LA-UR-00-4429

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Author(s): Verne W. Loose

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Verne W. Loose, Los Alamos National Laboratory

Research Sponsored by USDOE, Office of Fossil Energy

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Introduction and Purpose

The intent of this paper is to identify and discuss issues and possible effects that electric power industry restructuring may have on the introduction of new electric power generation technologies, including retrofits. The focus is particularly on coal generation technologies funded through the five phases of the Clean Coal Technology Program sponsored by the Department of Energy (DOE). While this focus serves the immediate interests of the sponsoring organization it has more general appeal in that it sheds some light on the industry debate regarding the role that coal will play in a deregulated future. Environmentalists have argued that deregulation will lead to greater utilization of older (read cheaper) coal plants, particularly in Midwestern States. Meanwhile, many believe that natural gas-fired combustion turbines will displace coal facilities. Lurking in the background to further confuse the issue are emission standards pertaining to recent Clean Air Act Amendments and the possibility of new regulations addressing global climate change concerns.

Technology diffusion is important also because it sheds light on government policy formation. A sea change has taken place in the industry during the course of the Clean Coal Technology Program. Now, in addition to the usual uncertainties, lags, and delays accompanying the introduction of new technology into an existing technology mix, the electric power sector is undergoing fundamental change in its structure. This process of change will probably add significantly to uncertainty in the industry, which may further delay or preclude introduction of new technology for some time into the future.

The Emerging New Electric Power Industry Structure

Context for the Discussion, and Assumptions

A full and complete discussion of the current status, likely near-term progress, and future of electric power industry restructuring is not intended. Nevertheless, some context will be enable the discussion. While restructuring may eventually take place on a national it is presently proceeding on a state-by-state, incremental basis. Future federal legislation mandating restructuring may be passed. Such future legislation will likely allow significant latitude in the means that states employ to implement restructuring. Features and methods of each states' implementation may diverge from those of other states.

However, some common themes are emerging. Actual deregulation in those states that have implemented either legislative or regulatory restructuring initiatives restricted deregulation to the generation function. Monopoly franchises become null and void and the *quid pro quo* service requirement is removed from the *formerl*y regulated utility. To increase the number of producers in the market some form of divestiture of generation assets owned by the *formerly* regulated monopoly must be conducted. Future entry to the industry is unrestricted, subject only to the economic forces of the market.

The "wires" functions—transmission and distribution—are being re-regulated. Transmission continues to be recognized as a natural monopoly [1] that will be controlled by a public-spirited, probably non-profit, organization composed of a board of stakeholders with a staff of experts. These organizations are referred to as independent system operators (ISOs). While ownership of the transmission facilities probably won't change, control will be vested in the ISO. Distribution facilities will continue to be owned and operated by regulated entities subject to performance-based regulation. The latter regulatory method will replace rate-of-return regulation and emphasizes price and cost efficiency and non-discriminatory access to the wires. Owners of distribution facilities will probably not be permitted to be in the generation business in the same general service area.

The Deregulated Generation Market

The new model applicable to the generation market will be comparatively free of administrative procedure. There will be no hearing to justify the need for new generation projects via forecasts of future demand; there will be no hearing on the allowed rate-of- return and no need to calculate revenue requirements that flow into prices required to generate these revenues. The future owners of generation capacity will not report to a utility commission and will not need approvals to invest in generation capacity--beyond zoning, permitting, and environmental approvals customary for large construction projects.

This is not to say that investors considering installing generation capacity will not perform such analyses for their accounts. Indeed they will and probably in much greater detail than previously. Now the cost of output from the new facility in relation to the costs of already existing facilities and in relation to market price for the product is *the* all-important determinant of whether the investment goes forward. Only if the new facility is able to operate to at least the designed break-even levels of output will the investors earn sufficient returns to replace capital. In return for this flexibility of action, investments in electric generation capacity will not have guaranteed returns. They will have to stand the test of the market and compete with other generators on a cost basis to supply a portion of the load. The main point is that the decision-making environment for investors is significantly different from that which exists at the present time.

Investment Decision-Making in the Deregulated Generation Market

In the deregulated generation market, investors in new generation equipment will want to assure themselves that a market for the output of the facility actually exists. The new facility must be able to generate electricity at a cost that is competitive with other generation facilities. For this to be the case there must be demand that cannot be served by the existing facilities and/or the new facilities must have a average cost per unit that is lower than that of the highest cost existing generator. Looking forward in time over the project's entire life cycle, this relationship must also hold for the expected value of these relative costs. Investors will seek to reduce investment and market risk by adopting a variety of strategies including: (i) placing a

[1] The supposition that transmission and distribution constitute natural monopolies is being challenged. However, deregulation of the generation sector and re-regulation of the remainder of the industry is causing enough headaches that policy debate on this issue will probably be deferred for quite some time. See, for example Clyde Wayne Crews, Jr., Electric Utility Reform: "The Free Market Alternative to Mandatory Open Acces*s," The Electricity Journal*, Vol. 10, No. 10, December 197, pp. 32-43.

higher variance on expected future revenues, (ii) planning for shorter payback periods, or (iii) delayed investment. Delayed investment amounts to holding open the option to invest for a longer period which implies greater system-wide risk. This can occur only if the facility is selling power whenever it is available for generation. It will be capable of selling power only if its cost is lower than other generation sources.

Issues Pertinent to Clean Coal Program Technologies

The preceding discussion laid the groundwork for the next two sections that deal specifically with the prospects for adoption of Clean Coal Program technologies. The intent is to apply the observations about changes in the market structure to make some inferences about how these changes will impact adoption of the Clean Coal technologies. Before proceeding to that subject the Clean Coal Technology Program is briefly described. Then a distinction is made between two major types of Clean Coal Project Technologies.

Clean Coal Technology Program

The Clean Coal Technology Demonstration Program is a unique partnership between the United States Department of Energy (DOE) and US industry that has as its primary goal the successful demonstration of a new generation of advanced coal-based technologies. The most promising technologies will be moved into the domestic and international marketplace. The program resulted in a combined capital investment of nearly $6 billion in 40 competitively selected projects as of September 1966. Of these 40 projects, 20 have completed operations, 7 are in operation, 5 are in construction, 7 are in design, and 1 is in negotiation. The demonstrations are at a scale large enough to generate the data needed to enable potential domestic and international users to make judgments about the commercial viability of a particular process. These demonstrations will improve the global environment and enhance global energy security through the use of technologies and services provided by United States industry.

Types of Clean Coal Projects

Quite wide ranges of clean coal technologies were among the projects funded as part of the program. Some of the projects represented bulk-of-plant systems such as coal combustion and boiler technologies (e.g., the fluidized-bed combustion projects and integrated gasification combined cycle projects). Other projects represented smaller systems or components that could be retrofitted onto existing major components of electric power plants, primarily those that treat flue gases (e.g., nitrogen oxide control projects and sulfur dioxide control projects) or treat coal prior to combustion (coal preparation technologies). This distinction between these major categories of technologies is important for the discussion below. More than likely, different investment decision criteria may pertain to each of the major categories.

Possible Impact of Deregulation on New Bulk-of-Plant Clean Coal Systems

In a following section some `evidence indicating a significant cost advantage to gas turbine technologies is presented. Based upon this evidence and a significant amount of industry literature not directly referenced, but also making the same point, it seems reasonable and prudent to conclude that gas turbines would be the technology of choice based strictly upon price. Other significant decision considerations identified below also appear to favor gas turbines. This would be the case irrespective of any change in the structure of the market.

In the regulated industry from which the US is transitioning, coal would likely have fared well. The monopoly franchise and rate-of-return regulation relieve the pressure to be cost competitive. Economies of scale in the boiler and other components of a large coal plant favor the construction of large facilities. The “lumpiness” of investment in large facilities could be mitigated partially by aggregating a number of generators into a plant and staging them over time. And anyway, the revenue requirements rate calculation would ensure an adequate return on investment. Centralized coal transportation, storage, and handling facilities make management of these activities more reasonable and probably also reduce their cost. The cost of connecting a large central station plant to the existing transmission grid may have been lower than connecting a number of smaller, dispersed facilities. It may be more rewarding to be manager of a very large plant than a smaller one. Guaranteeing a return on investment reduced the risk of trying a new technology. This is clearly indicated by the manner in which the industry pursued nuclear technology in the late 1950s through the early 1970s. Many reasons explain the investment strategy of the past. Most of these factors do not seem likely to carry into the future.

As indicated by the market model, stylized though it is, cost of production will be the over-riding determinant of technology choice in the deregulated generation industry. None of the factors identified above are likely to hold much sway in the new market structure. Investors will seek to build a new plant using the lowest cost technology available. At this time advanced boiler and coal combustion technologies do not appear to be lowest cost.

Repowering Existing Coal Plants

There are approximately 1245 coal-fired power plants in the US today. This represents a very large inventory of existing plants many of whose process technologies are economically or otherwise obsolete. As these plants age further and, assuming air quality regulations become more stringent particularly for coal plants, more of them will be faced with a limited range of options for continued operation. In these situations where rail lines or barge unloading facilities exist, coal handling and storage facilities exist, replacing the boiler and combustion technology may be a cost-effective and viable option for plant owners. In this situation, the advanced Clean Coal technologies have a good chance of being implemented.

There is extensive plant level data and information available on these plants through the data collection efforts of the Federal Energy Regulatory Commission. The DOE's Energy Information Administration, and a number of private vendors who package and distribute this data. The point is, vendors of Clean Coal Technologies can access this information and know with fairly good precision the technology status of each plant and therefore have good information on the potential market for advanced coal technologies they are attempting to market. Some of these plants may be changing hands as many utilities are selling their fossil generation units. Pending auctions and sales may delay decisions to repower but the potential market is there.

Retrofitting Clean Coal Technology Program Components

For the remainder of the 1245 coal-fired power plants in the US whose boiler and /or combustion technologies are not obsolete there may be opportunities to improve their economic and/or environmental performance. This can be accomplished by retrofitting some of the many Clean Coal Project Technologies aimed at improving combustion, cleaning stack gases or beneficiating coal prior to its combustion. This may be the most available market to vendors of these technology components. Retrofitting these technologies can extend the useful lives of such plants. To decide how best to meet emission regulations, utility planners will perform a cost analysis of the alternatives that are available. A variety of techniques are available to perform these cost minimization or cost effectiveness analyses.

One of the industry trends is utility divestiture of generation assets. As this trend continues and as the generation market becomes increasingly open, the prices at which capacity is bought and sold will reflect its future potential to compete in the market. Existing facilities that are efficient and have good availability and performance records will be valued relatively highly by the market. Other facilities with less attractive performance records will not be so highly valued. Eventually the existing capital stock in the industry will be re-valued, either through market transactions or through stranded cost cash flows, or both. As the cost basis of coal-fired generation assets gets reworked through this process there will be room for these facilities to rework their physical structure to align their environmental performance with required standards and regulations

Other Considerations

Discussion in this paper has focused primarily on the aspects of a competitive market that drive producers in that market to keep cost to the minimum. Investors will tend to be very conservative with respect to their technology choices. However, there are other general considerations that must be taken into account with reference to technology adoption. And there are specific considerations that could affect the future relative attractiveness of clean coal technologies and their main rival—gas turbines.

Coal Steam Turbine vs. Natural Gas Turbine Technologies

Evidence available in the literature indicates a current clear cost advantage in favor of gas turbine technologies. In its *Annual Energy Outlook for 1998* the Energy Information Administration presents data for plants constructed to be available in 2005. The levelized life cycle cost of a conventional, pulverized coal plant is 40.4 mills per kWh while the advanced combined cycle, gas turbine technology has a cost of 31.0 mills per kWh. This 25% cost advantage is significant. While the coal plant has a significant fuel cost advantage over the gas turbine of 6.9 mills per kWh versus 20.7 mills per kWh, the capital cost of the gas turbine facility is much lower at 7.5 versus 26.6 mills per kWh for coal. Projections for plants coming on line in 2020 show similar differentials but the gas turbine cost increases a little, eroding the cost differential between the two technologies to 19.2 percent.[2]

The EIA publishes a report on planned capacity additions between the years 1996 and 2005 as part of their power plant inventory. [3]This report shows capacity additions by state, utility, capacity, technology and fuel source. The chart in Figure 2 is adapted from a similar chart in the Executive Summary of this report. It clearly shows that natural gas based generation technologies are the choice over the medium term.

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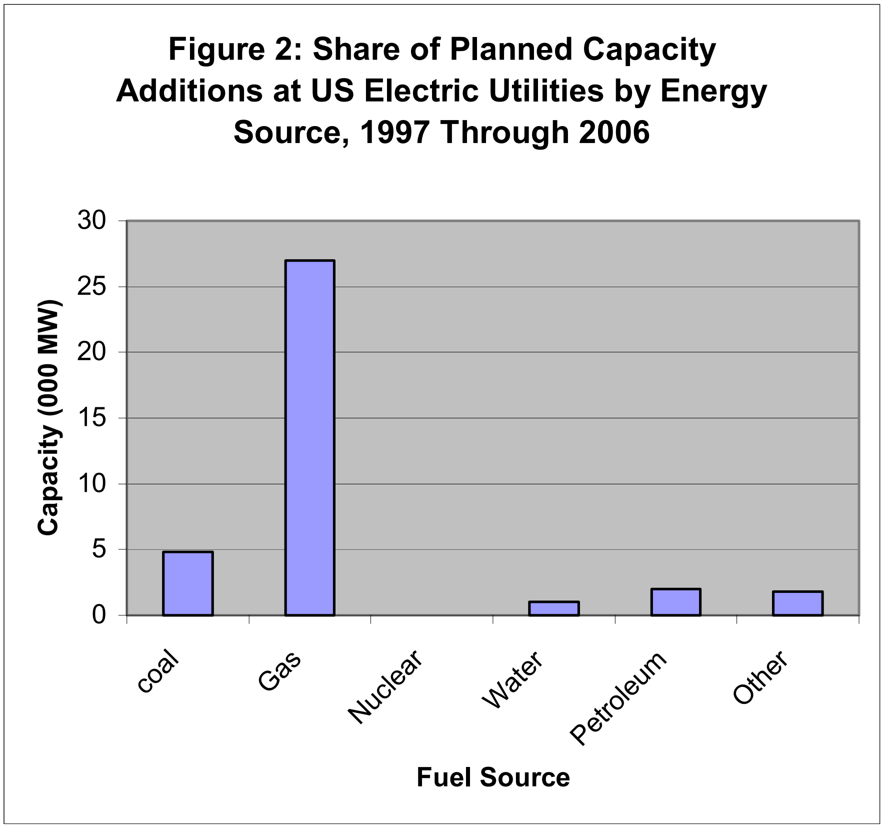
[2] Energy Information Administration, Annual *Energy Outlook, 1998, With Projections to 2020,* DOE/EIA 0380(98), December 1997, p.58.

[3] Energy Information Administration, *Inventory of Power Plants in the United States: As of January 1, 1997,* Office of Coal, Nuclear, Electric and Alternate Fuels. US Department of Energy, Washington: DC, Report Number DOE/EIA-0095(97).



Rate of Technology Diffusion

There is a vast and growing literature dealing with the rate of technological diffusion.[4] This literature deals both with the general theoretical issues of what and how economic forces operate to induce existing and new firms to adopt a new technology or process. It also deals with specific technologies and industries in an attempt to identify and quantify those forces. One of the main lessons of this literature is that frequently new technologies require decades before they are thoroughly diffused throughout an industry.

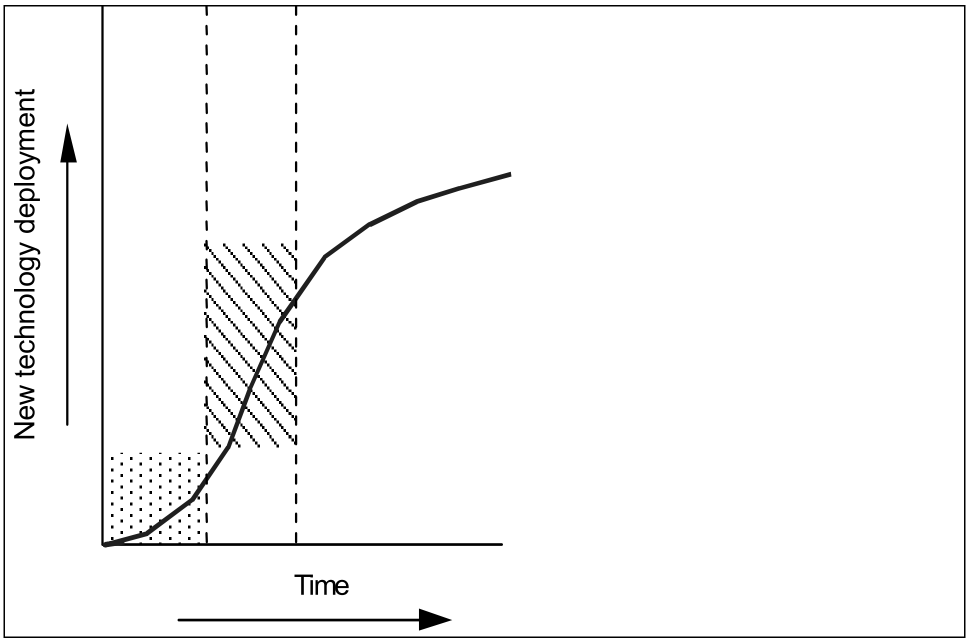
Initially an existing technology has the advantage because it is well understood, its reliability is usually high, users have confidence in its applications, and both equipment and knowledgeable operators are readily available. Any new technology is unfamiliar, its reliability is questionable, and it's supporting equipment and trained staff is scarce. As the initial problems are overcome, communications spreads knowledge about the technology, the rate of substitution increases, and adoption tends to proceed exponentially during early years. The rate of substitution slows only after very rapid growth, when the existing technology presents fewer and fewer opportunities for replacement.

This process produces a sigmoid-shaped curve that can be used to relate technology diffusion rates to time. In the early years of a new technology its adoption rate increases at an increasing rate. As penetration continues the rate of adoption slows, reaches a peak and then declines.

[4] Some possible lead references into this literature include *Innovation, Technology, and The Economy: Selected Essays of Edwin Mansfield.* (2 Volumes) Ashgate, Brookfield, Vt., 1995. Dosi, Giovanni "Sources, Procedures, and Microeconomic Effects of Innovation, *Journal of Economic Literature,* Vol. XXVI (September 1988), pp. 1120-1171.

This sigmoid-shaped, "Pearl" curve, illustrated in Figure 3, employs the assumption that past adoption rates affect future rates and its parameters can be estimated from the growth rates of substitution in just the first few years of a new technology. This approach was applied in an informal means in developing generalizations about the penetration of DOE sponsored environmental technologies.

Figure 3: The Pearl Curve



Researchers found that the substitution model of technological change developed by John Fisher and Robert Pry was appropriate to their analysis.[5] The same paper showed data on several widely known technologies which took of the order of several decades (four in the case of water versus oil-based paints) to achieve a 50 percent penetration of the market. Their conclusion was that "DOE's Technology Development Program cost savings estimates are usually based on the premise that adoption of innovative technologies is nearly instantaneous upon their successful demonstration. However, from the many studies of new technologies documented in the literature it should be clear that adoption by users is not based solely on cost effectiveness or performance alone. A complex communication and adoption process takes place over an extended period of time."[6]

Environmental Regulations

A whole host of environmental regulations pertain to the mining, transport, storage, and burning of coal. The industry has adjusted successfully to most of the regulations that govern current activities relating to coal use. However, there is the threat of increasingly stringent regulation, particularly of sulfur dioxide, nitrous oxides, and particulate matter. A number of the clean coal technologies that were selected for funding by the program address the possibility that these regulations will come to fruition. To the extent that the technologies are

[5] Cummings, Mark, *A Response to Congressional Concern Over the US Department of Energy's Technology Development Program.* Unpublished Working Paper, May 13, 1997
[6] *Ibid,* p. 11.

successful in reducing emissions to or below potential future standards, they help coal to maintain its place in the alternative mix of electric energy generation technologies.

However, the coal and electric power industries have not been silent during the policy discussions concerning tightening environmental, particularly air quality, legislation and regulation. A strong lobbying effort has been undertaken to influence the outcome of these discussions in a manner favorable to the industry's interest. At this stage it is too early to conclude the outcome of this policy debate. However, we can conclude that it is unlikely the industry will adopt the new clean coal technologies unless forced by regulations to do so. Thus, we should expect delay in the introduction of the technologies until the outcome of the environmental policy debate becomes crystal clear.

Scalability

The volume to surface area engineering relationships for steam boilers that results in the widely acclaimed economies of scale argument that used to be cited as the reason to build ever larger generation units may become important in the technology race. However, now it may work against coal-fired steam plants. Investors may deal with risk aversion by requiring short payback periods for investments. They may prefer technologies that allow generating facilities to be built at a scale that addresses current and near-term future market demand. This market strategy will again favor gas turbines because they have the advantage of being scalable up or down without a large sacrifice in cost per unit of output. This leads to further advantages for gas turbines because smaller facilities will be easier to finance. They will also easier to site and obtain the various permits and approvals required when constructing new facilities.

Summary

The Clean Coal Technology program was initiated at a time when coal was the technology of choice for large electric power plants. All of the economic, technology and policy forces to that time indicated that the major concerns with continued dominance of coal facilities had to do with their continued environmental acceptability. A great deal has changed since that time with respect to technology, alternate fuel prices and availability, and, most importantly, the restructuring of the industry. These factors will impact the status of coal as the technology of choice.

Major issues for the future use of coal in electric power generation have to do with:

- Cost, relative to alternate technologies (natural gas turbines);
- Restructuring of the generation market with entry of an entirely new group of entities responding to different economic incentives;
- Indirect cost factors having to do with ease of financing, siting, and approving of alternate electric generation technologies;
- A slow rate of diffusion of technology, especially when it is not driven by cost reduction;
- Environmental regulations.

Most of these factors do not favor the adoption of clean coal technologies for new electric power plants. However there are niche market opportunities of perhaps substantial size to repower existing coal plants or to add components to these plants that treat the coal prior to its combustion or stack gases afterwards. During the transition to competition in the generation sector, vendors of clean coal technologies should address these niche markets until the market uncertainty is resolved by more experience with the impacts of competition.