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CLEAN COAL GENERATION TECHNOLOGIES FOR NEW POWER PLANTS

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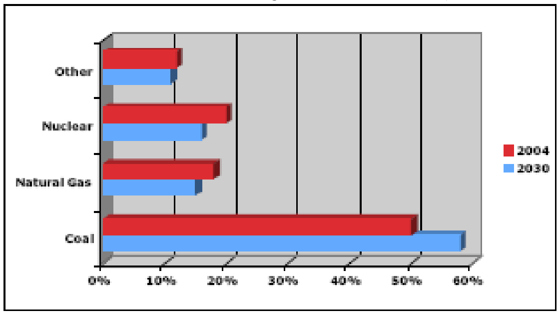
PRIMER FOR STATE REGULATORS: COAL GENERATION TECHNOLOGIES FOR NEW POWER PLANTS

1. Summary

Even with improvements in the efficiency of energy use, it is expected that substantial new generating capacity will be required before 2030 to meet the growing U.S. demand for electricity. A number of new technology types will be called upon to meet this increased demand. Coal-fired power plants currently provide half of the supply of electricity used in the United States. As climate change concerns increase, however, more attention is being paid to technologies that result in lower emissions of greenhouse gases like carbon dioxide (CO_2) for new power plants. Because of its high carbon content per embedded unit of energy, emissions of CO_2 and other greenhouse gases from coal are higher than for other fossil fuels. Even with the possibility of new greenhouse gas emission regulations, it is likely that coal will remain a major part of the fuel used in the U.S. to produce electricity. Its domestic availability, low cost, and the reliability of operating coal-fired plants make coal an attractive fuel-type for running baseload power plants. In fact, due to these characteristics and the predicted need for new baseload generation, some estimates predict coal will play an increasing role in the provision of electricity in the United States, as seen below:

Coal's Role in Electricity Generation (EIA 2005)



In 2007, one hundred and fifty-one proposed and new plants for a total of 90 GW of power were in some stage of the planning or permitting process before State Commissions (NETL 2007)[1]. In addition to subcritical pulverized coal (PC) technologies that are widely used today, the technologies which are part of total proposed projects include Circulating Fluid Bed (CFB) technology, Supercritical PC, Ultra-Supercritical PC, and Integrated Combined Cycle Gasification (IGCC).

These technologies, and their differences, are explained in greater detail later in this primer. It focuses on generating technologies that use coal and that may be proposed for approval by Public Utility Commissions in the coming decade and provides an introduction to the technology options Commissions may see in future power projects. It is important to note that this primer focuses only on generation technologies for new power plants: technologies to retrofit existing plants are also on the path to deployment. Many of these technologies, such as oxygen-combustion and post-combustion capture, can be used in new and retrofitted power plants alike. A companion primer, "Carbon Capture & Storage, Technology and Regulatory Considerations." explores some of the technologies and policy issues surrounding the long-term prevention of atmospheric release of greenhouse gases from new power plants.

[1] However, of the 36,000 MW announced to be built in 2002, only about 4,500 MW were actually constructed, or about 12% (NETL 2007). The number of cancellations appears to be due to the strain on project economics caused by escalating costs, uncertainty related to potential climate-related regulation, and changing conditions in the financial sector.

The following table, taken from work done by the Massachusetts Institute of Technology (MIT) and by the National Energy Technology Lab, provides a brief overview comparison of the technologies, their costs, and the impacts of applying carbon-capture technologies.

Table 1: Comparison of Fossil–Fueled Electricity Generating Technologies for New Power Plants

	SUBCRITICAL PULVERIZED COAL		**SUPERCRITICAL**		***ULTRA-SUPERCRITICAL***		***SUBCRITICAL CIRCULATING FLUID BED***		**IGCC[1]**		**NATURAL GAS COMBINED CYCLE (F Series)**	
	Without CO_2 capture	With CO_2 Capture	Without CO_2 capture	With CO_2 Capture	*Without CO_2 capture*	*With CO_2 Capture*	*Without CO_2 capture*	*With CO_2 Capture*	Without CO_2 capture	With CO_2 Capture	Without CO_2 capture	With CO_2 Capture
Total Plant Cost ($/KW, MIT)	$1,280	$2,230	$1,330	$2,140	*$1,360*	*$2,090*	*$1,330*	*$2,270*	$1,430	$1,890	N/A	N/A
Total Plant Cost ($/kW, NETL)	$1,549	$2,895	$1,575	$2,870	*N/A*	*N/A*	*N/A*	*N/A*	*$1,813 (GEE) $1,733 (CoP) $1,977 (Shell)*	*$2,390 (GEE) $2,431 (CoP) $2,668 (Shell)*	$554	$1,172
Efficiency (MIT)	34.3%	25.1%	38.5%	29.4%	*43.3%*	*34.1%*	*34.8%*	*25.5%*	38.4%	31.2%	N/A	N/A
Efficiency (NETL)	36.8%	24.9%	39.1%	27.2 %	*N/A*	*N/A*	*N/A*	*N/A*	38.2% (GEE) 39.3% (CoP) 41.1% (Shell)	32.5% (GEE) 31.7% (CoP) 32.0% (Shell)	50.8%	43.7%
Cost of Electricity (¢ per kWh, MIT)	4.84	8.16	4.78	7.69	*4.69*	*7.34*	*4.68*	*7.79*	5.13	6.52	N/A	N/A
Cost of Electricity (¢ per kWh, NETL)	6.40	11.88	6.33	11.48	*N/A*	*N/A*	*N/A*	*N/A*	7.80 (GEE) 7.53 (CoP) 8.05 (Shell)	10.29 (GEE) 10.57 (CoP) 11.04 (Shell)	6.84	9.74
Costs of CO_2 Avoided ($/tonne, MIT)[2]		41.3		40.4		*41.1*		*39.7*		19.3	N/A	N/A

1 - 500 MW plant. MIT uses an 85% capacity factor, NETL assumes 80% Capacity Factor for IGCC, 85% for PC and NGCC cases.
2 – MIT IGCC data assumes GE radiant gasifier for no-capture case and GE full-quench gasifier for capture case.
3 – MIT Cost of CO_2 avoided vs. same technology without capture; does not include costs of transportation, injection, storage
4 – IGCC technologies examined by NETL include GE Energy (GEE), ConocoPillips E-Gas (CoP), and Shell.

All MIT data from MIT 2007 study, "The Future of Coal," http://web.mit.edu/coal
All NETL data from " Cost and Performance Baseline for Fossil Energy Plants," http://www.netl.doe.gov/energy-analyses/pubs/Bituminous%20Baseline_Final%20Report.pdf

Table 1, on the previous page, demonstrates the importance of considering cost and performance of CO_2 capture, as well as reliability and capacity factors and operational (versus theoretical) performance when comparing these technologies. Cost advantages that could be attributable to any of the technologies without carbon-capture technology may shift substantially with the addition of CO_2 capture technologies and capital investments that may be needed to ensure reliability and efficiency of supply. For example, subcritical pulverized coal technologies appear to have advantages in total plant cost, and PC and CFB technologies provide the lowest cost of electricity per kWh. If regulations issued at the State or federal level require plants to be "carbon capture-capable," these cost advantages appear to be eroded. Additions to a power plant to provide carbon-capture capabilities may also create losses in capacity factor that Commissions would need to weigh on a case-by-case basis.

It is important to note that the information in Table 1 is based is intended to give a sense of the range of costs based on relatively recent literature, but that regardless of the technology, power plant construction costs are increasing dramatically due to increases in labor, materials, and other capital costs. A February 2008 estimate by CERA suggested that power plant construction costs increased 27% between 2006 and 2007 alone[2].

These various factors will also affect the actual (as opposed to the theoretical) cost of CO_2 avoided. Because carbon regulation may involve a "cap and trade" system that would allow allowance trading to be used as part of compliance, technologies that can demonstrate a lower cost of CO_2 avoided in actual operational performance would likely give it cost advantages under such a regime as well. (Further discussion on the difference between "capture-ready" and "capture capable" is included in the companion document, "*Carbon Capture & Storage, Technology and Regulatory Considerations.*")

One trend is clear: given today's available CO2 capture technology, the role of CO_2 capture in each analysis consistently points to increases in the cost of electricity across technology platforms. Between cases, however, numerous elements may affect these costs, and over the long term there is no clear leader in the technologies considered here. Different technologies may have cost advantages depending on factors such as the impact of coal rank on projected cost and efficiency, the recent escalation in actual equipment costs, and the lack of demonstration of CO2 capture on commercial power plants. Although the NETL report provides updated cost analysis data, and considers natural gas-fired technologies as well as coal-fueled technologies, it does not consider Ultra-Supercritical and CFB generators. Such factors lead to different conclusions among analyses. Both NETL and MIT's analyses vary from those provided by the most recent IPCC report (2007). It should also be noted that costs seen in the current industry press are much higher than in any of these reports, and as noted above are escalating rapidly. Further uncertainty in the total plant cost of any technology arises for several reasons: such studies typically do not factor in the step of verification and demonstration of the actual cost and performance of advanced combustion and IGCC technologies, untested assumptions are used regarding post-combustion CO2 capture technology improvements, and owners costs (such as interest during construction) are not included.

Research also suggests that there are geographic considerations that should be considered in the context of advanced coal generation technologies, both in terms of the location of the generation facility and its coal fuel type. In general it is believed that IGCC units constructed in the west, at higher altitudes, will experience some unique operating challenges attributable to degradation in turbine performance of the combustion turbine due to lower atmospheric pressures. It is worth noting that all of the discussed technologies facing the same conditions will experience similar regional challenges. Regarding fuel, research by the Electric Power Research Institute (EPRI) in 2005 indicates that there may be a difference in the overall lifecycle plant cost related to coal heating value. U.S. coal is 50% sub-bituminous or lignite; cost analysis must identify coal type and quality. In the EPRI analysis, as the Btu per pound decreases, the plant cost and heat rate trend up for pulverized coal and

[2] From Cambridge Energy Research Associates, as reported by Reuters, "U.S. power plant costs up 130 pct since 2000" on 2/14/2008 at http://www.reuters.com/article/rbssEnergyNews/idUSN1339129420080214.

IGCC generation technologies alike (EPRI, 2005). EPRI research indicates that the range of cost uncertainty is influenced by these types of regional differences, among other factors. Therefore, when Commissions consider new power plants, it may be that no technology has clear universal cost advantages with, or absent, a carbon-constraining regulatory regime. .Location, coal stock, and other factors may be the final determinants.

The remainder of this paper focuses on the differences between the generation technologies mentioned above. The companion primer to this document, "*Carbon Capture & Storage, Technology and Regulatory Considerations*," discusses the potential technology and policy issues facing regulators in the arena of removing CO_2 from the emissions stream and storing it to prevent its release into the atmosphere.

2. Technologies

Figure 1 (labeled ES-1 below, from the National Coal Council's report,) demonstrates a historical U.S. trend for coal-fired technologies. It is principally an evolution over time of emissions control technology for pollutants regulated under the Clean Air Act, ultimately also considering CO_2. Beyond the evolution of pollution control technology, there have also been advances in the technologies for generating electricity from coal. A recent report by the National Coal Council asserts that "new high-efficiency power plant designs using advanced pulverized coal combustion and gasification could reduce (compared to existing coal plants) more than 500 million metric tonnes (MMt) of CO_2 over the lifetime of those plants, even without installing a system to capture CO_2 from the exhaust gases." This primer focuses on additional technologies: supercritical combustion, circulating fluid bed, and IGCC.

Pollution Control Technology and PC Power Plants (NCC 2007)

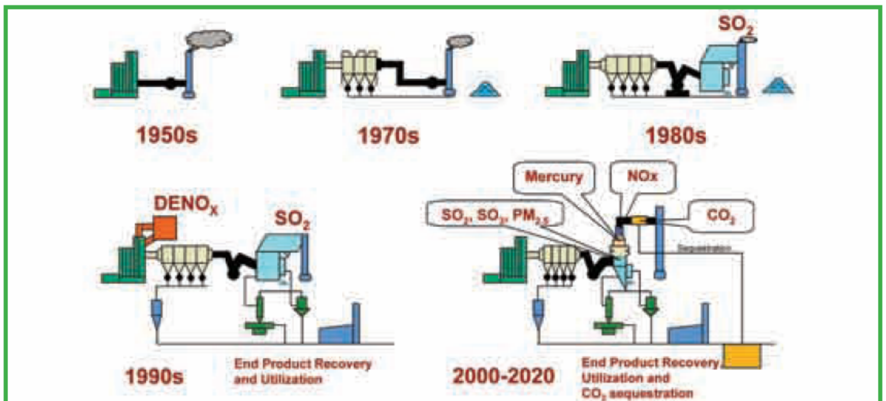


Figure ES-1
Evolution of Coal Fired Power Plant Emissions Capture[2]

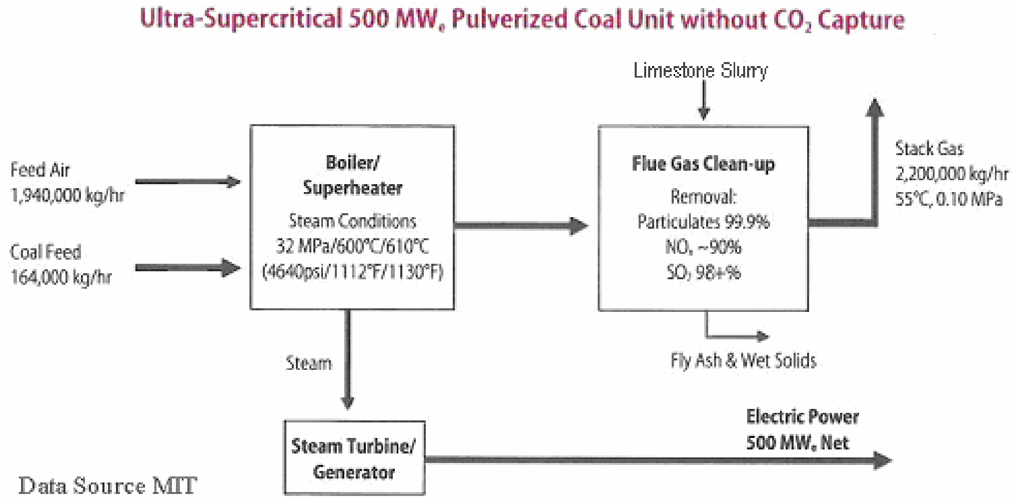
From NCC, "Technologies to Reduce or Capture and store Carbon Dioxide Emissions," June 2007.

Subcritical, Supercritical and Ultra-Supercritical Pulverized Coal

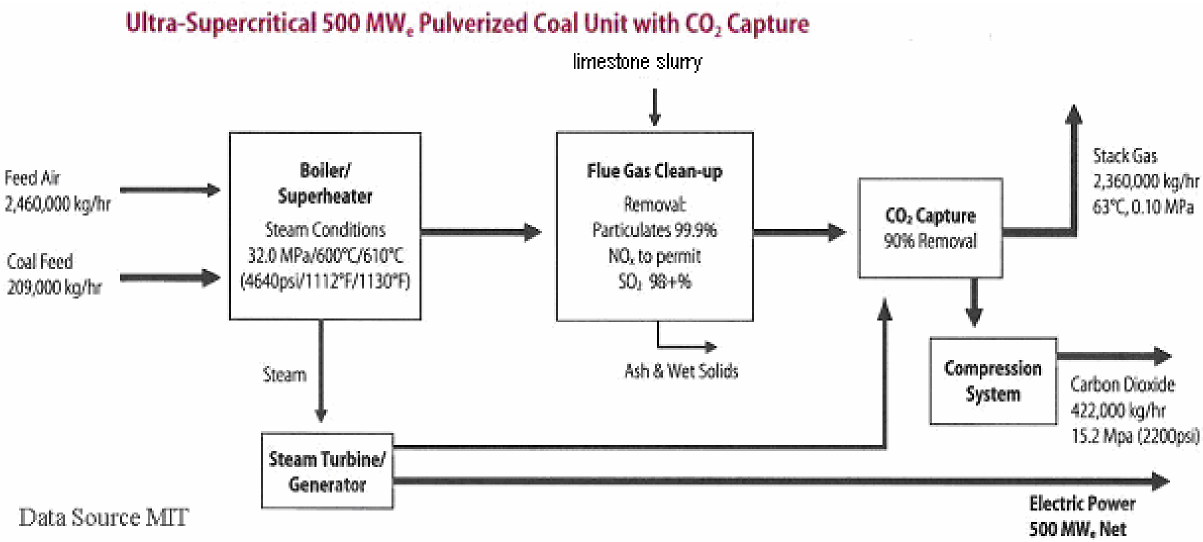
In any steam-electric power plant, main steam from the boiler is expanded through a steam turbine to generate electricity. After expansion through the high-pressure turbine stage, steam is typically sent back to the boiler to be reheated before expanding through the intermediate- and low-pressure turbine stages. Reheating, single or double, increases the cycle efficiency by raising the mean temperature of heat addition to the cycle.

A typical existing subcritical unit is designed to operate at a turbine inlet pressure of 2400 psi, with main steam temperature at 1000F, reheat to 1000F, and an overall net output efficiency of about 35%. A supercritical unit will operate at a pressure of at least 3500 psi, with main and reheat temperatures of 1050F or higher, and an efficiency of 38% or more. An ultra-supercritical unit might operate at 4500 psi, with temperatures of 1100F or higher, and an efficiency of 42% or more, Such a unit is illustrated in the diagram below.

The Operation of a 500-MW Ultra-Supercritical Pulverized Coal Power Plant, (MIT, 2007)



Adapted from MIT, "The Future of Coal", 2007[3]



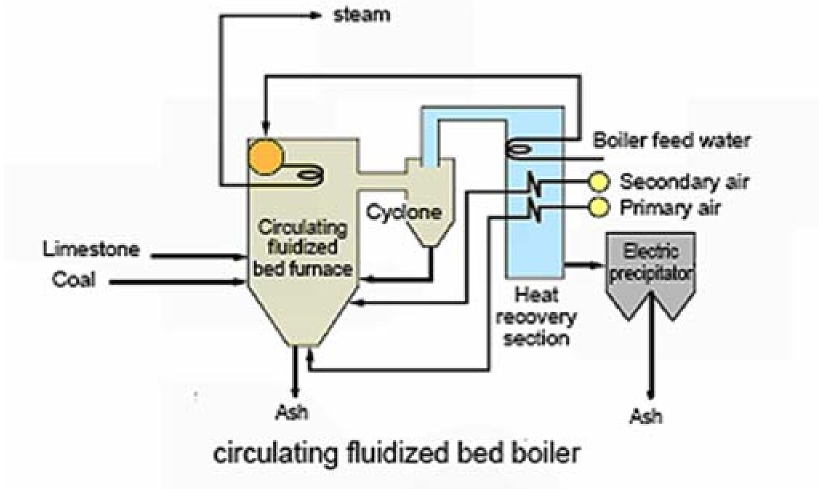
Adapted from MIT, "The Future of Coal", 2007[1]

Generation efficiency can be further increased by designing new coal-burning units to operate at even higher steam temperature and pressure. As temperature and pressure increase, the technology moves from subcritical to supercritical to ultra-supercritical steam parameters. Although a number of supercritical units were built in the U.S. through the 70's and early 80's, most of the existing U,S. coal fleet is in the subcritical category. Today, most new PC plants proposed in the U.S. are higher efficiency supercritical designs.

Circulating Fluid Bed (CFB)

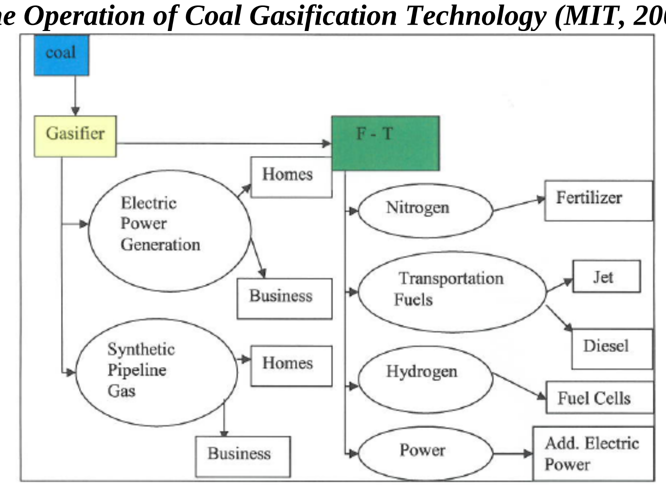
A variation on PC combustion is fluid-bed combustion in which coal is burned with air in a fluid bed, typically a circulating fluidized bed. Crushed coal and limestone are fed into a fluidized bed, where the limestone exposed to the heat of coal combustion undergoes calcination to produce lime. The fluid bed consists mainly of coal, limestone reaction products, and ash. The bed operates at relatively low temperatures, which favors low NOx formation and SO_2 capture by the lime. Fluid bed combustors are also well suited to co-firing biomass. The largest CFB unit constructed in the US to date is 500 MW; a larger supercritical unit is being constructed in Europe. The diagram below illustrates the operation of a CFB power plant.

The Operation of a Circulating Fluid Bed Power Plant



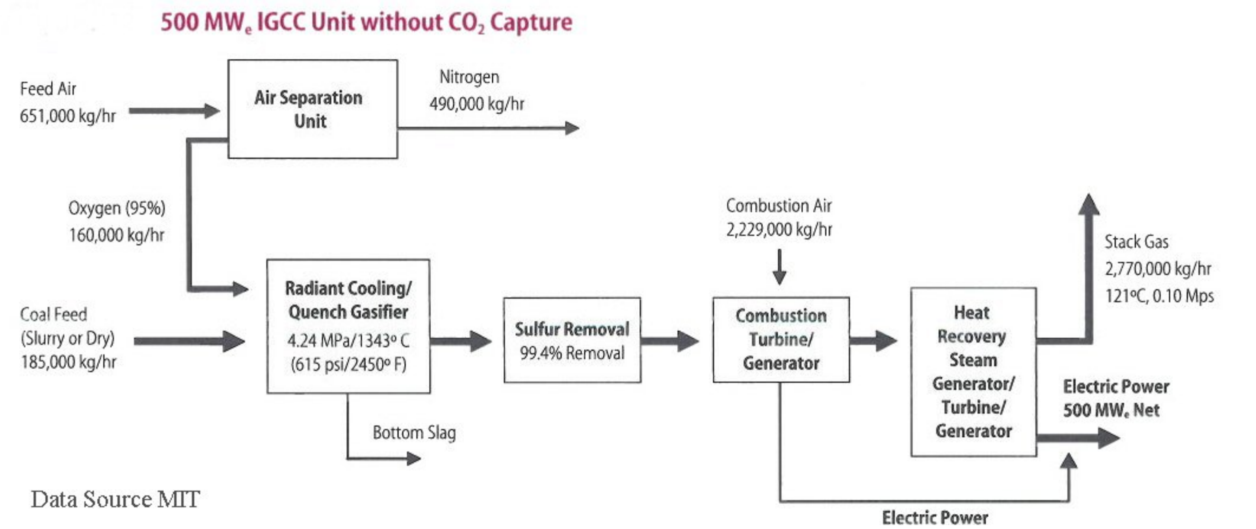
Integrated Gasification Combined Cycle (IGCC)
Coal gasification technology has been employed for some time for the following three purposes: the production of chemicals from coal, the production of synthesis gas, or "syngas" (explained below) and as fuel in power plants (these plants are located in Florida and Indiana). Using a variety of control technologies, syngas can be cleaned of particulate and sulfur and either used as fuel for electricity production in a gas turbine or further processed to create methane and put into a pipeline to replace natural gas. Alternately, syngas also can be sent to a chemical processing unit to produce fertilizer, clean transportation fuels, and hydrogen as final products. The system diagram below details how this technology works.

The Operation of Coal Gasification Technology (MIT, 2007)

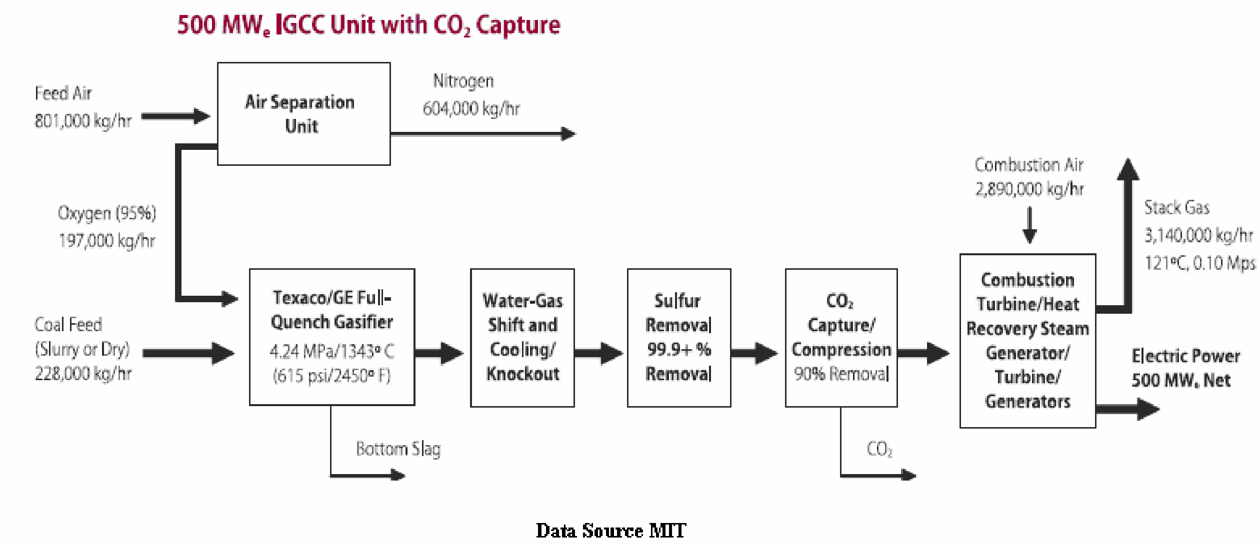


There are several types of commercial gasifiers which can be employed with IGCC. The production of syngas follows a similar process in all gasifiers. Finely ground coal (either dry or slurried) is mixed with oxygen or air and steam in a gasifier. The oxygen is provided by an air separation unit, and the partial oxidation of coal raises the temperature to assure complete carbon conversion with steam to form a gas mixture that is largely hydrogen and carbon monoxide – syngas The syngas is cleaned and then burned in a combustors of a gas turbine to make electricity. Hot exhaust from the gas turbine raises steam in a heat recovery steam generator, which is sent to a steam turbine in the combined-cycle power block for additional electricity production. This process is illustrated in the diagrams below, which also highlight the differences between units with and without CO_2 capture.

System operation of a 500MW IGCC Power Plant, with and without CO_2 Capture (MIT, 2007)



Source: "The Future of Coal" MIT, 2007



Source: "The Future of Coal" MIT, 2007

3. Conclusion

State Regulatory Commissioners already face a number of new proposals for new coal-fired generators. As such, it is important to put the various technologies in context to facilitate decision-making that best achieves the goals of a safe, reliable, affordable, clean supply of electricity for consumers. Deployment of technologies that best meet the goals of State Regulatory Commissioners may require improved cooperation between federal, State, and local governments and private industry. State incentives may also play a role and can jump-start early facilities, complement federal incentives, and stimulate early private sector commitments. However, some may express a concern that incentives originating at a State Commission would fall on a utility's ratepayers, while those created by State or Federal legislative activity would pass costs more broadly to all taxpayers.

Regardless of the technology, underestimation of cost and construction lead times for the initial rounds of projects may complicate their actual implementation. Eventually, lessons learned should bring substantial improvements in performance, cost, and reliability. To successfully go down the path of new technology deployment, it may be important for Commissions to provide predictable policies, clearly communicate a priority of sharing risk and cost, and timely information-sharing with affected stakeholders and the public.

4. Where can I find out more? This FAQ was authored by Miles Keogh and Julia Friedman of NARUC's Grants & Research Department (http://www.naruc.org/programs.cfm?c=Domestic) with funding from the U.S. Environmental Protection Agency. It was developed through research, interviews, and input from a number of parties, including members of the NARUC Subcommittee con Clean Coal Technology and Carbon Capture & Storage, the US Department of Energy, and the US Environmental Protection Agency. Oversight was provided by Commissioner Mark David Goss and Jim Welch of Kentucky PSC. Information was drawn from sources published in recent years as well input from experts in the field. More information can be found using the links below.

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Website for the Energy Information Administration, www.eia.doe.gov.