PROGRAM facts

U.S. Department of Energy
Office of Fossil Energy
National Energy Technology Laboratory

Carbon Sequestration

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The Cost of Carbon Dioxide Capture and Storage in Geologic Formations

The sequestration of carbon dioxide (CO_2) in geologic formations is a viable option for achieving deep reductions in greenhouse gas emissions without hindering economic prosperity. Due to the abundance of fossil fuels in the United States and around the globe as compared to other energy sources, there is strong interest in geologic sequestration, but cost is a key issue. The volume of CO_2 emitted from power plants and other energy systems is enormous compared to other emissions of concern. For example, a pulverized coal (PC) boiler operating on Illinois #6 coal (2.5 percent sulfur) may generate 0.03 pounds of sulfur dioxide per kilowatt hour (kWh) and emit CO_2 at a rate of 1.7 pounds per kWh.

The United States Department of Energy (DOE) has set two cost goals in its Carbon Sequestration Program: (1) CO_2 capture technologies for a greenfield PC plant should achieve 90 percent CO_2 capture with an increase in the cost of electricity (COE) of no more than 20 percent, and (2) CO_2 capture technologies for coal gasification should achieve 90 percent capture with no more than a 10 percent increase in COE. DOE's National Energy Technology Laboratory (NETL) has conducted systems analyses to estimate the cost of CO_2 capture and sequestration using a range of technologies. DOE has partnered with a number of respected engineering firms in conducting these analyses, including Nexant, Noblis, Alstom Power, Air Liquide, Babcock & Wilcox, SAIC, and Parsons. Every effort has been made to use real-world data and incorporate appropriate contingencies into the cost estimates.

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One NETL study titled, “The Cost and Performance Baseline for Fossil Energy Power Plants” establishes performance and cost data for fossil energy power systems, specifically integrated gasification combined cycle (IGCC), natural gas combined cycle (NGCC), and PC plants with and without carbon capture and sequestration capabilities. The analyses performed in the study reflect market conditions for power plants starting operation in 2010.

A second NETL study titled, “Pulverized Coal Oxyfuel Combustion Power Plants” investigates a PC oxycombustion process that can be built in the 2010 timeframe using “off-the-shelf” technologies such as cryogenic oxygen separation. The study also assesses oxycombustion using next-generation ultra-supercritical power plant designs projected to be available in the 2020 timeframe and advanced air separation unit processes (ion transport membrane). The report provides a foundation for oxy-fuel combustion and amine-based scrubbing as methods to reduce CO_2 from new coal-fired power plants and will be used as a point of reference to which research and development progress in the areas of oxy-fuel combustion and post-combustion CO_2 capture technologies can be compared.

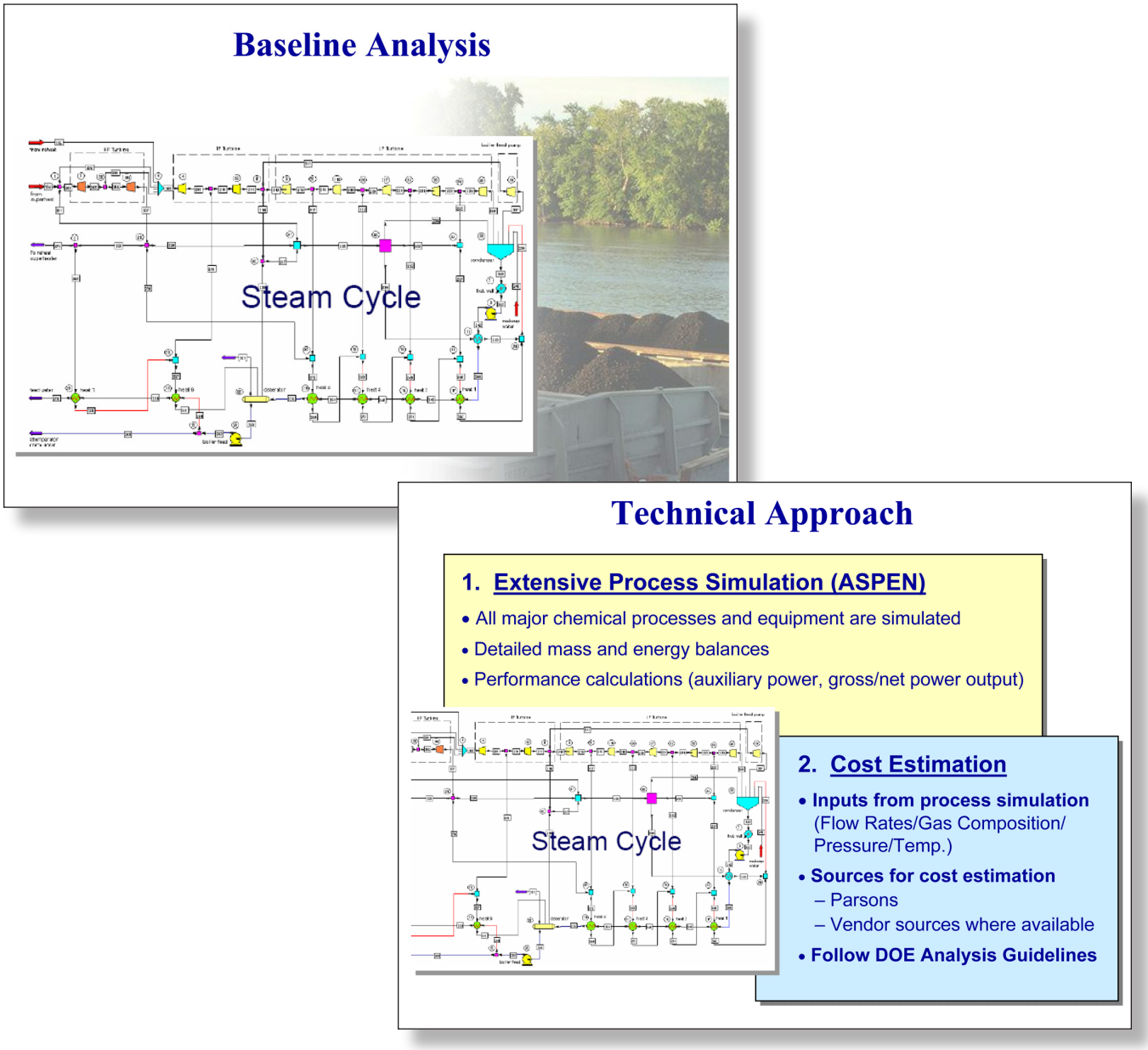

Table 1. Estimates of the Cost of CO_2 Capture from Coal-Fired Power Plants and Sequestration in Geologic Formations

		Pulverized Coal									
CO_2 Capture		***Subcritical***		***Supercritical***		***Ultra-Supercritical***		***Supercritical Oxyfuel***		***Ultra-Supercritical Oxyfuel***	
		No	Yes	No	MEA	No	MEA[b]	No	Oxyfuel	No	Oxyfuel
Capital Cost ($/kWe)	Base Plant	1,302	1,689	1,335	1,724	1,437	1,845	1,335	1,893[c]	1,437	1,937[c]
	Flue Gas Cleanup	246	323	228	300	204	273	228	318	204	292
	CO_2 Capture	-	792	-	749	-	673	-	210	-	197
	CO_2 Compression	-	89	-	84	-	76	-		-	
Total Plant Cost[1] ($/kWe)		1,549	2,895	1,563	2,857	1,641	2,867	1,563	2,930	1,641	2,898
COE											
Capital Charges[2] (¢/kWh)		3.41	6.81	3.44	6.71	3.86	6.74	3.44	6.89	3.86	6.81
Operating Costs (¢/kWh)		2.99	4.64	2.85	4.33	2.60	3.86	2.85	4.01	2.60	3.56
CO_2 TS&M[d2] (¢/kWh)		-	0.47	-	0.40	-	0.38	-	0.40	-	0.36
Total[3] (¢/kWh)		6.40	11.88	6.29	11.44	6.46	10.98	6.29	11.30	6.46	10.73
Increase in COE (%)[a]		-	85	-	82	-	75	-	80	-	71
$/ton CO_2 avoided[a]		-	75	-	68	-	61	-	57	-	50

The following are the steam cycle design conditions (design pressure [psig] / main steam [°F] / temperature [°F]) for the five pulverized coal (PC) power plant types: Subcritical 2400/1050/1050; Supercritical 3500/1100/1100; Ultra-Supercritical 4000/1350/1400; Supercritical Oxyfuel 3500/1110/1150; and Ultra-Supercritical Oxyfuel 4000/1350/1400.

		Integrated Gasification Combined Cycle					
CO_2 Capture		***GE Energy***		***E-Gas***		***Shell***	
		No	Yes	No	Yes	No	Yes
Capital Cost ($/kWe)	Base Plant	1,323	1,566	1,272	1,592	1,522	1,817
	Air Separation Unit	287	342	264	329	256	336
	Gas Cleanup/CO_2 Capture	203	414	197	441	199	445
	CO_2 Compression	-	68	-	69	-	70
Total Plant Cost[1] ($/kWe)		1,813	2,390	1,733	2,431	1,977	2,668
COE							
Capital Charges[2] (¢/kWh)		4.53	5.97	4.33	6.07	4.94	6.66
Operating Costs (¢/kWh)		3.27	3.93	3.20	4.09	3.11	3.97
CO_2 TS&M[d2] (¢/kWh)		-	0.39	-	0.41	-	0.41
Total[3] (¢/kWh)		7.80	10.29	7.53	10.57	8.05	11.04
Increase in COE (%)[a]		-	32	-	40	-	37
$/ton CO_2 avoided[a]		-	35	-	45	-	46

[a] With respect to its non-capture case
[b] MEA (monothanolamine)
[c] Base plant capital includes cryogenic ASU
[d] TS&M (transportation, storage and monitoring)

[1] Total Plant Capital Cost (includes contingencies and engineering fees)
[2] 50-mile pipeline, saline formation storage 4,500 ft below the surface, monitored for 100 years
[3] January 2007 Dollars, Capacity Factor 85%, Capital Charge Factor 16.4% (no capture), 17.5% (capture), Coal cost $1.80/$10^6$Btu

References:
1. "Cost and Performance Baseline for Fossil Energy Plants" August 2007 Presentation

2. "Pulverized Coal Oxycombustion Power Plants" November 2007 Presentation

The table above presents a compendium of results from these DOE-funded studies. Highlights from the studies include the following:

- Coal-based plants using today's technology are capable of producing electricity at relatively high efficiencies of about 39 percent higher heating value (HHV), without capture, on bituminous coal, and at the same time meet or exceed current environmental requirements for criteria pollutants.

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- Capital cost (total plant cost) for the non-capture plants are as follows: NGCC $554/kW; PC $1,562/kW; and IGCC 1,841/kW (average). With capture, capital costs are: NGCC $1,172/kW; PC $2,883/kW (average); and IGCC $2,496/kW (average).

- At fuel costs of $1.80/ton of coal and $6.75 MMBtu of natural gas, the 20-year levelized COE for the non-capture plants are: 64/mills kWh (average) for PC, 68/mills kWh (average) for NGCC, and 78/mills kWh (average) for IGCC.

- When today's technology for carbon capture and sequestration is integrated into these new power plants, the resultant 20-year levelized COE including the cost of CO_2 transport, storage, and monitoring is: 97/mills kWh (average) for NGCC, 106/mills kWh (average) for IGCC, and 117/mills kWh (average) for PC. The cost of transporting CO_2 a 50-mile distance for storage in a geologic formation with over 30 years of monitoring is estimated to add about 4/mills kWh. This represents only about 10 percent of the total carbon capture and sequestration costs.

- A sensitivity study on natural gas price reveals that the COE for IGCC is equal to that of NGCC at $7.73/MMBtu, and for PC, the COE is equivalent to NGCC at a gas price of $8.87/MMBtu. In terms of capacity factor, when the NGCC drops below 60 percent, such as in a peaking application, the resulting COE is higher than that of an IGCC operating at baseload (80 percent capacity factor).

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