energy generation comes directly from coal-fired power plants, with an additional 40% of total generation coming from other fossil fuels (U.S. Energy Information Administration, 2015). The role of coal in the national and global energy market cannot be understated. In some areas of the United States (such as Indiana, Kentucky, and West Virginia), coal provides over 80% of the total power generation. Coal also plays a large role in the job markets of many states, with over 100,000 individuals employed in coal-mining and power plant jobs as of 2013 (National Mining Association, 2015). Fossil fuels, especially coal, are essential for sustaining a reliable global energy market, and while progress is being made to further diversify the energy market through the use of renewables and other low carbon forms of energy, discussions about the role of coal and its future are a top priority for the Department of Energy and the United States.

In addition to providing for a reliable energy economy, coal power also serves as a strong supplier of baseload power for the United States[2]. Along with nuclear power plants, coal-fired power plants run for long periods of time to provide a set amount of power at minimal costs. During winter or summer, when energy demands are high, nuclear and coal-fired power plants supply a large amount of power, with renewables and natural gas providing additional power where needed. While it is difficult to continuously calibrate coal power plants to match day-to-day demand, as is the case in natural gas power plants, baseload power is essential to ensuring that energy production does not lag behind demand, especially during high-demand seasons.

Deliberations around the future of coal have greatly intensified (more so than in regard to other energy sources) with recent developments in climate change science. According to the Environmental Protection Agency (EPA), increasing greenhouse gas (GHG) emissions has led to large-scale climate changes across the world. For many states, average temperatures have risen—globally, seven of the top ten warmest years on record have occurred since 1998—and climate and weather disasters have

[1] "Organisation for Economic Co-operation, or OECD, countries are members of an international organization that promotes policies that tackle challenges of a globalized economy" (OECD, 2015). OECD includes 34 member countries, in North and South America, Europe, and the Asia-Pacific region.

[2] Baseload power generation operates continuously and is available 24 hours a day. Baseload power is used to "maintain a large-scale electrical grid" at all times and provides low-cost electricity (Idaho Energy, 2015).

cost the United States economy approximately $100 billion since 2012 (EPA, 2015). As a result of these developments, there has been a greater national and global emphasis in the past decade on the need to protect the air, water, and climate for future generations. In 2014, the International Energy Agency (IEA) released an energy technology perspective report which outlined a goal to limit global warming to 2 degrees Celsius by 2100 in order to "mitigate the more catastrophic effects of climate change" (IEA, 2014). President Barack Obama has led the United States in global environmental initiatives with China and the European Union. In November of 2014, President Obama and Chinese President Xi Jinping announced a joint action on climate change in which Obama unveiled a 2025 target to reduce climate pollution by 26-28% from 2005 levels (White House, 2014). In December of 2015, President Obama will join other nations at the Paris Climate Conference to discuss a new international climate change agreement for all countries (European Commission, 2015). These international conferences suggest that there is a universal ambition to reduce GHG emissions and protect and preserve the planet for future generations.

How Carbon Regulations Impact Coal

In 2013, President Barack Obama released a "series of executive actions to reduce carbon pollution, prepare the U.S. for the impacts of climate change, and lead international efforts to address global climate change" (White House, 2013). Encompassed in Obama's plan was a goal to reduce carbon pollution from power plants by introducing carbon pollution standards for all power plants. In addition to carbon regulations, the emissions of SO_2, NO_2, ash, and mercury from coal-fired power plants have been addressed through a suite of regulations. In order to support the President's climate targets, the EPA proposed the "Clean Power Plan" (CPP), which is designed to cut carbon emissions from the power sector by 30% from 2005 levels by 2030 (EPA, 2015). The CPP represents a large step toward a unified national effort to make significant carbon emission reductions.

The CPP utilizes a "building-block" approach to offer three technology options that states can take to reach their individual goals. The EPA suggests that states do the following three things: "make fossil fuel power plants more efficient, use low-emitting power sources more, and use more zero- and low-emitting power sources" (EPA, 2015). The three building blocks are not intended to be applied to individual power plants. Instead, the EPA sought to give states a flexible guideline so that they can consider all options for their existing power plants and various energy situations. In addition to the generalized building blocks, the EPA also outlined several specific suggestions that states can take advantage of to reach their emissions goals. These suggestions for states include: improving their energy efficiency programs, expanding renewable energy sources, co-firing coal-fired power plants (combusting both coal and

natural gas inside the same system) or switching to natural gas, constructing new Natural Gas Combined Cycle (NGCC) plants, expanding their nuclear power generation, retiring power plants, and implementing market-based trading programs on emissions.

With these options in mind, the EPA provided rate-based goals for each state and an option to consider a mass-based standard. A rate-based goal considers the tons of CO_2 emitted per megawatt-hour (MWh) produced from fossil power plants, while a mass-based standard allows the state to simply sum the CO_2 outputs of all power plants. Taking into account each state's current emission rate, the CPP determined how much each state needs to reduce its emissions by 2030. These goals varied by state and reflected the state's current and projected energy profile. Factors such as a states' existing and potential capacity for renewable energy, nuclear power, and existing fossil fuel plants greatly affected the state's emissions goals. In order to reach their goals, states were encouraged to create their own mitigation plan and submit it to the EPA for review (EPA, 2015). States also retained control over their individual power plants, and could determine when the plants must make reductions, as long as interim and final targets are achieved. The EPA produced several technical support documents that provided optional year-by-year standards that each state could use as milestones to help achieve its final goal in 2030 (EPA, 2014). The final version of the CPP was released on August 3, 2015.

These increasing regulations put forth by the President's Climate Plan, especially restraints on carbon pollution in the CPP, will significantly affect many coal-fired power plants across the United States as they are the largest emitters of carbon dioxide. In 2013, over 2.9 billion metric tons of CO_2 were released in the atmosphere[3]; coal power plants with more than 50 MW of capacity released over 1.5 billion metric tons alone, constituting approximately 54% of total U.S. power emissions (EPA, 2014). Therefore, states should analyze their largest emitters and develop an implementation strategy in order to ensure CPP compliance by 2030. This regulatory pressure is nothing new for coal-fired power plants as of late. Since 2000, approximately 50 GW of power plants have announced retirement for a variety of reasons, including the potential costly investments due to compliance with EPA regulations. Some power plants that emit more per MWh than other plants are often dispatched less, making it difficult for these plants to financially justify additions to their infrastructure in order to comply. The premature closure of power plants can be harmful to the employees of the plants, the generation capabilities of the region and state, and the energy market for coal. In addition, the closure of a power plant before the end of its projected lifespan could

[3] The data come from the GHG Reporting Program, which implements the EPA rule for mandatory reporting of all GHGs (EPA, 2013). The total emissions are from all sources that emit more than 25,000 metric tons of carbon dioxide per year. Smaller sources, small businesses, and the agricultural sector and land use changes are not included in this program.

compromise the expected lifetime energy production, which may cause a serious financial burden on the owners. Many states rely on coal for their own generation, but some states like Pennsylvania rely additionally on financial gains from exporting coal and exporting energy from coal. Should the demand for coal decrease from the closure of power plants, adverse market effects may occur for states like Pennsylvania. The reduction of coal as a primary power supply is not the EPA's chief goal, yet the increasing number of regulations on coal-fired power plants has complicated the financial situation of power plants across the country, and the CPP is no exception.

Opportunities for CO_2 Reduction in Coal

The Obama Administration has continuously pushed for an "All-of-the-Above" energy strategy, which aims to "harness American innovation and develop a diverse portfolio of American-made energy" (White House, 2015). This strategy embraces renewable energy technologies, improvements in efficiency for all power systems, reductions on the United States' dependence of foreign energy, and production of cleaner energy. A more diversified energy sector provides reliable and cost-effective energy at prices that the American consumer can afford, while also providing for national energy security. This approach specifically incorporates the use of coal and other fossil energy sources as integral parts of the energy balance of the United States for the future. However, evolving fossil energy systems need to properly incorporate the increasing number of environmental standards outlined by the EPA. For the CPP, in order to reduce emissions from coal-fired power plants, only three options exist.

First, a power plant can simply retire. This would cut all emissions, but also eliminate all power generation. Coal-fired power plants often produce a sizeable percentage of a region's and state's total energy generation, and the removal of these power generating stations would leave a gap in the state's energy security. For example, in northeastern states during the severe winter storms in 2014, eight of the ten highest winter demand levels for electricity of all time occurred in January (Energy Research Council, 2014). The cold weather hampered power generation, including gas, coal, and nuclear power plants, and many power plants were forced to run at full capacity to account for the extreme demands. Also, during the 2014 winter storms, American Electric Power reported that 89% of the coal-fired power plants that were used for baseload power generation were slated for retirement by mid-2015 (Murkowski, 2014). For states that rely on coal-fired power plants for a large percentage of their generation, another weather storm could cause brownouts[4] or blackouts in the future if coal does not remain a baseload provider.

[4] A brownout is a "reduction or restriction on the electrical power in a certain area," and typically occurs when there is high demand (Department of Energy, 2015).

Second, a power plant can switch to co-firing the plant with natural gas, or completely switching to a natural gas fired power plant. Currently, some power plants operate their natural gas units during times of low demand and then switch to coal use during times of high demand. Natural Gas Combined Cycle (NGCC) units are now widely used and provide higher efficiencies and fewer emissions than a traditional coal-fired power plant. With the recent drop in natural gas prices due to shale gas production, increased hydraulic fracking, and horizontal drilling, power generation from natural gas units is becoming increasingly attractive for its current affordability and relatively low emissions. However, numerous projections for natural gas prices do not predict that its cost will remain low. This concerns some economists, who state that a reliance on natural gas as an energy source over coal will harmfully affect energy prices should they rapidly change. In addition, natural gas combustion in boilers specifically designed for coal is less efficient than using an NGCC unit, and this power would need to be accounted for by using other energy sources or power plants.

The previous two options solve the issue of emissions from coal-fired power plants, but they have severe negative impacts on states reliant on coal. In order to offer an alternative to promote the coal industry and the future role of coal, the Department of Energy has come together in the Office of Clean Coal and Carbon Management and the National Energy Technology Laboratory to solve the dual conundrum produced by the increasing energy demands of an industrialized world and the more stringent environmental conditions on carbon dioxide. The solution to this conundrum is termed "Carbon Capture & Storage (CCS)," and is sometimes referred to as "Carbon Capture, Utilization, and Storage (CCUS)." As its name implies, CCS uses "carbon capture and storage technologies to separate approximately 90% of CO_2 emissions from coal and natural-gas power plants" and then "stores it in geologic formations below ground" (Department of Energy, 2015). Additionally, the captured CO_2 can be used for the process of Enhanced Oil Recovery (EOR), where CO_2 is injected into oil reservoirs and can recover approximately 20-40% more oil than standard methods. CCS offers a permanent solution for power plants to reduce their CO_2 emissions and remain complaint under the CPP. Furthermore, prospects of EOR allow power plants to make additional profits from the capture of CO_2. Using CCS is essential for meeting the 2 degree Celsius plan, which states that "widespread implementation of CCS accounts for 14% of cumulative emission reductions by 2050" (IEA, 2014). According to the Office of Clean Coal & Carbon Management, CCS will also contribute to the economic strength of the United States. With the use of CCS, the DOE predicts that by 2040, "2.4 million job years will be produced, $92 billion in electricity expenditures will be saved, $133 billion will be generated in income, $242 billion will be added the United States' GDP, 2.9 Gigatons of CO_2 will be captured, and 4 billion barrels of oil will be recovered using EOR"

(Department of Energy, 2015, p. 31). Therefore, in order to preserve the future of coal in the energy market of the United States, protect the environment, and provide for the economic welfare of the United States, CCS must be implemented.

Deployment of Carbon Capture and Storage Technologies

CCS is key to maintaining energy security. According to the Office of Clean Coal & Carbon Management, "[CCS] will enable continued diversification in the U.S. electric power sector due to the inclusion of fossil fuel systems" (Department of Energy, 2015, p. viii). The diversification of an electric power sector is a primary goal of the Obama's Administration's "All-of-the-Above" energy strategy. Therefore, the Administration has proposed the POWER+ Plan addition to the FY2016 budget (White House, 2015). The POWER+ Plan specifically targets areas in the United States that use coal the most, especially Appalachian communities, and is designed to "bring middle class economies into the 21st Century" and revitalize coal country (White House, 2015, p. 1).

These initiatives are especially important for areas that have been negatively impacted by the closure of coal power plants, as employees of the plants, their families, and their communities struggle financially with the loss of employment in the region. In order to properly provide for the citizens most negatively affected by regulations, the POWER+ Plan provides resources for "economic diversification, job creation, job training, and employment services for workers and communities impacted by layoffs at coal mines and coal-fired power plants and investing in health and retirement benefits for coal miners" (White House, 2015, p. 1). By actively engaging with local officials and state legislators, the appropriate role of coal in communities can be communicated and an economically and environmentally-friendly agreement can be reached.

The POWER+ Plan also provides over $2 billion in tax credits to all electric generating units that deploy CCS (White House, 2015, p. 5). In order to qualify, the specific power plants must have capacities over 250 MW, capture and store at least 75% of CO_2 emissions, and store over one million metric tons of CO_2 per year. The tax credit would account for 30% of the installation cost of the CCS technology, including pipelines and infrastructure of the units. In addition, $50/metric ton of CO_2 permanently stored and $10/metric ton of CO_2 sold for EOR would be provided for up to 20 years. These proposed tax credits provide powerful incentives for power plants and companies to invest in CCS technology.

These tax credits are essential to the development of CCS, because as of 2015, "state-of-the-art post-combustion capture technology retrofits in most cases… [are] still not economically competitive with other power generation options" (Department of Energy, 2015, p. 30). Therefore, it is a primary goal of the DOE to refine existing technologies and provide cheaper, more efficient technology. It is estimated that 2nd generation

technology will lower the cost of electricity by 20% from 1st generation CCS technology (Department of Energy, 2015, p. vi). Large-scale demonstrations going on right now are continuing to accumulate a base of knowledge of CCS, its implementation, and its efficiency and cost improvements, which are further expected to reduce costs of CCS.

Assessment of State CCS Potential

Therefore, in looking towards the future of the CPP and the expectation of reduced CO_2 emissions, CCS presents a powerful alternative for coal-fired power plants that want to avoid premature retirement. Each state in the United States, however, differs greatly in its individual relationship with coal and the coal market. In an attempt to target specific states and regions of the United States with CCS technology, this study analyzes various states' capacity, ability, and need for CCS implementation. A holistic view of each state's energy profile, emission amounts, and environmental needs was compiled, utilizing data from a variety of government agencies. This cumulative analysis compiles five individual analyses of each state's reliance on coal, environmental impact due to coal, capability to implement CCS cost-effectively, capability to implement CCS at a low cost of electricity, and need demanded from the CPP.

Coal-Reliant States

First, an analysis was conducted to determine which states in the United States depend the most on coal for economic and energy-based needs. This analysis was conducted in order to determine which states would be most negatively impacted by a reduction in coal as an energy source and/or as an employment source. In order to determine the impact of coal in each state, four factors were considered:

1. The number of coal-related jobs in the state
2. The percent of employment in the state that is related to coal
3. The total generation of the state that is from coal-fired power plants
4. The percent of generation from each state that is from coal-fired power plants

States whose residents are employed by the coal industry, whether in mining or in power plant work, should be interested in CCS, as it ensures the future of coal for their state and local economies. Data on the number of coal-related jobs were obtained from the National Mining Association, and these data were combined with estimates on the number of coal-fired power plant jobs in each state (National Mining Association, 2015).[5] The percent of employment in the coal industry in each state was calculated using data on the total number of coal-related jobs and the total number of

[5] Data are not readily available for employees of coal-fired power plants for each power plant, so the estimate from Virinder Singh and Jeffry Fehrs was used that states that 0.18 jobs are needed per MW (Singh & Fehrs, 2001). Combining this with data from the EIA-860 on total power generation, a state-by-state estimate was made (EIA, 2013).

jobs. Employment data for each state were collected from the Bureau of Labor Statistics (United States Department of Labor, 2015). The total generation of each state from coal-fired power plants was determined from the EIA-860, a generator-level database that included data on the power plant and utility name, the nameplate and summer nameplate (machine-rated) capacity, and the primary energy source of the generator (EIA, 2013). These data were sorted, and the sum of the summer nameplate capacity of coal-fired units was found for each state.[6] To find the percentage of generation from coal for each state, the EIA-860 was used and included all generation.

The states were ranked in each category from the greatest dependence on coal to the least dependence on coal on a scale from 1-51 (including Washington, DC). For example, the state with the greatest percentage of its workforce involved in coal, West Virginia, was given a ranking of 1, and the state with the highest total energy capacity for coal, Texas, was given a ranking of 1, and so on. The results of the four components are shown below in **Table 1**. Then, the average ranking of each state was found based on the four components, and the states were again ranked from 1-51. The states with the lowest average ranking were determined to be the states most reliant on coal. Therefore, according to this analysis, states with the lowest rankings should support the continuation of coal for their region. This analysis determined that West Virginia, Kentucky, and Indiana, respectively, were the most reliant on coal.

[6] Two important assumptions were made in looking at the data. First, only units that used bituminous, sub-bituminous, and lignite coal sources were included. Therefore, if a coal unit co-fired with natural gas but primarily used natural gas, the data were not included. Second, only units with capacities greater than 50 MW were included in the total generation, as this effort was designed to target units whose primary goal was to produce electricity.

Table 1: Top 10 States with Reliance on Coal					
Rank	**Coal jobs**	**% Coal employ-ment**	**MW coal production**	**% Genera-tion from coal**	**Reliance on coal**
1	West Virginia	West Virginia	Texas	West Virginia	West Virginia
2	Kentucky	Wyoming	Ohio	Kentucky	Kentucky
3	Penn.	Alaska	Indiana	Wyoming	Indiana
4	Wyoming	Kentucky	Kentucky	Indiana	Wyoming
5	Indiana	North Dakota	Illinois	Utah	Ohio
6	Ohio	Montana	West Virginia	North Dakota	Penn.
7	Illinois	Alabama	Penn.	Ohio	Alabama
8	Texas	Indiana	Georgia	Missouri	Missouri
9	Alabama	New Mexico	Missouri	New Mexico	Illinois
10	Virginia	Penn.	Alabama	Wisconsin	Utah

TABLE 1: Top 10 States with Reliance on Coal

High Coal Emission States

Second, an analysis was conducted to determine to what extent each state's environmental emissions are due to coal-fired power plants. Every state has several facilities that emit greenhouse gases, but this analysis attempted to isolate the effects of coal. With this, the contribution of coal's emissions can be quantified, which, in turn, can be used to determine whether the emissions are significant enough to warrant their limitation. In order to determine the environmental impact of coal on each state, four factors were considered:

1. The total emissions, in metric tons, of CO_2 from coal-fired power plants per state
2. The percent of the total emissions that are from coal-fired power plants per state
3. The average number of CO_2 emissions per coal-fired power plant per state
4. The average number of CO_2 emissions per MW of capacity per state

Emission data for 2013 were collected from the GHG Reporting Program, which provided the amount of CO_2 emitted by each individual power plant (EPA, 2014). Using data from the EIA-860 to determine which power plants use coal as a primary energy source, individual coal-

fired power plants and their CO_2 emissions were summed.[7] To find the percent of the total emissions from coal, the total CO_2 emissions from all sources were summed for each state. The number of coal-fired power plants per state was calculated from EIA-860 data, as well as the total capacities for coal generation per state.

The data were ranked similarly to the first analysis, and the results are presented in **Table 2**. These results show which states have power plants that are the largest emitters of CO_2 nationally, and how much of each state's environmental emissions are due to coal-fired power plants. Again, the averaged ranking indicates which states should focus on environmental controls over their coal-fired power plants in order to meet regulations set by the CPP. Therefore, according to this analysis, coal-fired power plants in Arizona, Wyoming, and Illinois are most significantly accounting for the states' emissions.

Table 2: Top 10 States with Coal Emission Rankings

Rank	Coal CO_2 emissions	% Coal emissions	Coal emissions per power plant	Coal emissions per MW	Coal pollution
1	Texas	North Dakota	New Mexico	Maine	Arizona
2	Indiana	Nebraska	Texas	Wyoming	Wyoming
3	Illinois	Missouri	Washington	North Dakota	Illinois
4	Kentucky	Kentucky	Arizona	Arizona	Utah
5	Penn.	Utah	Louisiana	New Mexico	Texas
6	Ohio	Arizona	Arkansas	Utah	Missouri
7	Missouri	Illinois	Wyoming	Hawaii	Kentucky
8	West Virginia	Wisconsin	Alabama	Montana	North Dakota
9	Michigan	Iowa	Oklahoma	Nebraska	New Mexico
10	Alabama	Montana	Utah	Colorado	Indiana

TABLE 2: Top 10 States with Coal Emission Rankings

[7] Similar to the generation data for each state, only power plants that had a capacity greater than 50 MW were included.

Carbon Capture Retrofit Database (CCRD)

In the third analysis, data from the National Energy Technology Laboratory (NETL) Carbon Capture Retrofit Database (CCRD) were used to determine which power plants across the United States have the lowest CCS capture cost (Office of Clean Coal & Carbon Management, 2015). Several assumptions of the costs were made and include: that this is an n^{th}-of-a-kind CCS retrofit (as opposed to first-of-a-kind), capture and compression are included, CO_2 transportation and storage are excluded[8], plants were given a 30-year economic life, there is a 90% CO_2 capture rate, capital costs are approximately 8%, and the capacity factor of the plant is 75%. From over 831 coal-fired units, the top quartile of plants based on capturing costs was determined, ranging from \$55-58/ton of CO_2 captured. In the top quartile, 50 power plants in 22 different states were included. The analysis also included data on the estimated capital cost and heat rate of each plant with CCS.

In order to implement this study into overall analysis, a list of the various states suggested by the NETL CCRD study and the number of power plants were compiled into **Table 3**. These states represent the areas where it is cheapest to implement carbon capture technology into existing power plants. Therefore, according to the third analysis, Illinois, Louisiana, North Carolina, Texas, and West Virginia have the most plants that NETL determined to be cost effective to retrofit with CCS technology.

[8] Transportation costs through new or existing pipelines have been estimated to account for 7-12% of the total cost of CCS. Storage costs vary significantly, based on the availability of storage sites in the region, the cost variability between on-shore and off-shore storage, and the characterization of the chosen site. Due to the low cost of transportation and the unpredictability of the cost of storage, transportation and storage costs were excluded, providing a generalized study. A fuller analysis could account for availability of carbon storage in each state.

Table 3: States with Recommended Power Plants for CCS (NETL CCRD Study)	
State	**Number of recommended power plants**
Illinois	4
Louisiana	4
North Carolina	4
Texas	4
West Virginia	4
Missouri	3
Ohio	3
Pennsylvania	3
Florida	2
Indiana	2
Iowa	2
Maryland	2
Michigan	2
Nebraska	2
Wisconsin	2

TABLE 3: States with Recommended Power Plants for CCS (NETL CCRD Study)

ISOMAP Rankings

In the fourth analysis, a tool designed by Carnegie Mellon University (CMU) was utilized. CMU developed an ISOMAP program through Microsoft Excel that proposed solutions on how individual coal units can cost-effectively comply with the emission standards set by the CPP (Fischbeck, Zhai, & Anderson, 2015). This study financially analyzed which compliance method coal-fired generators should follow in order to produce the lowest cost of electricity for the consumer. This highly detailed tool allows for manipulation of various economic factors, including the cost of natural gas and coal, a possible carbon tax, the cost of CCS technology, and efficiency improvements. The ISOMAP tool included many possibilities for compliance for coal units—CCS, NGCC upgrades, retirement, co-firing—and included the calculated cost of electricity for each method. For this analysis, by varying the prices of coal and natural gas for 2030 (based on projections from the Annual Energy Outlook 2015), a list of coal generators was compiled for whom CCS is the cheapest alternative to satisfying the CPP.

The states with the most coal units recommended by the CMU analysis listed below in **Table 4** are listed similarly to the items in **Table**

3. Compared to the NETL study, which looked at the power plants that would be able to capture CO_2 at a reasonable cost, the CMU analysis determined which power plants are recommended to implement CCS to reduce their emissions and maintain the lowest cost of electricity. Also, in the CMU analysis, individual coal units were analyzed instead of entire power plants.[9] One disadvantage of using the CMU analysis, however, is that multiple states were excluded from the analysis, which may unfairly exclude viable CCS coal units.

Table 4: States with Recommended Coal Units for CCS (CMU ISOMAP)

State	Number of recommended coal units
Pennsylvania	12
Maryland	5
Texas	5
Illinois	4
Louisiana	4
Virginia	4
Wyoming	3
Alabama	2
Colorado	2
Illinois	2
Montana	2
North Dakota	2

TABLE 4: States with Recommended Coal Units for CCS (CMU ISOMAP)

Clean Power Plan Analysis

The fifth analysis was conducted to determine which states require the most emission reduction due to the CPP. Data retrieved from the mass-based equivalencies for each state was analyzed, and with projected renewable sources accounted for, the total percent reduction was determined from 2020-2030 (EPA, 2014). Requirements of the CPP are important to consider for possible CCS implementation opportunities, but states should not be solely targeted based on the CPP requirements, as various factors went into the determination of state-based goals. In **Table 5**, North Dakota, West Virginia, and Nebraska have the largest expected decrease from the CPP, with natural gas capabilities, current power plant

[9] For example, one large coal-fired power plant may have 3-5 coal units incorporated in it.

emissions, and the ability for plants to co-fire considered by the EPA (EPA, 2015).

Table 5: Rankings of States Based on CPP Expectation		
Rank	**State**	**CPP expected decrease in emissions**
1	North Dakota	17.43%
2	West Virginia	17.43%
3	Nebraska	17.33%
4	Kansas	17.30%
5	Kentucky	17.23%
6	Maryland	17.23%
7	Iowa	17.19%
8	Missouri	17.07%
9	Illinois	16.76%
10	Indiana	16.73%

TABLE 5: Rankings of States Based on CPP Expectation

Results Analysis

All of these independent analyses investigate various driving factors for a state to implement CCS: a desire to keep coal in the energy market for the state, coal emitting a large amount of environmental pollutants, an availability of coal-fired power plants that could cost-effectively install and run CCS technology, an availability of coal units to provide low-cost electricity using CCS, and a need to comply with the CPP requirements. Therefore, in order to determine which states should be targeted for outreach, a compilation of the previous five analyses is shown below in **Table 6**. In this table, each state is listed, and a checkmark is given to each state that is determined to have each of the previously defined driving factors. In order for each state to receive a checkmark, it must have appeared in the top 10 states in **Tables 1**, **2**, and **5** and appeared on the NETL or CMU analysis in **Tables 3** or **4**, respectively. In addition, this table lists the number of power plants recommended by at least 2 of the following analyses: the NETL study, the CMU tool, and a list of the largest emitters per energy generated.[10]

[10] In determining the total number of power plants each state has that are recommended for CCS retrofits, three independent factors were considered: plants recommended by the NETL study, units recommended by the CMU ISOMAP tool, and plants that emitted the

Table 6: Summary of Each State's Driving Factor for CCS							
State	**Large Coal Reliance**	**Large # Coal Emissions**	**Low Cost of Capture (NETL)**	**Low Cost of Electricity (CMU)**	**Need from CPP**	**# Power-plants**	**Count**
Illinois	X	X	X	X	X	3	5
Missouri	X	X	X	X	X	3	5
North Dakota	X	X	X	X	X	3	5
West Virginia	X	X	X	X	X	3	5
Iowa	X	X	X	-	X	1	4
Indiana	X	X	X	-	X	1	4
Michigan	X	X	X	-	X	2	4
North Carolina	X	-	X	X	X	1	4
Texas	X	X	X	X	-	7	4

TABLE 6: Summary of Each State's Driving Factor for CCS

Based on these results, Illinois and Texas (as stated earlier) would be ideal candidates for a CCS implementation, as they have 3 and 7 power plants with CCS capabilities, respectively. Therefore, according to this final analysis, Illinois, Missouri, North Dakota, and West Virginia are the most recommended states for CCS implementation, as they have been identified as ideal candidates in all five analyses.

In **Figure 1**, **Table 6** is shown geographically.

most. The lattermost factor was included to focus the analysis on the largest CO_2 emitters in each state, as successful CCS implementation is recommended on larger-scale power plants. If any power plant had two or more of these factors, it was considered for CCS outreach.

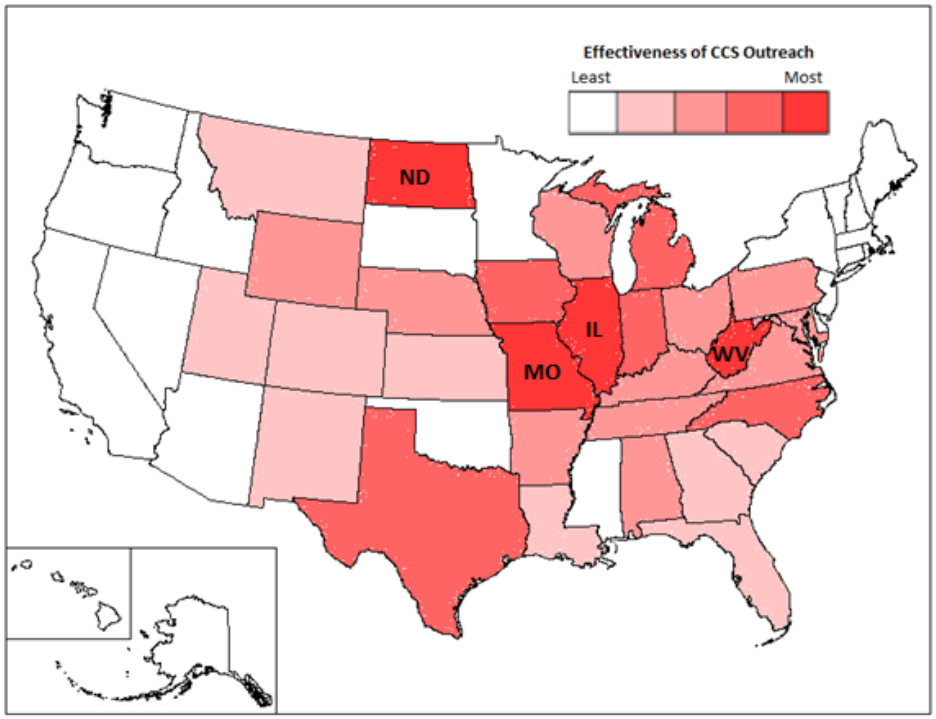

FIGURE 1: Map of the United States shaded to show the results of **Table 6**. A darker red color indicates states that would be most driven to implement CCS technology, and the white color indicates states that would be driven very little towards CCS.

Overall, this project sought to provide a quantitative measure of each state's driving factors towards implementing CCS technology. In all, this study is able to provide three key deliverables. First, this study determined which states would be best suited for CCS, and ranked them based on five different factors. Second, this study provided specific areas that the DOE and Office of Clean Coal & Carbon Management could use to persuade each state to consider CCS. For example, using **Table 6**, one can easily discern that Kentucky should pursue CCS in order to maintain coal as a key role in the economy of Kentucky, to significantly reduce state emissions, and to comply with the CPP. Third, this study identified 52 unique power plants in 23 different states that have at least 2 independent studies indicating its cost-effectiveness and utility in implementing CCS. Using these results, effective state outreach can be conducted by explaining to states their various options in complying with the CPP and reducing their emission levels, informing them of funding opportunities provided by the DOE and through tax credits, and ensuring the future of coal in key states.

Summary

Going forward, support for a cleaner planet is growing. A push for cleaner, more efficient energy is a key philosophy of the Department of Energy and the Obama Administration, and efforts will continue to provide for national energy security while protecting the United States' unique energy profile. CCS is a clean, forward-thinking option that emphasizes the importance of fossil energy in the modern world; however, much work needs to be done to make it an economically viable option for the majority of power plants. Continued research funded both by the DOE and industry "will have significant impacts in the area of economic growth, environmental sustainability, and energy security" (Department of Energy, 2015, p. vi). Research in carbon capture will continue to lower the financial costs of the capture process, reduce the energy penalty of using carbon capture technologies, lower the environmental impact of CCS use, and lower the cost of electricity compared to 1st generation technology. Research in geologic storage will be improved through advances in site characterization, geologic modeling software, monitoring technologies, and improved litigation and permitting procedures, all lowering the operational costs of permanent CO_2 storage (Carr, 2015, pp. 1-7).

In addition to funding large-scale research projects, the DOE will need to create competitive markets for CO_2. Supporting projects leads to increased confidence in CCS technology, which stimulates industries and financial institutions to make long-term investments in state-of-the-art technology. Though a politically complicated idea, a carbon tax or a cap-and-trade program on CO_2 would place a definitive price on carbon, which would enable power plants and industries to further justify investments in CCS technology. In addition to national solutions, as international coal power plants continue to be built, questions of CO_2 emission control and CCS will escalate in coming years.

The importance of coal cannot be understated, as it fuels the world's energy supply and provides thousands of jobs for low-income areas. While climate change is a pressing issue of today, and many groups propose that fossil energy be completely abandoned, the inclusion of fossil energy is essential to the Obama Administration's "All-of-the-Above" energy strategy and the national security of the United States. Rather than removing coal completely from its energy profile, the United States should instead use state-of-the-art research and development to improve the efficiency and environmental impact of coal. CCS provides for a cleaner future for generations to come, a more reliable energy grid, and a continued way of life for thousands of communities dependent on coal.

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