

The Future of Coal

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Summary

Coal reserves: *The U.S. has the world's largest recoverable coal reserves [1], about 250 years worth at the current consumption rate of about one billion tons/year. The quality of the coal varies significantly across the country. For example, Eastern coal generally has a higher heat content but also more sulfur than Western coal. This is an important consideration for meeting environmental constraints on emissions. Coal is produced in over twenty states. Almost all of the coal consumed in the U.S. is for electricity production.*

China is the world's largest coal consumer [2]—about three billion tons/year—and has about 35 years of recoverable resources at this consumption rate. China is likely to continue to increase coal imports both to meet coastal demand and to ameliorate urban pollution by import of higher quality coal (e.g., lower sulfur content than domestic coal).

China and the U.S. together account for well over half of global coal use.

Coal for electricity: Coal fuels nearly 40% of global electricity generation. In the U.S., it is even higher—about 45%—followed by natural gas and nuclear [3]. These three sources account for nearly 90% of U.S. electricity supply, providing an excellent security of supply situation for the U.S. (especially since the remainder is mostly renewables, with oil playing

a very minor role). Almost every state generates some fraction of its electricity from coal. [4]

With today's fuel prices, new natural gas plants have lower levelized electricity costs than do new coal plants. [5]

The existing fleet of U.S. coal power plants totals about 340GWe of capacity, and much of it is very old. About 30% still lack major pollution emission controls, and about half specifically lack flue gas desulfurization (FGD) equipment (scrubbers); we note that FGDs are also an important part of mercury control.

Relatively small plants (less than 300 MWe) make up more than a quarter of the total coal plant capacity, most have no scrubbers, and the majority are over forty years old. These plants are strong candidates for retirement as a result of utility business decisions. Many already have marginal costs higher than natural gas plants (at today's coal and natural gas prices), and forthcoming EPA rules (discussed below) that bring these plants into compliance with the standards already met by the majority of coal plants will further lessen their economic competitiveness with natural gas, another abundant U.S. resource (as recognized fairly recently by the dramatic increase in shale gas production). [6]

Environmental impacts: The end-to-end environmental impacts of coal use—from mining to combustion—are considerable and have called for strong regulation. In particular, sulfur

dioxide, nitrogen oxides, mercury, and other hazardous air pollutants (HAPs) emissions are dominated by coal-fired power plants. The EPA has two rule makings in process: a Clean Air Transport Rule for SO_x and NO_x, and, as required by the Clean Air Act, a Maximum Achievable Control Technology rule for mercury and other HAPs. The latter rule may be the more difficult for the non-complying plants to meet, especially for the old, small, inefficient plants without control equipment. The capital cost of retrofits can approach that of a new-build efficient natural gas combined cycle (NGCC) plant, making retrofit an unlikely business decision.

It is widely anticipated that a minimum of 15% of the coal capacity (again: old, small, inefficient) will be retired in this decade, possibly as high as 30%, after the EPA rules come into effect (2014, or possibly a bit later). However, the U.S. also has a large underutilized fleet of NGCCs, the legacy of an earlier exuberant construction period. The fleet is running at about 40% capacity factor. Model calculations indicate that about 20% reduction in coal capacity can be absorbed just by increased existing NGCC utilization. Consequently, this substitution of natural gas for coal can be accomplished with relatively little impact on the overall U.S. electricity system. [7, 4]

The associated reduction in domestic coal requirements is likely to be offset to some extent by increased coal exports from the U.S., including to China. Today, over 7% of U.S. coal is exported. [8] Infrastructure projects are underway to increase the export capacity.

Climate change: Coal is also the *most carbon-intensive of fossil fuels*, accounting for over 80% of CO₂ emissions from U.S. power plants. Accounting for the higher efficiency of NGCC plants relative to supercritical coal plants, coal emissions are more than double those of NGCC for the same amount of produced electricity. There is not an expectation that the Congress will implement explicit policies to price CO₂ emissions in the next few years, although EPA actions might limit emissions through the Clean Air Act.

The vast majority of engaged scientists anticipate that nature will be providing increasingly strong signals about the need for prudent government action to lower greenhouse gas (GHG) emissions. There is **no credible pathway towards stringent GHG stabilization targets without substantial CO₂ emissions reduction from existing coal power plants**. This requirement falls most heavily on the U.S. and China and suggests that marketplace options be developed now for coal use in the event of strong CO₂ controls.

For the U.S., the substitution of natural gas for coal, as discussed above, would accomplish much of the CO₂ emissions reduction called for in this decade (supplemented by the many energy demand reduction actions that meet economic tests). However, it will also be *important to make major Research, Development and Demonstration (RD&D) advances in this decade that lower the costs of “carbon-free” supply* so that increasingly stringent targets can be met in the future. Among the important options to be pursued is *carbon capture and sequestration (CCS)* from coal (and natural gas) power plants.

CCS: The challenges with carbon capture and with sequestration are quite distinct, although they must work together as a system. For a single utility-scale coal plant, several megatons per year of CO₂ will need to be captured, compressed, piped, injected, and stored in geological formations.

The U.S. *appears to have considerable capacity for CO₂ sequestration* located suitably in relation to coal plants. [9] Nevertheless, there is much to do to establish sequestration as a commercially viable option: reservoir characterization, design of monitoring and verification systems for CO₂ storage, determination of injectivity and ultimate reservoir capacity, design of the regulatory regime and assignment of responsibilities, assumption of long-term liability and monetization of the stored CO₂. *The U.S. has been slow to field large-scale, integrated, sustained demonstrations* that are needed to provide public confidence and inform industry risk management. Strong government support is needed for these

demonstrations, especially in the absence of a CO₂ emissions price signal. Nevertheless, we anticipate a successful outcome if an effective program is carried through.

Carbon capture presents a different challenge. Technology exists today, but it is too expensive and too big. As much as 30% of a power plant's output is needed to operate the capture process to provide transportation-ready CO₂, which makes it very expensive indeed even apart from the capital cost. A *dramatic cost reduction is needed*, and this calls for a large scale research program that emphasizes new concepts and scales the promising ones to commercial demonstration. If this is not accomplished, coal would eventually be squeezed out of the U.S. electricity mix by future stringent CO₂ emissions constraints. [10]

An aggressive and sustained RD&D program is needed now (at least \$1B/year) for CCS RD&D if this technology is to be economically viable and implemented at large scale in 15-20 years. A promising approach for funding such a program (and many other crucial areas for the power sector) is through a small "line charge" on electricity sales, as has been proposed in Congress and advanced recently by the President's Council of Advisors on Science and Technology (PCAST). The scale is such that a

1 mill/kWh charge yields about \$4B/year. Clearly, industry and consumer support is essential for such an approach to be viable.

Relatively large (300 MWe or greater), high-efficiency coal plants with installed FGD and selective catalytic reduction (SCR) equipment are the best candidates for CCS retrofits. This represents a bit more than half of the current fleet. However, additional site-specific criteria are also important, such as proximity to sequestration sites, available land, and access to increased water supply. These would substantially lower the number of suitable retrofit opportunities with current capture technology.

An important *near term opportunity for advancing sequestration may be government support for enhanced oil recovery (EOR) using CO₂ from anthropogenic sources* (e.g., coal-fired power plants). This turns the CO₂ from a "waste" into a valuable product, especially given a growing shortage of CO₂ from natural sources, and can partially offset the high costs of CCS development.

If readers wish to view these charts in color, this entire document and color charts are available at: <http://web.mit.edu/mitei/>

Fig 1.

COAL RESERVES BY COUNTRY

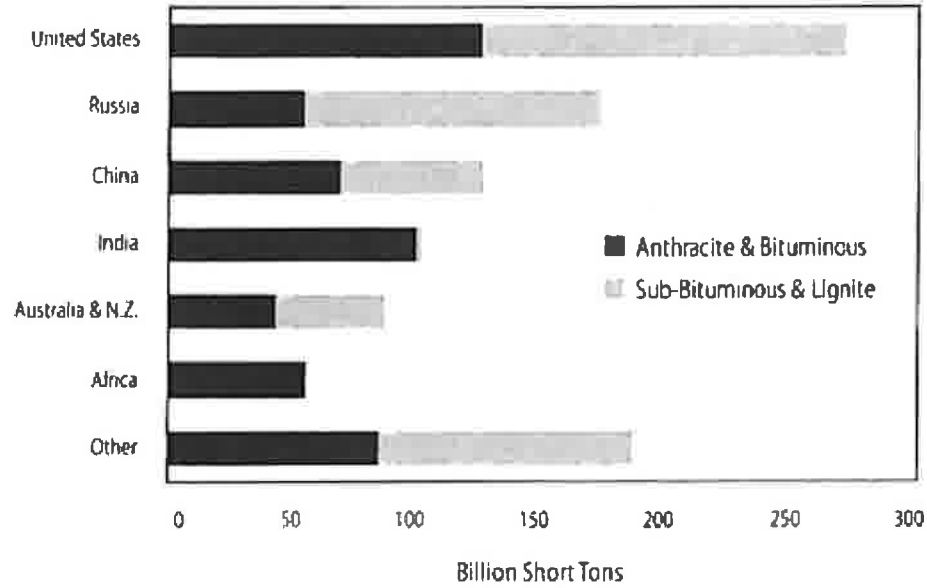


Figure 2.1 on page 5 of the MIT Future of Coal study (2007)

Fig 2.

COAL CONSUMPTION BY COUNTRY

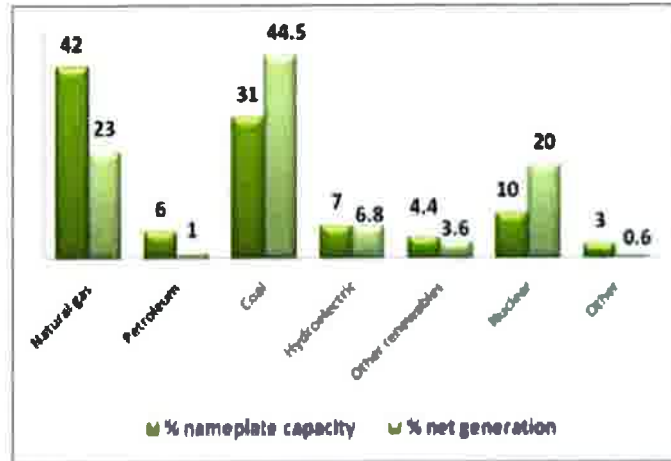
[2009, Millions of short tons]

U.S. Energy Information Administration
International Energy Statistics

China	3,475
United States	1,000
India	686
Germany	250
Russia	223
South Africa	199
Japan	181
Australia	150
World total	7,577

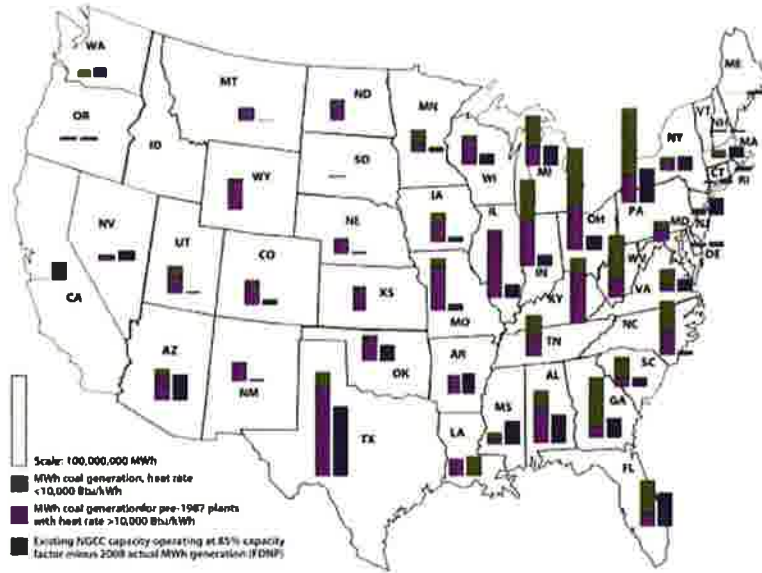
Fig. 3

**U.S. Electricity Generation and Capacity by Fuel
(2009, U.S. Energy Information Administration)**



Coal	Petroleum	Natural Gas CC	Natural Gas other	Nuclear	Hydroelectric Conventional	Other Renewables	All energy sources
73.6	13.4	42	11.4	91.8	36.3	40	48.7

Figure 4. Coal generation and underutilized NGCC capacity by state



from the MIT Future of Natural Gas Interim Report – Fig. 4.4

Fig 5. COSTS OF ELECTRIC GENERATION ALTERNATIVES

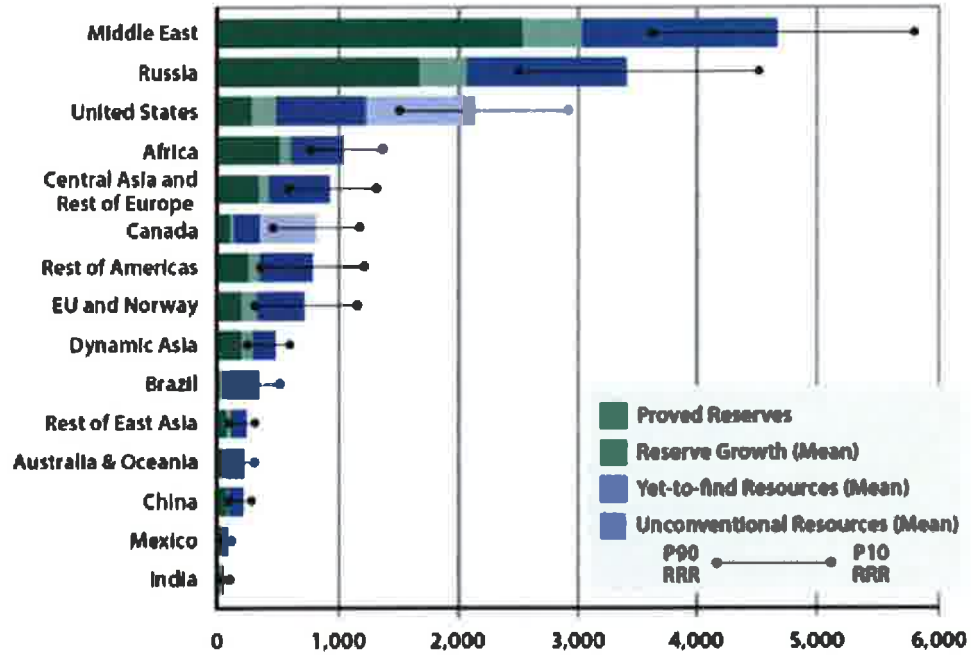
(2007\$)

	Overnight cost (\$/kW)	Fuel cost (\$/MBtu)	Levelized cost of electricity (cents/kWh)		
			base case	\$25/ton-CO2 price	same cost of capital
Nuclear	4000	0.67	8.4		6.6
Coal	2,300	2.60	6.2	8.3	
Gas	850	4/7/10	4.2/6.5/8.7	5.1/7.4/9.6	

Taken from MIT Future of the Nuclear Fuel Cycle summary report (2010)

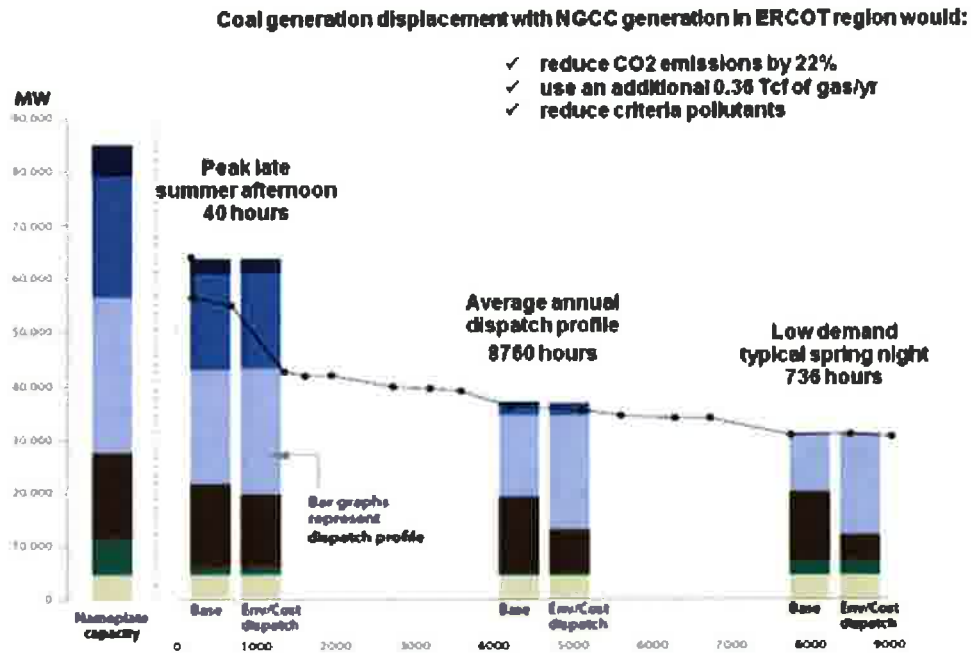
Figure 6.

Remaining Recoverable Natural Gas Resources
(Excludes unconventional gas outside North America)



from the MIT Future of Natural Gas Interim Report – Figure 2.2

Fig. 7. NG substitution for coal in the electricity sector (ERCOT)



from the MIT Future of Natural Gas Interim Report— Figure 4.5

Fig 8.

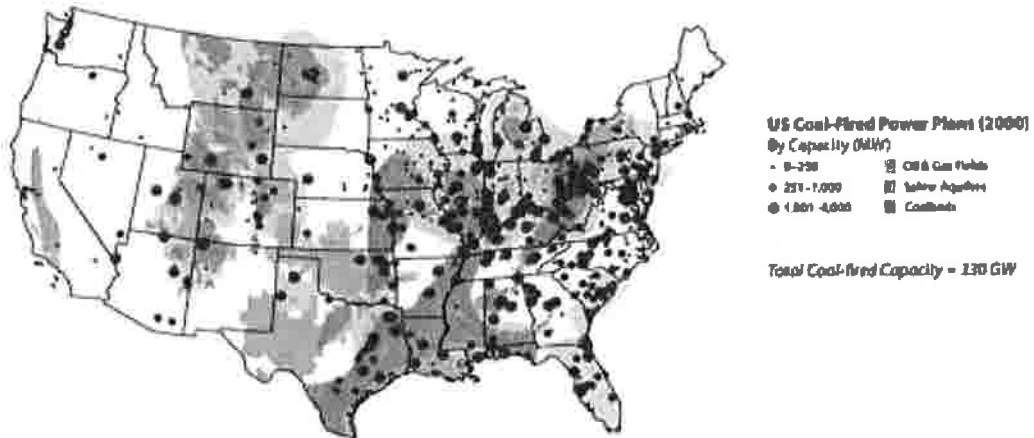
U.S. COAL PRODUCTION AND EXPORTS

[Millions of short tons]

U.S. Energy Information Administration

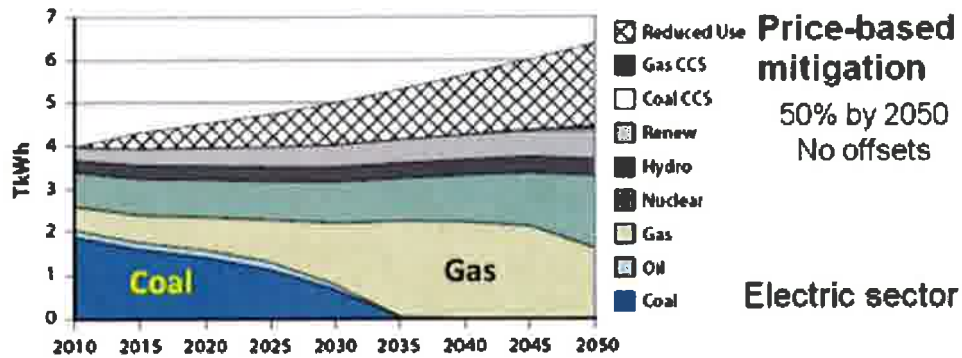
	Production	Exports
2004	1,112	48.0 (4.3%)
2005	1,131	49.9 (4.4%)
2006	1,163	49.6 (4.3%)
2007	1,147	59.2 (5.2%)
2008	1,172	81.5 (7.0%)
2009	1,075	59.1 (5.5%)
2010 (9 mos)	809	60.8 (7.5%)

Fig 9. LOCATION OF COAL PLANTS RELATIVE TO POTENTIAL STORAGE SITES



Map comparing location of existing coal-fired power plants in the US with potential storage sites. As stated earlier in the report, our knowledge of capacity for sequestration sites is very limited. Some shaded areas above may prove inappropriate, while detailed surveys may show sequestration potential in places that are currently not identified.

Fig. 10 Evolution of U.S. power sector with CO2 emissions pricing



Economic model for evolution of U.S. electricity sector with CO2 emissions pricing so as to effect 50% reduction by mid-century. No breakthroughs assumed in technology costs (e.g. carbon capture).
 Taken from MIT Future of Natural Gas Interim report (2010)

from the MIT Future of Natural Gas Study – Figure 3.3a