The Need for the Elimination of Coal – Clean or Otherwise

Adam Schulze
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I. Introduction

In the United States, coal has historically been used in as a source of power in industry and transportation, but it has steadily grown as a dominant source of electric power. However, as the U.S. has begun to propose policies regulating CO_2 emissions, coal has become a less attractive energy source. To meet government emissions standards, clean coal technologies have been proposed as a way to continue burning coal while reducing CO_2 emissions. In this paper, I will analyze the viability of clean coal technology to illustrate that any form of coal, clean or not, must be eliminated as a source of energy in the United States.

II. Current State of Coal in the U.S.

93% of the coal mined in the United States is used to generate electricity. In 2014, coal accounted for 39% of the total electricity produced in the U.S, making it the largest source of the country's electricity generation.[1] There are four types of coal: anthracite, bituminous, subbituminous, and lignite. Bituminous coal is the most abundant type of coal found in the United States, accounting for 48% of the country's coal production.[2]

Type	Heat Value (BTU/ lbs)	Average Mining Price ($/ton)	Heat Value (kWh/ lbs)	Price ($/kWh)
Anthracite	15,000	87.82	4.39625	0.00999
Bituminous	10,500 - 15,500	60.61	3.07737 - 4.54279	0.00985
Subbituminous	8,300 - 13,000	14.86	2.43259 - 3.81008	0.00305
Lignite	4,000 - 8,300	19.96	1.17233 - 2.4359	0.00851

Heat Value data from <http://www.ket.org/trips/coal/agsmm/agsmmtypes.html>
Average Mining Price data from <http://www.eia.gov/energyexplained/index.cfm?page=coal_prices>

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[1] "What is the role of coal in the United States?" *EIA's Energy in Brief*. US Energy Information Administration. Accessed February 29, 2016. <http://www.eia.gov/energy_in_brief/article/role_coal_us.cfm>

[2] "Coal Prices and Outlook" *Energy Explained.* US Energy Information Administration. Accessed February 29, 2016. <http://www.eia.gov/energyexplained/index.cfm?page=coal_prices>

As seen in the table above, all four types of coal are able to produce a relatively high amount of energy, and cost less than 1¢/kWh to mine. Coal is also an abundant resource in the United States. As of January 1, 2014, the estimated recoverable reserves of coal in the United States contained 256.7 billion short tons. The estimated recoverable reserves represent the coal that could be mined with today's mining technology.[3] If the United States were to mine the same amount of coal per year as it did in 2013 (984.8 million short tons), these reserves would last another 261 years. The price and high quantity of coal in the United States have made it an attractive source of energy, but transportation costs and externalities detract from its appeal. In 2013, it cost $20.93 per ton to transport coal by rail, $5.68 per ton to transport it by barge, and $6.36 per ton to transport it by truck.[4] If we assume this is for bituminous coal, this would increase the price by $0.00230/kWh - $0.00340/kWh for rail, $0.00063/kWh - $0.00092/kWh for transportation by barge, and $0.00070/kWh - $0.00103/kWh for transportation by truck. Nearly 70% of all coal delivered in the United States is transported by rail.[5] Thus, transporting most coal in the United States costs an additional 20–30% of the mining cost. In addition to the transportation costs, coal has large externalities, which are costs to people's health and the environment. A study by Harvard Medical School found that the total externalities of coal cost between $175 billion per year ($0.09/kWh) and 523 billion per year ($0.27/kWh), with the best estimate costing $345 billion per year ($0.18/kWh).[6] If we add the average cost of rail transportation and the best estimate for externalities to the cost of mining bituminous coal, we get a new cost of $0.1927/kWh. With transportation costs and externalities factored in, coal is no longer as attractive of an energy source as it was initially thought to be. Coal further loses its viability as an energy source now that regulations are being placed on emissions. In October

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[3] "How Much Coal is Left" Coal. US Energy Information Administration. Accessed March 1, 2016. <http://www.eia.gov/energyexplained/index.cfm?page=coal_reserves>

[4] "Coal Transportation Rates to the Electric Power Sector" *Coal.* US Energy Information Administration. Accessed February 29, 2016. <http://www.eia.gov/coal/transportationrates/>

[5] 5 "Coal Mining and Transportation" Coal. US Energy Information Administration. Accessed March 1, 2016. <http://www.eia.gov/energyexplained/index.cfm?page=coal_mining>

[6] Paul R. Epstein. "Full cost accounting for the life cycle of coal" Annals of the New York Academy of Science (2011). Accessed February 29, 2016. <http://www.chgeharvard.org/sites/default/files/epstein_full%20cost%20of%20coal.pdf>

2015, the Environmental Protection Agency (EPA) announced the Clean Power Plan, which proposes that by 2030, power plants will reduce CO_2 emissions by 32% of the emission levels in 2005.[7] Emissions from coal have fallen since 2005, with 2014 coal emissions down by 21.4% of the 2005 emissions level. However, total emissions have only fallen by 9.8%. As seen in the graph to the right, emissions from natural gas have risen since 2005, so emissions from coal will have to be further lowered to counter this effect and meet the EPA regulations.

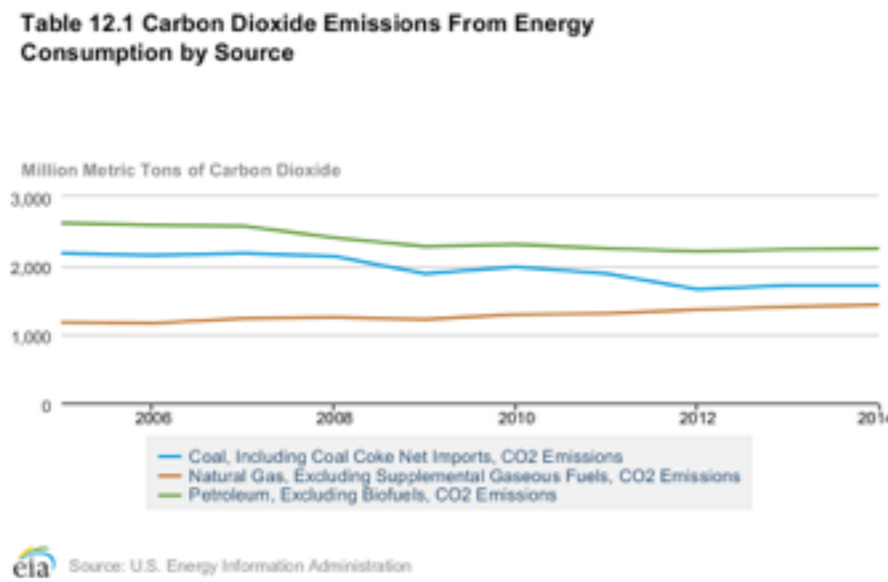

Table from <http://www.eia.gov/beta/MER/index.cfm?tbl=T12.01#/?f=A&start=2005&end=2014&charted=0-1-13>

III. Clean Coal

Clean coal technologies are presented as ways to reduce emissions without eliminating coal. Some of the prominent clean coal technologies are carbon capture and gasification. As its name suggests, carbon capture is the capture, storage, and utilization of carbon dioxide that results from burning coal. There are two types of carbon capture: post-combustion capture and pre-combustion capture. According to the U.S. Department of Energy,

> "Post-combustion capture is primarily applicable to fossil fuel based systems such as conventional pulverized coal (PC)-fired power plants, where the fuel is burned with air in a boiler to produce steam that drives a turbine/generator to produce electricity. The

[7] Environmental Protection Agency. *Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units.* EPA–HQ–OAR–2013–0602. <https://www.gpo.gov/fdsys/pkg/FR-2015-10-23/pdf/2015-22842.pdf> (accessed March 1, 2016).

carbon dioxide is captured from the flue gas after fuel combustion."[8]

This form of carbon capture can be used in traditional coal power plants, as it captures the carbon dioxide released after the combustion process has been completed. Meanwhile, Pre-combustion capture is better suited for integrated gasification combined cycle (IGCC) power plants, in which the carbon dioxide is captured before completing the combustion process.[9] This carbon dioxide is then injected into an oil or natural gas reservoir, a coal bed, or a saline formation. In a coal bed, oil reservoir, and natural gas reservoir, the injection of carbon dioxide allows for easier extraction of methane, oil, or natural gas, respectively. Saline formations do not produce any desired products, but they are able to store large amounts of carbon dioxide and are relatively close to most large CO_2 sources. All forms of carbon capture are intended to keep carbon dioxide out of the atmosphere by storing it underground. Coal gasification aims to reduce emissions by avoiding the combustion of coal altogether. In gasification, coal is broken down into its basic chemical constituents through exposure to

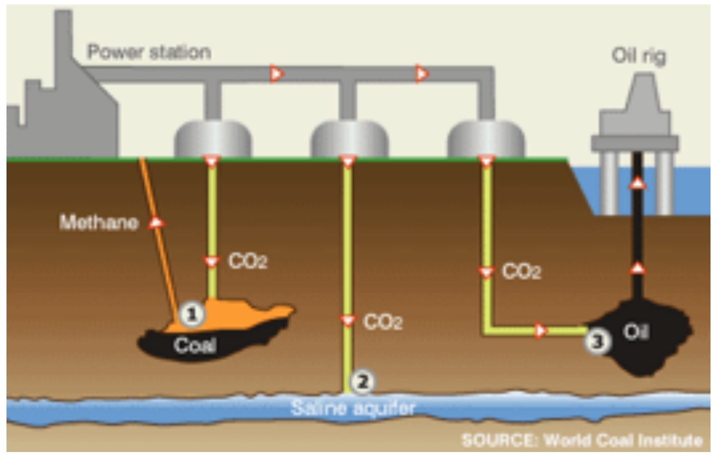

Image from <http://www.policymeasures.com/content/files/_41058606_carbon_options_416.gif>

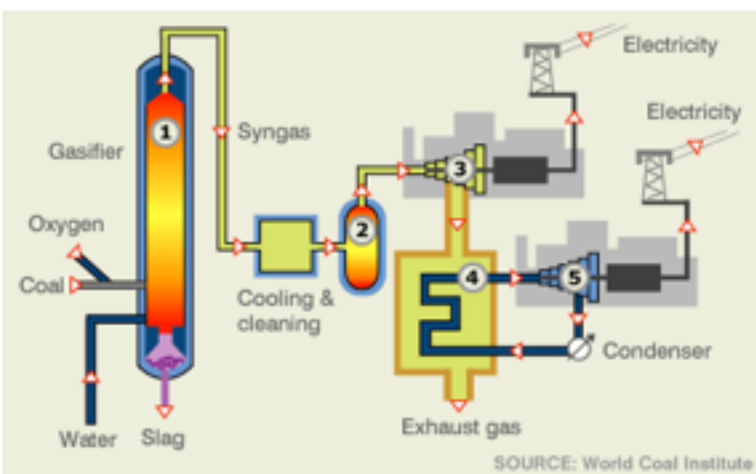

Image from < http://newsimg.bbc.co.uk/media/images/41058000/gif/_41058602_combo_coal_cycle_416.gif>

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[8] "Carbon Capture R&D." Accessed March 1, 2016. <http://energy.gov/fe/science-innovation/carbon-capture-and-storage-research/carbon-capture-rd>

[9] "Carbon Capture R&D." Accessed March 1, 2016. <http://energy.gov/fe/science-innovation/carbon-capture-and-storage-research/carbon-capture-rd>

steam and air. The sulfur and nitrogen in the coal are then removed to prevent NOx and SOx emissions, and the remaining carbon monoxide and hydrogen gas are then burned in a gas turbine to produce electricity. The exhaust from the gas turbine and the heat generated in the gasification process are then used to generate steam for use in a steam turbine, generating more electricity.[10] Coal that has undergone gasification with air still emits some carbon dioxide when burned. This carbon dioxide is diluted by the nitrogen in the air, and is costly to separate. However, if coal undergoes gasification with oxygen instead of air, the carbon dioxide is emitted as a concentrated gas, making it easier to separate. This can also be applied to traditional coal-burning plants in a process known as oxy-combustion, in which the coal is burned in the presence of oxygen rather than air to emit a concentrated CO_2 gas.[11]

IV. Why Clean Coal Falls Short

There are several concerns associated with clean coal technologies. Will the technology actually reduce emissions? Do these technologies have any negative effects? Is this technology

Table 2. MIT cost estimates for some representative CCS systems.[5]

		Subcritical PC		Supercritical PC		Ultra-supercritical PC		SC PC-Oxy	IGCC	
		No capture	Capture	No capture	Capture	No capture	Capture	Capture	No capture	Capture
CCS performance	Coal feed (kg/hr)	208,000	284,000	184,894	242,950	164,000	209,000	232,628	185,376	228,115
	CO_2 emitted (kg/hr)	466,000	63,600	414,903	54,518	369,000	46,800	52,202	415,983	51,198
	CO_2 captured at 90%, (kg/h)	0	573,000	0	490662	0	422000	469817	0	460782
	CO_2 emitted (g/kWh)	931	127	830	109	738	94	104	832	102
CCS costs	$/kWh	1,280	2,230	1,330	2,140	1,360	2,090	1,900	1,430	1,890
	Total $, assuming 500 MW plant	$640,000,000	$1,115,000,000	$665,000,000	$1,070,000,000	$680,000,000	$1,045,000,000	$950,000,000	$715,000,000	$945,000,000
	Inv. Charce ¢/kWh @ 15.1%	2.6	4.52	2.7	4.34	2.76	4.24	3.85	2.9	3.83
	Fuel ¢/kWh @ $1.50/MMBtu	1.49	2.04	1.33	1.75	1.18	1.5	1.67	1.33	1.64
	O&M ¢/kWh	0.75	1.6	0.75	1.6	0.75	1.6	1.45	0.9	1.05
	COE ¢/kWh	4.84	8.16	4.78	7.69	4.69	7.34	8.98	5.13	6.52
	Cost of CO_2 avoided vs. same technology w/o capture ($/ton)		41.3		40.4		41.1	30.3		19.3
	Cost of CO_2 avoided vs. supercritical technology w/o capture ($/ton)		48.2		40.4		34.8	30.3		24
	Energy penalty		1,365,384,615		1,313,996,128		1,274,390,244			1,230,553,038

[10] "Gasification." Accessed March 1, 2016 <http://energy.gov/fe/science-innovation/clean-coal-research/gasification>

[11] "Oxy-combustion." Accessed March 1, 2016. <http://www.netl.doe.gov/research/coal/energy-systems/advanced-combustion/oxy-combustion>

economically feasible? The table above[12] compares standard pulverized coal plants with carbon capture to those without carbon capture, as well as gasification plants with and without carbon capture and an oxy-combustion plant. Across the board, emissions from plants with carbon capture are at about 12-13% of the emissions from plants without carbon capture.
However, the gasification plant (IGCC) has higher CO_2 emissions than an ultra-supercritical pulverized coal plant (a PC plant with pressures at 4640 PSI and temperatures between 1112 and 1130 degrees Fahrenheit). An oxy-combustion plant has nearly the same emissions as an IGCC, making it less clean than an ultra-supercritical pulverized coal plant with carbon capture. Of the three clean coal technologies that we have examined, carbon capture is currently the only one that significantly reduces emissions. Although carbon capture reduces emissions, the Harvard Medical School study lists the following concerns associated with the storage of CO_2 obtained from carbon capture:

> "1. Storing compressed and liquefied CO_2 underground can acidify saline aquifers (akin to ocean acidification) and leach heavy metals such as arsenic and lead, into ground water.
> 2. Acidification of ground water increases fluid-rock interactions that enhance calcite dissolution and solubility, and can lead to fractures in limestone ($CaCO_3$) and subsequent releases of CO_2 in high concentrations.
> 3. Increased pressures may cause leaks and releases from previously drilled (often un-mapped) pathways
> 4. Increased pressures could destabilize underground faults and lead to earthquakes.
> 5. Large leaks and releases of concentrated CO_2 are toxic to plants and animals.
> 6. Microbial communities may be altered, with release of other gases."[13]

The possibility of CO_2 leaks defeats the purpose of carbon capture and storage. If there is a chance that CO_2 stored underground will leak out in a large, toxic release, then carbon capture

[12] Katzer, J., E.J. Moniz, J. Deutch, *et al* . 2007. *The future of coal: an interdisciplinary MIT study*. Technical report, Massachusetts Institute of Technology, Cambridge, MA. <http://web.mit.edu/coal/The_Future_of_Coal.pdf> accessed March 2, 2016.

[13] Paul R. Epstein. "Full cost accounting for the life cycle of coal"

and storage is even worse than the current coal burning process. Even if these risks are somehow eliminated, are these clean coal technologies economically feasible? The table above lists costs of constructing new power plants in $/kWh. For pulverized coal plants, carbon capture costs between 50–75% more than no capture. For IGCC plants, carbon capture only costs about 32% more than no capture, but as we noted before, IGCC plants have higher emissions than ultra-supercritical pulverized coal plants. The Harvard study also notes that for carbon capture,

> "25-40% more coal would be needed to produce the same amount of energy, would increase the amount of coal mined, transported, processed, and combusted, as well as the waste generated, to produce the same amount of electricity"

The need for more coal further increases the cost of operating carbon capture plants. The following table lists the operating costs of each type of plant in $/kWh. This table assumes each plant uses bituminous coal as the fuel (with transportation costs and externalities included), and that carbon capture plants require 32% more fuel to produce the same amount of energy and reduce externalities to $0.09/kWh (the Harvard study's estimated lower bound on externalities).

	Subcritical PC (no capture)	Subcritical PC (capture)	Supercritical PC (no capture)	Supercritical PC (capture)	Ultra-supercritical PC (no capture)	Ultra-supercritical PC (capture)	Oxy-combustion (capture)	IGCC (no capture)	IGCC (capture)
Fuel ($/kWh)	0.1927	0.1643	0.1927	0.1643	0.1927	0.1643	0.1643	0.1643	0.1643
O&M ($/kWh)	0.0075	0.0160	0.0075	0.0160	0.0075	0.0160	0.0145	0.009	0.0105
Generating Electricity ($/kWh)	0.0484	0.0816	0.0478	0.0769	0.0469	0.0734	0.0898	0.0513	0.0652
Total Operation Cost ($/kWh)	0.2486	0.2619	0.2480	0.2572	0.2471	0.2537	0.2686	0.2246	0.2400

When externalities are factored in, coal is no longer the cheap fuel that made it so attractive. Even if clean coal technologies are implemented to reduce these externalities, coal will still cost more than $0.20/kWh. With the rise of new CO_2 emissions standards, coal's viability as an energy source further decreases. Unless clean coal is somehow able to guarantee a reduction in emissions and decrease costs, coal of any kind has no place in the United States as an energy source.

Word Count: 1735 words