Strategic Management Journal
Strat. Mgmt. J., **19**: 1145–1168 (1998)

THE DIALECTICS OF COMPETENCY ACQUISITION: POLLUTION PREVENTION IN ELECTRIC GENERATION

ALFRED MARCUS* and DONALD GEFFEN
Carlson School of Management, University of Minnesota, Minneapolis, Minnesota, U.S.A.

Strategy researchers now recognize that distinctive competencies are critically important for sustained competitive advantage. The processes by which such competencies are acquired, however, has only started to be examined. Connections between macro-industrial system level properties and micro-developments in proprietary technology at the firm level need to be made. This paper argues that system-wide properties, such as long-standing elementary and opposing logics in societal forces like governments and markets, and micro-developments, such as the firm's capacity to search for talent, technology, and ideas and to harmonize what it learns internally, can contribute in significant ways to the creation and acquisition of new competencies. Based on the case of pollution prevention in electric generation, it shows how the system-wide properties channel and direct the paths that the acquisition of new competencies take and how they interact with micro-developments at the firm level. © 1998 John Wiley & Sons, Ltd.

INTRODUCTION

Growing recognition of the significance of distinctive competencies for sustained competitive advantage (Henderson and Cockburn, 1994; Lado and Wilson, 1994; Lado, Boyd, and Wright, 1992; Hall, 1993; Prahalad and Hamel, 1990; Winter, 1987) has led to increased attention to the processes by which such competencies are acquired (McGrath, MacMillan, and Venkatraman, 1995; Amit and Schoemaker, 1993). This paper illustrates a novel approach to the problem. We use theories that explain the processes of change at the system level (Van de Ven and Poole, 1995; Van de Ven, Angle, and Poole, 1989; Van de Ven, 1993a, 1993b) to examine competency acquisition by specific firms embedded in the system. We combine an organization theory focus on macro-system change with a strategic management focus on firm-specific competency acquisition.

Macro-system change

At the system level, government can establish a purpose or goal which drives movement toward an end-state (March and Simon, 1958). It can monitor progress and modify its intentions based on what it learns (Braybrooke and Lindblom, 1970; Jones, 1970; Anderson, Brady, and Bullock, 1978; Dye, 1978; Mitnick, 1980; Marcus, 1984). Rivals in the marketplace then compete to meet this goal (Friedman, 1972, 1979). From their competition variations emerge, mostly slight and successive but some punctuated and major (Tushman and Romanelli, 1985; Gersick, 1991). The market selects and retains some of the variations and discards others. The government logic is *teleologic*; it leads toward an end-state. The market logic is evolutionary; it is driven by cycles of variation, selection, and retention (Hannan and

---

Key words: strategy process research; competence acquisition; innovation and change; corporate environmental management
* Correspondence to: Alfred Marcus, Carlson School of Management, University of Minnesota, 3-353 CarlSMgmt, 321–19th Avenue South, Minneapolis, MN 55455, U.S.A.

CCC 0143–2095/98/121145–24 $17.50

Received 4 October 1996
Final revision received 17 March 1998

Freeman, 1977; Astley, 1985). The conflict between these logics is a *dialectic* (Benson, 1977; Coser, 1956) that can result in a unique and unanticipated *synthesis*.

Firms embedded in the system

These system-wide developments affect firm-level choices (Brumagim, 1994; Powell, 1995). Firms both *look outside* their organizations for talent, technology, and ideas (Hamel and Prahalad, 1994) and try to *harmonize* what they learn with what they know internally (Hamel and Prahalad, 1994; Chakravarthy, 1996). Looking outside involves the capacity to confront novel problems (Nelson and Winter, 1982; Winter, 1987), assess future developments (Chamberlain, 1968), and reposition the firm in the face of changing conditions (Lenz, 1980). Harmonizing what is known internally involves dealing with organizational problems (Amit and Schoemaker, 1993) that might require high degrees of trust and cooperation, deft, heedful interrelating, and the renegotiation of explicit and implicit contracts (McGrath *et al*., 1995).

This paper develops an approach to competence acquisition that is built on the interaction between these system-wide properties and firm-specific capabilities. We illustrate this approach by analyzing the electric utility industry's responses to the 1990 amendments to the Clean Air Act. We start by defining what a distinctive competence is and connecting it to management of the physical environment. We examine the process of acquiring a competence from the perspective of strategic process theory, discuss the paper's methods, and present the findings. Implications for research and practice are brought out in the conclusion.

A DISTINCTIVE COMPETENCE

Industrial economics holds that superior performance comes from competitive position (Porter, 1980). A contrasting approach focuses on the firm's distinctive competencies (Hamel and Prahalad, 1994), unique accretions of rigidities and capabilities that it acquires over time in the course of accepting commitments and adapting to external and internal pressures (Selznick, 1957). Top management's role is to identify, acquire, build, deploy, protect, and defend such competencies (Hamel and Prahalad, 1994). Doing so is a complex process affected by both uncertainty and conflict (Amit and Schoemaker, 1993).

Distinctive competencies can be created by uniting previously unconnected elements or developing new ways to fuse elements previously unassociated (Nahapiet and Ghoshal, 1997; Usher, 1954). Such competencies are based on the integration and combination of component elements, whether they be tangible resource inputs or intangible understandings, know-how, and techniques (Kogut and Zander, 1992; Henderson and Cockburn, 1994; Galunic and Rodan, 1998). These elements are transformed, organized, and reconfigured to create useful products and services. While the most basic competence is the capacity to integrate and combine components in new ways, the list of capabilities which support this basic one is much longer (Afuah, 1998).

Managing the physical environment

Like total quality management (Powell, 1995), establishing a distinctive competence for managing the physical environment is important, as it can mean less waste, fewer emissions, less accidents, lower costs, and better integrated systems (Shrivastava, 1995; Gladwin, 1993). To the extent that this competence is tacit, casually ambiguous, rare, firm specific (Hart, 1995), and adds value to customers through product differentiation or lower costs, it provides competitive advantage. Indeed, many companies have made substantial advances in reconciling their business and environmental goals. They have created 'win–win' solutions where being 'green' rather than a cost of doing business has become an impetus for the development of new market opportunities and innovation (Porter and Van der Linde, 1995). However, these instances of win–win outcomes are becoming increasingly difficult to realize (Walley and Whitehead, 1994).Thus, understanding how they are achieved is important.

Examining how environmental competence is acquired can be a good way to understand how distinctive competencies in general are obtained. In electric generation, a competence for environmental management is highly important (Torrens and Platt, 1994). The U.S. EPA (1989) estimates that electric utilities generate about 70 percent of all U.S. sulfur dioxides and 30 percent of all U.S. nitrogen oxides. They are major greenhouse gas contributors, emitting more than 500 million tons of carbon per year. Gollop and Roberts (1983) found a very large and negative effect of environmental regulations on their productivity. Jaffe *et al.* (1995) calculated it as the largest and most negative impact on any industry, a 44 percent share reduction in productivity due to environmental regulation in this industry compared to 8–12 percent drop-off in other industries.

According to *Power Engineering Magazine*, the Acid Rain Program (Title IV) of the Clean Air Act Amendments was '*the central management issue*' electric utilities faced in the 1990s:

> in a recent survey, more than half (58%) of the utilities responding indicated that compliance with the Clean Air Act 'was the primary goal of their capital spending plans ... Industry sources estimate the cost of compliance at about \$3–\$5 billion per year between 1995 and 1999 and as much as \$7 billion by 2000. (Kuehn, 1993: 19).

Pollution prevention became very important to the utilities.

Acquiring a competence

Acquiring a competence to manage the physical environment is a complicated process. It involves socially constructed elements (Amit and Schoemaker, 1993). Key players are likely to interpret the conditions they face and assign meaning to the actions they take in fairly idiosyncratic ways. They make moves as much by experimentation, trial and error, opportunism, and accident as by planning (Collins and Porras, 1994). They learn from failure as much as from success (McGrath *et al.*, 1995). This process could not be otherwise if it is to produce hard-to-imitate *distinctive results* (Reed and DeFillippi, 1990).

At present, the concepts used to understand the process of competency acquisition are fairly amorphous (Miller and Shamsie, 1997). They have not been carefully defined or tested. Because the process of combining, deploying, and mobilizing competencies is path dependent and historically grounded (Barney, 1986a, 1986b, 1991), it does not make sense to examine it by means of logical deduction from well-established theory and by empirical testing of hypotheses. It makes more sense to work inductively using the methods of process research pioneered by Van de Ven (1992) and others (see Pettigrew, 1985; Abbott 1990, 1992; and Holmes and Poole, 1990).

The *process* of acquisition

Van de Ven (1992) makes the distinction between strategy process research that relies on constructs measured as fixed variables and research that investigates the unfolding of events over time. He criticizes the former for its 'highly restrictive and unrealistic assumptions' (1992: 170), and calls on researchers to open 'the ... "black box" between inputs and outputs' in order to observe how stories unfold (1992: 170). According to Van de Ven (1992), rather than exclusively emphasizing cause-and-effect relationships between variables, researchers should take a 'historical development perspective that focuses on the "stages" and "sequences" of events' (p. 170).

To understand the progression of events, Van de Ven (1992: 172) notes that process models often are developed 'inductively' on the basis of 'retrospective case histories.' The contribution of our paper is in this realm. We aim to present not a variance model of the competence acquisition process but a process model that describes how events unfold. As Van de Ven (1992) suggests, we are interested in 'underlying generative mechanisms' that help explain why observed events occur in particular sequences (1992: 177).

CASE METHODS

Our research is based on extensive investigation of publicly available documents and interviews about the electric utilities' responses to the 1990 Clean Air Act Amendments. Documents were read, and to clarify what was learned, open-ended, background interviews were done with key industry participants and experts who provided additional insights and documents. The methods (Yin, 1989) involved going back and forth between the documents and interviews, comparing information with theory, and allowing the analytical framework to emerge from the evidence (Eisenhardt, 1989). These methods were iterative and closely linked to the data. They relied on multiple collection methods, quantitative and qualitative information, multiple investigators, and the use of public and corporate records as well as interviews.

The initial question

The initial question that motivated the research was 'What were the competitive implications of the 1990 Clean Air Act on the electric utility industry?' To assemble the information and write preliminary reports (Geffen and Marcus, 1995a, 1995b), we prepared an outline. The categories in this outline included: the environmental pressures the electric utilities faced; the structure of the utility industry; the inputs the industry needed to make its products; the market size of the companies that provided these inputs; their market projections and market share; the existence of new entrants and competing technologies; and the likely competitive position the new entrants and competing technologies would achieve.

Public documents

Extensive public documents on the electric utility industry were used to gather information about these topics. We relied on reports from the Department of Energy (especially the Energy Information Agency within the Department of Energy) and the Environmental Protection Agency and examined publicly available 10K reports as well as the work of industry analysts (Prudential Securities, 1993, 1995; Merrill Lynch, 1993) on the utilities and their suppliers. Some of these documents were quite useful in helping us compare and rank the utilities based on their environmental costs, the percentage of power they derived from coal and other forms of power generation, the percentage of their customers who came from the industrial, as opposed to commercial or residential, sector, and other attributes.

Interviews

To supplement what we learned from these documents we carried out interviews. We started out by talking to two key experts from the industry. One was an authority on environmental issues and the other on the industry's technology options for dealing with the Clean Air Act. Our subsequent contacts for additional interviews came from these initial ones. In this way, the initial interviews snowballed into many more. We were referred to three industry experts on generating electricity from coal and to three industry experts on generating electricity from natural gas. Our discussion with these individuals led us to three knowledgeable insiders in the industries that supplied coal and natural gas technology and to three knowledgeable insiders in the industries that transported these fuels. In total we did 14 in-depth interviews.[1] Those we talked to were promised anonymity. The interviews were carried out in the spring and summer of 1995. The typical interview lasted 1–2 hours and was conducted in the form of a conversation usually with both investigators present. The interviews were tape recorded, rendered into type-written form, and used in composing our preliminary reports (Geffen and Marcus, 1995a, 1995b). We also consulted experts on the phone for short discussions to clarify points when needed.

These contacts with people in the industry provided us with very specific types of information. For instance, the environmental experts clarified the meaning of the 1990 Clean Air Act and its effects on the utilities. The experts on coal-fired power provided insights about the shift to clean coal that was occurring. The experts on natural gas discussed new generating technologies that were being introduced. The experts on clean coal technologies told us about advances in these technologies and why the advances had not gone as far as anticipated. The experts on transporting fuels described the innovations taking place in these methods. When possible, we asked for and received specific analyses of the market penetration of these different options and their comparative prices at the time that the interviews were carried out.

Openness to the evidence

As the research proceeded, our impressions and understandings began to evolve. For instance, at the start of the research, we believed that the focus of the acquired competencies would be the utilities. We would discover how they gained competitive advantage based on their responses

[1] The titles of the 14 people with whom we conducted in-depth interviews were President of Utility Subsidiary, Vice President for Energy Resources, Director of Fuel Resources, Director of Electric Marketing, Director of Technology Strategy, Environmental Manager, Senior Vice President of Business Development, Vice President of Engineering and Technology, Director of Engineering Services, Divisional Marketing Director, Regional Marketing Manager, Environmental Consultant, Director of Coal Research Center, and Professor with Expertise in Coal.

to the Clean Air Act. However, as more was learned, we discovered that the key players were not the electric utilities but their suppliers. The electric utilities did not originate the unique pollution prevention solutions they adopted. These solutions were brought to them by their suppliers. The suppliers created new technological systems that served the utilities' needs. The suppliers that best accomplished this task achieved competitive advantage.

In particular, two suppliers were named again and again by our sources. These were the Burlington Northern (BN) Railroad and the General Electric (GE) Company. BN and GE were especially good at integrating, combining, and configuring technologies, some lying outside their organizations (e.g., BN and computer processing for better scheduling and traffic control) and some lying within (e.g., GE and jet engine technology). They brought together countless, incremental innovations from diverse areas in a manner Usher (1954) describes as cumulative synthesis. These suppliers competed in their specialized areas to provide the utilities what they needed to deal with the Clean Air Act. The utilities then deployed what the suppliers brought them. They looked outside their organizations for answers to the challenges they faced, a process that was much less burdensome than having to develop the solutions themselves.

A framework

To organize the analysis we needed a framework. Normal science divides reality into fixed variables and attributes causation to the probable relations between them (Abbott, 1990, 1992). The analogue to causality in a narrative structure is the interpretive framework—a theory of 'enchainment' (Abbott, 1990, 1992) that gives coherence to events (Holmes and Poole, 1990). Thus, how the analysis is organized tends to be very important.

Because our subject matter was change, we were not interested in a functional model of stability or maintenance of the status quo (Gioia and Pitre, 1990). In accord with Pettigrew, we also were not interested in a 'singular theory' (1985: 279) of decision-making, such as rational, boundedly rational, incremental, or garbage-can. We felt that the juxtaposition of elements from different levels—government, the market, and firms—drove our story forward. The ecology of change (Marcus, 1981) which consists of the government and the market (the macro-industrial system) and individual companies looking outside for talent, technology, and ideas and harmonizing what is known internally was important (see Figure 1).

We considered but decided not to use a number of frameworks commonly found in the innovation and change literature. The problem with theories of induced change (Ruttan and Hayami, 1984) was that they too narrowly focused on one level—changes in the external economic environment. They did not take into account government. Processes internal to the firm remained inside a 'black box' (Ruttan, 1997: 1521). Evolutionary theories got inside the 'black box' and examined organizational routines in relation to market processes (Burgelman, 1984). However, like theories of induced change, they failed to adequately incorporate the role of government. Path dependency, with its focus on micro-level historical events, placed too much emphasis on the 'lock-in' phenomenon; it did not sufficiently account for changes in the rate and direction of change. The role of government again was underemphasized. Government also did not figure prominently enough in theories of diffusion (Rogers, 1983), which rely heavily on interpersonal networks and information exchanges to explain the spread of new ideas.

Thus, we accepted Pettigrew's (1985) 'contextualism,' which involves juxtaposing external conditions with internal organizational processes, but with a significant exception. While he starts with the firm and moves from it to government and the market, we started with government and the market and moved from it to the firm. The analysis that follows starts with elements of the macro-industrial system. Then, micro-developments at the firm level are examined with the emphasis on the supplier firms BN and GE that acquired the competencies that allowed them to benefit the most from the passage of the 1990 Clean Air Act.

TELEOLOGY AND EVOLUTION WITHIN A DIALECTICAL FRAMEWORK

What takes place in governments and markets (Wolf, 1988; Lindblom, 1977; Dahl and Lindblom, 1976; Preston and Post, 1975) is compli-

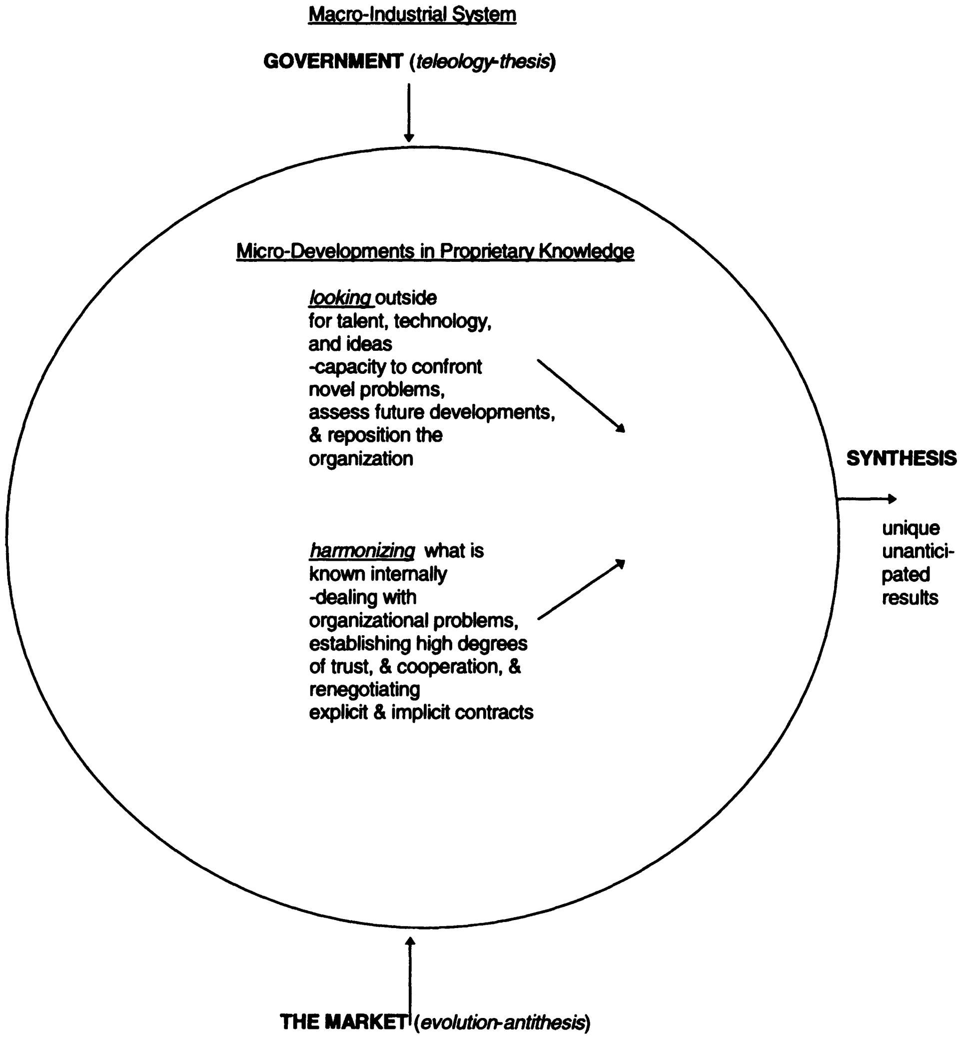

Figure 1. The process of competence acquisition: System-wide developments and firm-specific changes

cated. Few would unequivocally grant that what government does is goal seeking and rational. A large literature (e.g., see Lindblom, 1977) sees it as haphazard, incremental, blundering, emergent, and conflict ridden. Similarly, few would maintain that markets completely lack logical, goal-seeking behavior. Firms have profit-making goals that are fundamental to their continued existence. Though governments and markets do not in general behave in the stylized fashion that we describe, we argue that *in the case we analyze* the driving force in government is *teleological,* while in markets it is *evolutionary.*

THESIS: THE TELEOLOGICAL FRAMEWORK WITHIN GOVERNMENT

To understand the teleological framework within government, some background on the history of regulation is needed. In 1955, Bernstein suggested that vague statutory language was a reason for the 'capture' of regulatory agencies by business. Drawing upon existing legal literature about delegation of authority to agencies, he argued that the character of the law affected an agency's relationships to the businesses it tried to control.

The vaguer the laws that the agency administered, the less likely that it would be independent of the businesses it was supposed to regulate. Lowi (1979) brought together this scholarly criticism. Relying heavily on the works of Davis (1977) and Friendly (1962) he emphasized the problems of undefined discretion in government agencies and argued that the remedy for agency problems attributable to vague and ill-formed legislation was statutes drafted by Congress that had clear goals and explicit means of implementation. Statutes of this character would institutionalize and make binding the sentiments of the public originally mobilized for the purpose of passing the legislation. Armed with strict legal authority, a regulatory agency was less likely to perform inadequately, even if its activities no longer commanded general interest or attention (Bryner, 1987).

Since 1970, U.S. environmental policy has been based on this principle that vague delegation of administrative responsibilities would not work. Without specific goals, timetables, and other means of implementation that force technological change, industry would not budge. When the EPA was created in 1970, Congress had been searching for 'handles' that would prevent industry from evading the achievement of environment goals (Jones, 1975; Marcus, 1980). It addressed the problem of vague delegation of authority with statutes that had clear goals, specific dates, and other means of implementation. Instead of Congress in effect saying to the bureaucracy 'Here is the problem, deal with it,' it used such statutes to give the bureaucracy binding authority to coerce industry into complying with the law.

The goal of the 1970 Clean Air Act was to achieve 'healthy air' by 1975. Healthy air was defined in terms of reducing concentrations of such pollutants as particulate matter, sulfur dioxide, carbon monoxide, photochemical oxidants, and nitrogen oxides. Three months after the law was passed, the EPA set national standards for these pollutants. Nine months later each state issued an implementation plan in accord with congressional deadlines. The states had to relate emission production from industrial sources to ambient air quality goals and develop a 'roll back technique' which would involve a percentage reduction on the part of major emitters. After each state wrote its plan, the EPA had to review it. If the state submitted a plan that the EPA found unacceptable, the agency had the right to impose a different one.

The 1977 amendments to the Clean Air Act

Congress thus put in place a teleological logic with envisioned end states and actions to reach them. When progress was examined in 1975, the Council on Environmental Quality found that healthy air had been fully attained in 91 of the nation's 247 air quality regions (Marcus, 1980). In relatively unpopulated rural areas, where it had never been below safe levels, air quality was achieved, but in major metropolitan areas it often was not met. Congress, therefore, following a teleological logic modified the Clean Air Act based on what it had learned. It amended the Act to give industry more time to comply, dealt with ambiguities in the law, and provided new authority to control hazardous air pollutants (HAPs).

A major element in the revision had to do with new coal-burning facilities. Under 1977 amendments to the Clean Air Act, the EPA set a new goal for these facilities—no more than *1.2 lb. of sulfur dioxide* (SO_2) *per million British thermal units (MBtu)* of coal burned. This goal encouraged utilities to design new plants using low-sulfur coal, a development favorable to western coal, but one which threatened eastern and midwestern coal interests, many of whose mines might have to be closed. Environmental advocacy groups and high-sulfur coal producers therefore urged Congress to attach language to the 1977 amendments that required the use of scrubbers, since with scrubbers at the end of a stack a utility could continue to burn high-sulfur coal and the coal miners' jobs would not be threatened (Ackerman and Hassler, 1981).

Scrubbers were an end-of-pipe technology that did not lower emissions at the source. From a pollution prevention perspective that emphasizes changing the inputs to production rather than end-of-pipe treatment (Freeman *et al.*, 1992), scrubbers were not the preferred solution. With prevention, fewer noxious substances are introduced to begin with and costs can be contained because capital-intensive treatment equipment is avoided. Congress, nevertheless, mandated that plants using coal had to install scrubbers capable of 70–90 percent sulfur dioxide (SO_2) removal depending on the sulfur content.

The 1990 amendments to the Clean Air Act

The teleological logic of evaluation and modification in government continued to unfold (Landy, Roberts, and Thomas, 1990; Vig and Kraft, 1990; Fiorino, 1995). By 1987, regular monitoring showed that particulate matter levels had fallen by 21 percent, sulfur dioxide by 35 percent, carbon monoxide by 32 percent, photochemical oxidants by 16 percent, and nitrogen oxides by 12 percent; but most major air quality regions *still failed to meet federal standards* for some time period during a typical year (Marcus, 1996). Given that these results were not what Congress wanted, after a decade of debate, it again decided to amend the Clean Air Act. It focused on the 'acid rain' problem from coal-fired power plants. Formed mainly when SO_2 and to a lesser extent nitrogen oxides (NO_x), precipitate out of the atmosphere, acid rain was viewed as the source of damage to forests and lakes. The culprit was thought to be the high-sulfur coal used by electric utilities and the nitrogen oxides, or NO_x, that were formed as a consequence of the combustion process. According to the EPA's 1989 emissions inventory, utilities were responsible for 69.4 percent of U.S. SO_2 emissions and 32.4 percent of NO_x emissions (U.S. EPA, 1989).

In conformity with the teleological logic, Congress passed new Clean Air Amendments in 1990 that established a fixed overall emissions goal of *8.95 million tons of* SO_2 *per year.* To put this cap in perspective, the Department of Energy (DOE) indicated that total power plant SO_2 emissions in 1993 were 14.4 million tons, leaving a required reduction of about 5.4 million tons (U.S. Department of Energy, 1993a). Since from 1989 through 1993, SO_2 emissions had dropped by only 1.3 million tons, the challenge to the electric utility industry was substantial.

Implementation was to be in two phases (U.S. EPA, 1992). The first affected 260 units that had the capacity to generate 100 MW or more of power. Situated at 110 sites in 21 states, these units were owned by 55 electric utilities. They comprised about 13 percent of total U.S. generating capacity and were chosen because they emitted SO_2 at an average annual rate of *over 2.5 lb per MBtu* of coal consumed. According to the teleologic logic that governed Congressional decision making, the *goal* Congress set for them was to lower their SO_2 emissions to *less than 2.5 lb per MBtu* by January 1, 1995. They also had to reduce their nitrogen oxide emissions starting in 1995. However, Congress remained concerned about the harm that these requirements could cause eastern and midwestern coal interests, and thus it gave a 2-year extension to plants that committed to buying scrubbing devices.

The approach in Phase II was similar. Starting in the year 2000, more than 1900 additional units, with the capacity to generate 25 MW or more of power, would be affected. Along with the Phase I plants, they would have to cut their SO_2 emissions *to less than 1.2 lb per MBtu.* Again, this deadline could be extended until 2004 for plants that used scrubbers.

With the teleological thrust evident in both Phase I and Phase II of this act, it was a surprise that Congress, unlike earlier, also introduced an innovative pollution-trading system, which tried to mimic market-like processes (U.S. EPA, 1992). Under Phase I, generators that cut emissions by more than the required amount earned pollution rights they could sell to other emitters or should they need to expand use themselves. Congress, however, continued to show its preference for scrubbers over market trading by placing a provision in the Act that earned bonus credits for utilities that installed these devices.

Clean coal technology

These amendments threatened to impose substantial costs on power plants that used high-sulfur coal. The original projections were from \$400 to as much as \$1000 per ton of SO_2 removed, as high as \$0.01 per kilowatt hour (kWh), or about the same as the utilities paid for fuel (U.S. EPA, 1992). The issue thus was of major strategic importance to the utilities. In response to protests from the utilities and out of concern for eastern and midwestern mining interests, the DOE initiated a 'Clean Coal Technology' program to develop better-working, low-cost scrubbers. The federal government, in partnership with private industry, committed to spending \$7 billion on clean coal technology R&D, about \$2.5 billion from the government and the rest from the utilities and technology companies (U.S. Department of Energy, 1994a).

The need for scrubbers was as great abroad as it was in the United States. Worldwide acid rain standards were very strict, and low-sulfur coal was scarce. In Sweden, Germany, and Japan, acid rain requirements were especially severe. In the former Soviet republics and Mexico, standards also were high but not effectively enforced. China alone among major countries did not have high standards. Plans to use scrubbers were strong in Asian countries like South Korea, whose SO_2 emission standard was 1.2 lb per MBtu, the level the United States required only by the year 2000. By 1999, South Korea's facilities would have to reach an emission level of no more than 0.6 lb per MBtu. While it had been using low-sulfur coal to meet the 1995 standard, South Korea could not attain the 0.6 lb per MBtu standard without scrubbers.

Thus, in establishing the clean coal program, the U.S. government also helped U.S. industry develop markets for scrubbers abroad. It not only set goals, but showed a clear preference for how to achieve them (the teleological logic), and it subsidized scrubbers, an approach that was at odds with the principles of pollution prevention.

ANTITHESIS: THE EVOLUTIONARY LOGIC IN MARKETS

To understand the evolutionary response in markets, classic work which describes how markets ideally function needs to be considered (e.g., see Stigler, 1965; Friedman, 1972, 1979; Ward, 1979). The evolutionary logic suggests that goals do not drive a system, but variation, selection, and retention among rivals competing for scarce resources. In classic descriptions of ideal markets, one finds spontaneous, free interplay among competing forces, many buyers and sellers, freedom of entry, and substantial mobility of resources. Decision making is decentralized and there is spontaneous coordination. Decision-makers base their choices mainly on information about alternatives provided by prices. The incentive they have to make a deal is self-interest, and their capacities to rationally calculate are great. Each deal they make is supposed to improve their economic situation without reducing that of others. The sum total of these mutually beneficial deals adds up to an increase in welfare (Ward, 1979).

Stigler (1965) describes the conditions associated with near perfect market conditions as:

- rivals acting independently;
- the number of rivals being great enough to prevent large gains by any of them;
- the rivals and other economic actors having reasonable information about the opportunities available;
- the rivals and other economic actors being eager to maximize their returns; and
- the rivals and other economic actors having the freedom to act based on the knowledge they possess.

These are *ideal* market conditions in which economic entities are unencumbered and have the right to enter and exit relationships without constraints.

In accord with a Darwinian logic, there is an analogy between the selection processes in natural systems and the selection processes in markets (Green and Miles, 1996). Like organisms, firms compete for survival. The products they make are found in many niches. Only some of these products survive. The market acts as a screen or filter to weed out unfit products. Buyers freely select based on the information they have about prices and other product attributes. Their choices are sovereign. This process of *variation, selection, and retention*, as it affected the choice of coal, natural gas, and scrubber options after the passage of the 1990 Clean Air Act, is described in the next section.

Variation one: Low-sulfur coal

Coal was the mostly commonly used fuel in the United States for generating electricity. In 1993, 56.9 percent of electrical energy came from its burning (U.S. Department of Energy, 1993a). In comparison to other fuels, reserves for this fuel were very ample. Coal also was one of the dirtiest fuels available and a large contributor to greenhouse gases and global warming. The types of coal available, however, were diverse. For the industrial market, the main competition (see Table 1) was between bituminous (high-sulfur) coal and sub-bituminous (low-sulfur) coal, though lignite, a very low-quality coal, played a small role, and, in some areas, like the southwest, dominated.

Bituminous coal tended to be roughly 70 percent carbon and a few percent hydrogen, which together represented the heating value of the mineral. The rest consisted of water, clays of various

Table 1. Bituminous (high-sulfur) and sub-bituminous (low-sulfur) coal

	Bituminous	Sub-bituminous
Main location in U.S.	East/midwest	West
Percentage sulfur[a]	1.71	0.41
Heat content (Btu/lb)[a]	12,045	8763
lb of sulfur/MBtu[a]	1.47	0.47
Reserves	Declining	Vast
Cost of mining	High	Low
Boiler modifications needed	No	Yes

[a]Average values of the coal sold to utilities in 1993. Adapted from U.S. Department of Energy (1993a).

oxides (the unburned ash), oxygen, nitrogen, trace compounds (such as chlorine and calcium), very small amounts of metals (including mercury), and sulfur in various forms. The sulfur content could be as high as 6 percent by weight but grades of coal in use by generating facilities usually contained less than 4 percent sulfur. In 1993, total bituminous coal purchased by utilities averaged 1.71 percent sulfur, which at an average of 12,045 Btu per lb corresponded to 1.42 lb of sulfur per million Btu heat content (U.S. Department of Energy, 1994b). The sulfur content of the coal in Appalachian mines, however, varied, and the proportion with less sulfur was uncertain and limited. Moreover, the mines from which this coal came were mature, fully exploited, and had high extraction costs.

Sub-bituminous coals were of lower quality than bituminous coals. Compared with a pound of bituminous coal, a pound of western sub-bituminous coal supplied about 30 percent less heat (U.S. Department of Energy, 1989). The moisture content of this coal tended to be much higher. Powder River Basin coal from Wyoming, for instance, was about 30 percent water. However, its sulfur content was low. In 1993, the average sulfur content of sub-bituminous coal sold to utilities was 0.41 percent and, with an average heat content of 8763 Btu per lb, this equated to 0.47 lb per MBtu (U.S. Department of Energy, 1994b). The Powder River Basin in Wyoming, and to a lesser extent Montana, had large reserves of low-sulfur coal (30 years or more) mostly ranging from 0.25 lb per MBtu to 0.60 lb per MBtu (Sansom, 1990; U.S. Department of Energy, 1989). These large reserves were available in thick veins close to the surface. Even greater reserves existed somewhat deeper below the surface, necessitating open pit mining to recover them, but at a cost still much below that in the east and midwest. Low-sulfur sub-bituminous western coal differed sufficiently from higher-sulfur bituminous coals, however, such that it usually could not be substituted for the latter without boiler modification.

Successive Clean Air Acts stimulated the development of low-sulfur coal from the Powder River Basin. The oil supply crises of the 1970s and skyrocketing energy prices inspired additional investment which began to pay off in the 1980s with substantial advances in productivity from larger, more efficient earth movers, trucks, and other equipment. A miner in Wyoming and Montana produced over 20 tons of coal in an hour, while one in Appalachia, where most bituminous coal was found, produced only 3 tons of coal (U.S. Department of Energy, 1994b). Western coal delivered to utilities sold for about $1 per MBtu in 1993 in states such as Nebraska, Iowa, Kansas, Minnesota, and Wisconsin (U.S. Department of Energy, 1994b). Spot prices were as low as $0.80 per Mbtu (U.S. Department of Energy, 1994b). To the south and east, prices also were falling (See Table 2).

Table 2. Average 1993 coal prices and sulfur content per million Btus delivered to outlying states from Powder River Basin, Wyoming, compared with the averages from all coal sources to that state[a]

Receiving state	Wyoming coal delivered price ($/MBtu)	Wyoming coal sulfur content (lb/MBtu)	Avg. price all coal delivered ($/MBtu)	Avg. sulfur content all coal (lb/MBtu)
Arkansas	1.70	0.38	1.70	0.38
Georgia	1.45	0.37	1.78	1.14
Indiana	1.20	0.39	1.27	1.61
Kentucky	1.22	0.59	1.17	2.09
Louisiana	1.63	0.52	1.59	0.66
Massachusetts	1.75	0.34	1.68	0.80
Michigan	1.09	0.33	1.53	0.59
Texas	1.67	0.40	1.44	1.15

[a]U.S. Department of Energy (1994b).

Variation two: Natural gas

Gas turbines (GTs) and combined cycle gas turbines (CCGTs) were the main alternatives to coal. They had outstanding environmental benefits, emitting no SO_2, much less NO_x, and no hazardous air pollutants (HAPs) like mercury. Equally important, they had less neighborhood impact than coal-fired units, (i.e., communities were less likely to protest the siting of a natural gas facility). Again, as with coal, a number of options existed.

Single gas turbine (GT) units were a spin-off of the aircraft jet engine, modified for stationary power application and for burning natural gas. Units could use fuel oil (as jet engines did) or natural gas. The models closest to jet engines ranged in power from 1/2 to 40 MW, while more advanced systems produced 150–250 MW of power. Their capital and fixed operating costs were half that of coal-fired systems and they had thermal efficiencies of up to 40 percent.

CCGT systems tended to be larger. Consisting of a GT unit of 100–150 MW plus heat recovery steam and steam turbine generators of 50–100 MW, they could attain thermal efficiencies of over 55 percent. Priced at about $800 per kW fully installed, they met extremely stringent new source performance standards for NO_x. While GT systems often were used to provide peaking power, CCGTs had sufficiently high thermal efficiencies so that they were suitable for intermediate and base load applications. Both GTs and CCGTs could be arrayed in modular units for additional power capacity. This feature was attractive to electric utilities and other power generators that preferred to respond to new capacity demands with an increment at a time. Time of installation was quick. A 250 MW CCGT could be installed within 2 years or less.

Gas turbine generating technology was blossoming with systems that achieved 60 percent thermal efficiency within reach. These changes, bred not by environmental regulation alone, but aided by it, enabled utilities to meet new capacity needs, especially peak power demand, but base load as well, at low capital and operating costs. Important factors that contributed to the increased demand for GT and CCGT were fear that high clean-up costs would be imposed on newly constructed coal-fired systems and growing local opposition to siting coal plants.

Variation three: Scrubbers

Rather than natural gas or low-sulfur coal, a utility could install a scrubber and continue to use high-sulfur coal. Scrubbers took two forms. Limestone wet flue gas desulfurization (WFGD) equipment sprayed limestone slurry and water into the flue gas which formed a calcium sulfite and sulfate sludge that had to be disposed of in a landfill. WFGD could be employed for a range of coal with different sulfur contents, and could be installed when constructing new units or in retrofitting old units. Usually, it removed 90 percent of the SO_2 from the flue gas; however, it could be enhanced to remove 95 percent and even as high as 98 percent at relatively low cost (an additional 5–10 percent in capital costs). For a burner using 4 percent sulfur coal, the 1995 capital costs were approximately $120–150 per kW for a new generating facility. For one using 2 percent sulfur coal, the cost was about $30 per kW less, while retrofitting an existing unit cost about 10–15 percent more.

Some facilities had insufficient space to install a WFGD system, making retrofitting even more expensive. Dry flue gas desulfurization alternatives existed, but though their costs were roughly 15 percent lower than WFGD, they did not, except in specialized applications, have enough SO_2 removal capability (they could remove only 50–90 percent of the sulfur) to be competitive.

In a variation on WFGD, instead of sending the sludge to a landfill, a utility could remove the water and impurities from the sludge and make gypsum, a marketable product. This capacity added only $4 per kW to the capital costs, but in the United States made sense only if a utility was located near an area of high gypsum demand. In Western Europe, on the other hand, the capability to convert scrubber sludge into a useful byproduct often was essential. Landfill permits to dump waste sludge were not easily available. In Germany a utility had to have this capability.

Labor and maintenance costs for WFGD systems were about 2.5–3.0 percent of capital cost per year. Parasitic power losses were about 1.5 percent of plant output and reagent prices were low, in the neighborhood of $0.050 per kWh, with limestone costing only $10 per ton. A good estimate of the additional revenues needed to pay for WFGD systems was $0.40 per kWh, a cost much less than anticipated when the Clean Air

Amendments were passed, but greater than the added cost of fuel for burning natural gas in a combined cycle turbine generator in most parts of the United States (U.S. Department of Energy, 1993b).

Selection: The U.S. electric utility companies

The electric utilities (see Sanchez, 1995) then had many variations from which they could choose: different types of coal, different ways of generating electricity from natural gas, and different scrubbing systems. In 1993, the utilities sold a record 2.3 trillion kWh of electricity in the United States (U.S. Department of Energy, 1993a). Their main product was ubiquitous and essential and almost taken for granted unless a power failure occurred. With widespread computers and other complex electronic devices, even a small variation in power could do damage, and the utilities had to be concerned not only with availability but with the reliability and quality of electricity transported over long distances from concentrated generating centers.

Until recently, utilities were virtual monopolies. Dramatic changes, however, had taken place driven by industrial customers in search of lower costs and by state and federal regulators slowly moving towards increased deregulation and competition. Large consumers of electric energy saw nearby utilities offering power at lower rates than their own utility and pressed regulators to permit 'retail wheeling' (i.e., they sought to require the local utility to transmit the power of another utility to supply them with electricity). Inject the 1990 Clean Air Amendments into this situation and the result was the utilities' relentless search for the lowest-cost solutions.

To illustrate how the utilities faced the challenges of complying with the Clean Air Amendments, we took 10 utilities in the southeast and southwest as examples. These utilities all were large and in an area of the country with above average growth in demand because of a vibrant economy, expanding population, and warm climate. They also were in an area of the country where the rivalry between eastern and western coal and between coal and natural gas was fierce. Because of augmented competition and advancing deregulation, it was likely that these utilities would be competitors for some of the same industrial customers. Together they generated 22 percent of all U.S. power. Table 3 shows the average prices in cents per kilowatt hour that they charged their industrial customers in 1994, the population they served in millions, and the percentage of their capacity from coal. A high level of coal (or lignite) fired power and high industrial prices meant a larger competitive effect from the 1990 Clean Air Amendments. Among these utilities, Carolina Power and Light was the most adversely affected. Based on analysis of 1994 10K reports, DOE data (U.S. Department of Energy, 1994b), and clarifying interviews with utility company representatives, we summarize how these utilities complied with Clean Air Amendments and met their new generation needs.

Compliance with Clean Air Amendments

1. *All* (with the exception of Florida Power and Light, which had almost no coal-based generating capacity) resorted to using *low-sulfur coal* as the core of their compliance strategy.
2. Along the *southeast* and closest to Appalachian coal mines, the source of this coal was *Appalachian.* Southern Company, however, with plants running from Georgia to Alabama, Louisiana, and Mississippi, was using some western coal and testing whether it could be delivered at a competitive price.
3. *Powder River Basin* coal had penetrated to the *South Central* United States. It was providing Entergy Corporation with the *complete* solution to its SO_2 compliance problems and helping Houston Power and Light meet New Source Performance Standards.
4. *None* of these utilities was contemplating the use of scrubbers.

Meeting new generation needs

1. The 10 utilities had planned a total of seven coal-fired units in 1990, but only three of these remained in their plans in 1993. In contrast, they planned nine gas units in 1990, but by 1993 the number of gas-fired units they planned to construct had gone up to 21.
2. In 1994, Duke Power announced that it would be completing a huge gas turbine station designed to provide peaking power up to 1184 MW. This $500 million facility was not included in the 21 units it had planned in 1993.

Table 3. Impact of Clean Air Act on southern and southwestern utilities[a] (based on three factors)

	Cost/kWh	Population	Percentage coal
Baltimore Gas and Electric	4.640	2.6M	44%
Dominion Resources (Virginia Power)	4.330	1.8M	39%
Duke Power	4.240	4.9M	43%
Carolina Power and Light	5.290	3.5M	60%
Southern Company (Georgia Power, Alabama Power, Mississippi Power, etc.)	4.300	11M	73%
Florida Power and Light (FPL Group)	4.910	6.5M	6%
Florida Progress Company (FPC)	4.840	1.2M	31%
Entergy Corporation (Louisiana Power and Light, Gulf States, Arkansas Power and Light, etc.)	4.470	2.4M	16%
Houston Industries	4.380	1.4M	43% coal + lignite
Texas Utilities	4.240	5.7M	26% lignite

[a]Adapted from work by Prudential Securities (1993, 1995) and Merrill Lynch (1993) analysts.

3. In the same year, Carolina Power and Light announced new plans for an additional 225 MW GT unit in 1997, 1200 MW of additional GT units in 1998–2000, and 1400 MW of additional GT units in 2000–2007.
4. Florida Power and Light planned to meet its capacity needs beyond 2000 by acquiring two 430 MW CCGT units and an existing 646 MW coal-based unit from the Southern Company.

Switching to low-sulfur coal was the primary approach taken by these utilities to reach compliance with the 1990 Amendments to the Clean Air Act. Natural gas turbines captured most of the new capacity market.

Retention: Prevention rather than end-of-pipe treatment

The government was looking at end-of-pipe solutions (scrubbers), but the market introduced a pollution prevention remedy at dramatically lower cost. Utilities simply reduced the amount of pollutant at the source either by switching to low-sulfur coal or converting to natural gas burners.

Low-sulfur coal rather than scrubbers for old plants

Nationally, out of the 65,000 MW of the 1990 Clean Air Act Amendments' Phase I impacted facilities, only about 14,000 MW involved the installation of limestone wet flue gas desulfurization systems. The remainder, or 78 percent, switched instead to low-sulfur coal. Total coal deliveries to utilities were steady from 1986 to 1993 and deliveries of bituminous coal did not increase, but deliveries of sub-bituminous coal grew at a rate of more than 3 percent per year (U.S. Department of Energy, 1994b).

Natural gas for new power production

Utilities added little new coal-fired capacity and had plans to add little in the future. For new power production, the trend was to switch to cleaner fuels rather than use end-of-pipe treatment. The utilities moved from coal to natural gas. As of 1990, there were 35 coal-fired units (16,380 MW) scheduled to come on line in the United States over the next 10 years, and 203 natural gas-fired units (18,475 MW). By 1993, the number of coal-fired units had dropped to 16 (6919 MW), while the number of gas-fired units had increased to 278 (28,516 MW). These results are summarized in Table 4.

Increasingly, utilities were filling new power generation needs by opening projects up for bids and treating their own power generation subsidiaries at arm's length, since construction delays and huge cost overruns had plagued so many of them and contributed to wide electricity price disparities in the United States in prior decades. Independent power producers (IPPs) played an

Table 4. Planned U.S. plant additions[a] (in the next 10 years), by energy source and year

	New units		New megawatts	
	As of 1990	As of 1993	As of 1990	As of 1993
Total	421	480	48,189	44,502
Coal	35	16	16,380	6,919
Natural gas	203	278	18,475	28,516
% Coal	8.3%	3.3%	34.0%	15.6%
% Gas	48.2%	57.9%	38.3%	64.1%

[a]Adapted from U.S. Department of Energy (1994d).

important role in the market share gain gas turbine generators achieved (U.S. Department of Energy, 1993a, 1993b). The burden of environmental regulations was being transferred to the IPPs that won the bids, thus reducing the utilities' risk.

International markets for scrubbers

With low-cost alternatives to conventional WFGD systems such as clean coal available, sales of scrubbers in the United States in 1995 were very slow. Competition in the United States increasingly was narrowing to a contest between low-sulfur coal for old plants and natural gas for new ones. SO_2 scrubbers, when not mandated, were not a viable option unless some special circumstance prevailed. The international market, however, was relatively healthy since Europe and Japan did not have the option of switching to low-sulfur coal.

In Western and Central Europe, acid rain problems were greater than in the United States. Basic industry—centered in a triangle comprising parts of Poland, the Czech Republic, and Slovakia—used very low-quality, high-sulfur coal or lignite, resulting in acid rain damage to forests throughout the area and beyond. Acid rain was having a greater impact on European forests and lakes than in the United States. Poland, the Czech Republic, and Slovakia burned very dirty 'brown' coal without adequate pollution controls. German forests also suffered significant damage. South Korea was developing similar problems and was just as aggressive in finding solutions to these problems. Since outside the United States low-sulfur coal was not as readily available, the market for WFGD was strong and projects were under way or being planned in many parts of Europe, Asia, and elsewhere (Mcilvaine Company, 1995b).

The demand for new generating capacity worldwide also was strong, with various projections ranging from 629,000 MW to 820,000 MW to be installed during the period from 1994 to 2003. Much of this new demand would be met by coal and thus projected demand for WFGD outside the United States was $4.3 billion (Mcilvaine Company, 1995a). From 1985 to 1995, conventional limestone WFGD systems came down in real price. Technological development centered on speeding up the limestone feeding system, thereby enabling designers to reduce the size of the unit. Overall advances were spurred by sales opportunities abroad and stiff competition for these opportunities.

SYNTHESIS

To recapitulate, the thesis is of a teleologic logic of goal formulation, implementation, evaluation, and revision in government. The antithesis is an evolutionary logic of variation, selection, and retention in markets. The confrontation between these logics and their synthesis yields a unique resolution not anticipated by either. The route to change is dialectical. Opposing government and market forces yield unique and unintended outcomes.

The way in which competitive forces unfold is hard for the government to predict. The U.S. government tended to favor an add-on device because it wanted to maintain the status quo. It did not want to appear as if it was favoring western coal interests over eastern and midwestern coal interests. However, market forces were more dynamic than these government desires. Though delayed by it, the market pushed beyond the government's vision of reduction by add-on devices and went for the more efficient solution of lower sulfur-burning fuel as an input to production. These innovations came at a critical time in the evolution of the utility industry. Deregulation, and the consequent need to reduce costs, forced the industry to find solutions to Clean Air regulations at lower costs than envisioned when legislation was forged.

Cost issues for the utilities were complex. As our analysis suggests, each case was highly peculiar to the operating characteristics of the system: what the demand profile was like, what peak demand was like and for how long it lasted, what kind of coal was being used and what its characteristics were (sulfur and ash content, etc.), how boilers were designed, what were the labor costs, whether there were space limitations for installing scrubbers, and so on. In general, the changes that took place, though more in conformance with the principles of prevention than the government intended, were also incremental in nature and less burdensome on the utilities than anticipated. While making the switch to Powder River Basin coal for an existing boiler was not cost free and not all boilers were able to make the switch at low cost, this type of change was much less difficult for a utility to make than installing scrubbers.

MICRO-DEVELOPMENTS IN PROPRIETARY TECHNOLOGY

At the nexus of the U.S. story is not just the electric utility industry, challenged both by deregulation and increasing competition and by new environmental constraints, but the industry's key suppliers, competing not only among themselves in each sector but competing sector against sector to provide the best and lowest-cost solutions to meet these challenges. These suppliers combined and recombined assets and acquired distinctive competencies that allowed them to capture the rents available from the Clean Air Act's passage.

The 1990 amendments unleashed competitive forces among the suppliers of coal, the developers of natural gas systems, and the providers of air pollution control technologies. The ability of any one company to achieve sustained competitive advantage in this setting was difficult. Two companies, BN and GE, did seize the opportunity. They had a keen sense for products that would add value to their utility customers. They put themselves in a position of not only recognizing this potential but acting on it. Their routes to competence acquisition differed, however, with BN primarily looking outside in external markets for talents, technologies, and ideas (See Figure 1) and GE taking mostly an inside track. We say mostly since all competence acquisition involves activity at both levels.

Looking outside

BN sought to position itself as the premier hauler of coal. It collaborated with suppliers, customers, and other external entities to deliver coal at the lowest cost possible. Created in 1970, the company was the result of the merger of a number of the nation's oldest and most well-known railroads. The 1960s and 1970s had been a period of widespread financial distress in the railroad industry (Reinhardt, 1991). In 1988, BN took the risky and controversial step of spinning off almost all its nonrailroad assets. About a third of its total revenues then came from hauling coal. It transported 144 million tons of coal, with coal being almost 50 percent of the freight it handled. About 90 percent of this coal came from the Powder River Basin.

Transportation costs were a large fraction of the delivered price of low-sulfur coal. Lowering these costs was not a trivial undertaking. There were no waterways for the transport of this coal as there was for eastern and midwestern coal. The coal was located in remote parts of the country far from established markets. The railroad industry vetoed a proposal to build a coal slurry pipeline that would have had to run over property for which it owned the right of way. For western coal to be a viable option, new track—heavier to endure the pounding from coal—had to be constructed.

During the 1970s, the position of the Interstate Commerce Commission (ICC) was that the railroads should build the lines together and share the costs. BN and the Chicago and Northwestern (C&NW) railroad jointly constructed a line to the Powder River Basin making the largest investment in new track by U.S. railroads since the

1930s. However, C&NW was in financial difficulty (Bailey and Benson, 1989) and was unable to meet its share of the costs. BN, as a result, did not allow C&NW to use the track for a period of over 5 years. During this time, BN continued to invest heavily in upgrading track, and it saw its traffic in coal from the Powder River Basin surge dramatically. For several years, BN enjoyed high monopoly rates until the Interstate Commerce Commission (ICC) stepped in after protests from BN's customers (Reinhardt, 1991).

C&NW then joined with the Union Pacific railroad (which now owns C&NW) to offer competing service. In 1984, competition was unleashed, rates dropped, and the rails started to cut operating costs and to improve efficiency. To meet the competition from C&NW, BN invested heavily in new technology to lower operating costs. It experimented with different train configurations and operating tactics to improve coordination of train movements and achieve higher utilization rates for cars and locomotives. It brought together the technology from many sectors: computers and automation for better scheduling and traffic controls (a major problem given the enormous volume of traffic involved), electric and diesel motor technologies for more powerful locomotives at lower cost (General Motors and GE were the suppliers), better coal hoppers, and improved tracks.

The end result was that the transportation costs to deliver a ton of Powder River coal to distant utility markets were lower than they were before 1984; in current dollars, prices in 1994 fell by more than 40 percent (U.S. Department of Energy, 1994b).The continued growth the railroads saw for western coal stimulated additional improvements. BN believed that a new, more powerful locomotive with AC electric traction motors would lower operating costs even more (Grinstein, 1993). In 1994, it took the unprecedented step of purchasing 404 of these locomotives (Burlington Northern, 1994). As it owned at the time only 583 locomotives, this investment was massive. BN was seeking to create a 'Trough Train' made up of extended cars of 13 sections that would increase coal-carrying capacity by 30–40 percent. It also was working with its suppliers to redesign doors for easier unloading, to have a more aerodynamic exterior to reduce wind resistance, and to use a lighter aluminum frame to improve efficiency (Burlington Northern, 1994). The company's vision was to market low-sulfur Powder River Basin coal in the Eastern United States, Canada, the Pacific Rim, Europe, and Mexico. Thus, the challenge was to drive prices down as much as it could. As Table 2 shows, its vision had become a reality in some parts of the United States.

In 1994, coal transport generated 33 percent of BN's rail revenues and 19 percent of Union Pacific's (UP); BN and UP reached as far east as Chicago to the north and St Louis and Memphis to the south. In 1995 UP announced an offer to purchase Southern Pacific. It wanted to own a rail line to transport coal to the east. BN, meanwhile, expressed its intention to purchase the Santa Fe Railroad for the same reason. The stretch of these railroads, thus, was truly immense. In interviews we were told of a midwest utility at a mine mouth, whose state was willing to subsidize a scrubber to save miners' jobs, but which opted instead for the delivery of coal from the Powder River Basin. The acquisitions the railroads made created two large and dominant carriers in the western part of the United States in fierce competition with one another for the coal market in the United States and beyond and capable of supplying coal at competitive prices to utilities that traditionally had not used western coal.

Harmonizing what is known

BN's accomplishments were to a large extent a result of external search. Rather than looking outside, GE was in the position of harmonizing what was known internally. It is a huge company with many divisions (aircraft engines, power systems, electrical distribution and control, information services, motors and industrial systems, and transportation). For years, it had been concerned about its ability to coordinate its diverse activities to effectively meet customer demand. The high cost of exchanging information among divisions was believed to be an impediment to change (see Galunic and Rodan, 1997). Separate organizational problems, solutions, agendas, and coalitions prevented trust and cooperation from developing. To 'get at the learning opportunities that abound in, and around, a multi-business global company,' GE tried 'to deal with the myriad boundaries that were impeding the generation and transfer of ideas' (General Electric, 1997: 4). The culture and values that it tried to instill were based on the principles of 'being open to ideas from anywhere,' 'having the confidence to involve everyone,' and 'behaving in a boundaryless fashion.'

> the desire, and the ability, of an organization to continuously learn from any source, anywhere—and to rapidly convert this learning into action—is its ultimate competitive advantage (General Electric, 1997: 4).

GE went after boundaries that impeded innovation with an initiative called 'Work-Out.' Management appraisal and compensation systems were used as 'critical enablers' to create a 'horizontal learning' organization that could develop and apply knowledge across diverse global business units.

As applied to natural gas, this initiative was very important. As well as having one of the world's largest and most diversified industrial research laboratories (in Schenectady, New York), GE historically had strong divisions in aircraft engines, power systems, and information services. It used these strengths to develop a low-cost, highly thermally efficient technology for burning natural gas. The independent technological developments that helped open the market for these systems were: constant technological advances in jet engine design and manufacture, fostered by a high level of both military spending and spending for commercial aircraft, that enabled GTs and CCGTs to be successfully adapted for electric power generation; and failing natural gas costs, due to high-performance PCs and workstations capable of processing 3D seismic data and to advanced drilling techniques such as horizontal systems. Low gas prices were a byproduct of the need to find petroleum more cheaply and of explosive innovations in microprocessors and memory devices that made new drilling methods possible. In both turbine technology and gas exploration, innovation came from incremental steps nurtured by countless innovations in other areas from better materials to computer-aided design and analysis.

GE focused on competing for the new power generation market as a spin-off of its jet engine technology. Because of its experience in jet engine technology and power production systems, it took the lead and captured the early rents. It increased investment in turbine technology at the same time that new reserves of natural gas were being discovered to fuel the expected growth in demand. However, it quickly faced very stiff competition from WX, ABB, and Siemens, who forged partnerships with the other jet engine suppliers.

GE's market share of gas turbine generators between 1990 and 1995 had been as high as 80 percent. It achieved this dominance by being the first company to introduce a CCGT system with thermal efficiencies of 55 percent. It benefited greatly from being a long-time manufacturer of jet engines, while its competitors had to form strategic alliances with Pratt & Whitney and Rolls Royce to gain proprietary technology. Most of its competitors, however, ultimately caught up, bringing GE's worldwide and U.S. market share down to about 50 percent in 1995. Most of the producers were slashing prices to get orders, as the industry had over-capacity and its growth had started to slow.

After the passage of the Clean Air Amendments, the four fiercely competitive major manufacturers of turbines, led by GE, worked to increase thermal efficiency. Top of the line Asea Brown Boveri (ABB) and Westinghouse (WX) models reached 57–58 percent efficiencies, while GE announced a new 60 percent thermally efficient model in 1995. Because the efficiency of coal-fired systems rarely exceeded 33 percent, the operating costs of a 60 percent efficient CCGT were roughly equal to those of coal. The capital costs were substantially lower and natural gas plants had clear environmental advantages. Natural gas, though it could not replace existing coal-fired plants, was highly competitive in the new power production market.

GE also led the way in scrubber technology (see Table 5).[2] Its major competitors for this mar-

[2]WX, a diversified company, was smaller and less successful than GE. Its financial services division, which had been discontinued, was beset with bad loans that put the company under stress and near bankruptcy. Profitability was dragged down by its Energy Systems division, which serviced nuclear power markets. WX had advertised 'The World's Largest and Most Efficient 60 Hz Industrial Gas Turbine' with an output of 230 MW (single turbine), 38.5 percent thermal efficiency, and producing (when in tandem with a steam generator and HRSG) the highest efficiency in the industry of about 58 percent. However, GE's turbine, which it announced in 1995, was able to surpass this level of efficiency. ABB, the Swedish company, became the world's largest manufacturer of electrical energy-related equipment with the purchase of WX's

Table 5. Installed base of wet flue gas desulfurization products (WFGD) and market shares of major companies[a]

World wide	46,809 MW
United States	18,839 MW
Germany	7,455 MW
Japan	5,925 MW
Italy	2,600 MW
Netherlands	2,585 MW
United Kingdom	2,000 MW
France	1,800 MW
Poland	1,440 MW
Taiwan	1000 MW
Finland	1000 MW
Austria	850 MW
Czech Republic	630 MW
Slovenia	275 MW
Slovakia	220 MW
Brazil	60 MW

Domestic WFGD market 1981–93		Worldwide WFGD market 1981–93	
GE	30%	GE	26%
ABB	30%	ABB	3%
B&W	30%	B&W	12%
Other	10%	SHU	8%
		MHI	6%
		D-B	6%
		Other	26%

[a]Adapted from internal General Electric marketing documents.

ket were ABB and Babcock & Wilcox (B&W). ABB owned Combustion Engineering, and B& W was a subsidiary of McDermott International. Mitsubishi Heavy Industries (MHI) and Deustche-Babcock (DB) also had some market share. All these competitors were working on advanced systems. GE, for instance, had a system which replaced limestone with ammonia and yielded a byproduct of granulated ammonium sulfate, a high-value-added fertilizer. The capital costs of the company's proprietary patented process were about 30 percent more than a limestone/gypsum system and the SO_2 removing capabilities were similar. Unlike gypsum byproduct, which was low priced and whose sale did not provide a positive cash flow, granulated ammonium sulfate could fetch a high price. The cost profile was favorable provided a growing market for the byproduct developed. A difficulty was that utilities did not want to enter the fertilizer production business, where they had no experience and which was subject to volatile pricing.

Other air pollution control devices, that could remove substantial percentages of SO_2, NO_x, and many HAPs, were in the testing and development stages. ABB Environmental Systems and Babcock & Wilcox had technologies that were being tested at Ohio Edison facilities (U.S. Department of Energy, 1994c). Both companies participated in DOE's Clean Coal Technology program, while GE did not become involved, preferring an internal route to development to this complicated entanglement. GE was big enough to go it alone and the unique culture and values it tried to instill of permeable organizational boundaries, continuous information exchange, and the melding of innovations from many sources within the company made doing so possible.

Combining components in new ways

Though their routes to competence acquisition were different, BN and GE did share one thing. They both had an uncanny ability to integrate innovations from diverse sources (see Figure 1) in order to create unique, though somewhat fleeting, competitive advantage. They both had a capacity for synthesis (Usher, 1954; Kash, 1989)—an ability to combine information, knowledge, experience, and materials in ways not previously combined and to create products and processes with characteristics not formerly available. This capacity enabled them to carry out tasks hitherto not thought possible such as delivering Powder River Basin coal in a cost-effective manner to the southeastern portion of the United States or achieving 60% thermal efficiencies in combined cycle gas generation. What stimulated their doing this was the dialectical process we have described—a government that defined goals that went beyond state of the art and a market process that encouraged intense

transmission and distribution business and the U.S. engineering firm of Combustion Engineering in the 1980s. The remainder of its revenues were in environmental controls, mass transit, and industrial equipment. Since 1990, its growth had been negligible because of a worldwide slump in the industrial capital equipment. Its most advanced CCGT, boasting an efficiency of 57–58 percent, was just behind WX. Siemens, the well-known German company, was a leader in a range of technologies for electrical engineering and electronics systems. Like ABB, however, Siemens had a difficult time in the 1990s due to the economic slowdown in Europe. Siemens and ABB, as European companies, did not have flexible labor forces, and preserved market share by slashing prices to maintain employment.

competition. The interaction of system-wide pressure from government and markets with competence acquisition by the companies hastened integration of diverse knowledge and skills. Each by itself—the dialectical process or company action—could not have induced change of this magnitude, but together these elements had the power to unleash unanticipated and unique results.

LESSONS: THE DIALECTICAL ROUTE TO CHANGE

In this paper, we combine dialectics, a focus on conflict between entities, with teleology and evolution, an emphasis on logics within entities. Bringing together theories of conflict and synthesis with theories of purposeful enactment and competitive selection provides a missing category (see Table 6) in the studies Van de Ven and Poole (1995) list. Van de Ven (1993a, 1993b) maintains that innovation emerges not just from micro-developments in proprietary technology but from the creation of macro-industrial infrastructures that arise out of the decisions of public and private actors over extended periods. Numerous events pertaining to the development of this infrastructure take place over time that both facilitate and constrain change. In accord with this theory, our study suggests that system-wide properties, such as long-standing elementary and opposing logics in societal forces like governments and markets, contribute in significant ways to the creation and acquisition of new competencies by business firms. These forces channel and direct the paths that the acquisition of new competencies take. The state of creative tension, the dialectic in which they exist, helps to forge new and unanticipated syntheses that can either forward or retard social progress and enhance or detract from economic benefit.

Table 6. Typology of organizational change and development processes[a]

	Teleology	Dialectics	Evolution
	Purposeful enactment	Conflict and synthesis	Competitive selection
Single-motor theories			
Teleology (March and Simon, 1958)	Yes	No	No
Dialectics (Benson, 1977)	No	Yes	No
Evolution (Hannan and Freeman, 1977)	No	No	Yes
Dual-motor theories			
Group conflict (Coser, 1956)	Yes	Yes	No
Community ecology (Astley, 1985)	No	Yes	Yes
Punctuated equilibrium (Tushman and Romanelli, 1985)	Yes	No	Yes
Tri-motor theories			
Competency acquisition (this paper)	Yes	Yes	Yes

[a]Adapted from Van de Ven and Poole (1995).

In government, the command framework of setting fixed goals and holding industry accountable can prevail. In markets, a less definitive process may be at work. No other fixed goals exist other than opportunism and a general desire to economize and achieve economic gain. The norm is to experiment and rely on trial and error decision making, with prices being the main, and often decisive, piece of information. The intricacies of market relationships have to be appreciated, however. Competition played an overwhelmingly important role in our case, but so too did specialization, another feature noticed by such great and early observers of markets as Adam Smith. Free, unencumbered markets help make this specialization possible.

In our case, markets, while not perfect, did operate with many levels of competition. There was competition between fuels—coal and natural gas, between types of coal, between different ways of generating electricity, and between different scrubbers. The utilities who needed a means by which to cope with the Clean Air Act had long been treated as a natural monopoly and removed from competition, but increasingly this status was changing and they were facing a more competitive environment as well. Owners of coal and natural gas competed, as did those that transported the fuels, made the technology to generate electricity from them, built the power plants (e.g., IPPs), and manufactured the scrubbers.

Thus, government goals, monitoring of progress, and revising of goals in light of what was learned were the thesis. The antithesis was market competition. It generated successive variations for selection and retention. Synthesis was a solution for electric generation in the United States which relied mostly on pollution prevention. The dialectic helped bring this win–win solution, that improved the environment and limited economic losses, into existence, but it was not the dialectic alone. The macro-process of system-level change was abetted by a micro-process of firm-level change. Also needed were individual firms which took advantage of the opportunities offered. The macro-system changes channeled and directed the paths that the acquisition of new competencies took at the *firm level*.

Implications for research

The case study methods we used to reach these conclusions have their limitations. System-wide properties form agglomerations of rigidities as well as capabilities that inhibit as well as facilitate competence acquisition. In our case, their capacity for facilitation overwhelmed their capacity for inhibition, but we can imagine other cases where their inhibiting characteristics would override their facilitating properties. Thus, the results we reached may be idiosyncratic and not generalizable beyond this case. Given these limitations, what implications are there for research?

First, the framework offered here differs from that proposed by prior process theorists of change and competency acquisition. It looks at competency acquisition as a combination of macro-system changes and micro-system developments in proprietary technology. It unites external elements in the context of the firm—both the political/legal environment and the economic environment—with elements internal to the firm, the capacities for *looking outside* for talent, technology, and ideas and for *harmonizing* what is known internally. This type of analysis is unique. It does not narrowly focus on the economic environment as do theories of induced change (Ruttan and Hayami, 1984). It also fully incorporates political and legal factors unlike evolutionary theories (Burgelman, 1984), path dependency, and theories of diffusion (Rogers, 1983). Moreover, it opens the 'black box' of change and begins to examine internal organizational processes. Though this type of analysis shares a great deal with the kind that Pettigrew (1985) has carried out, it is different in that it starts with the firm's context and moves from the context to firm-level decision-making, rather than the other way around.

Second, the framework used in this analysis, though interpretive, can be translated into the language of normal science. The interpretive framework of setting, complication, resolution, release, and completion (Bryson and Hostager, 1986), which provides coherence to how the story evolved, is as much in conformity with literary theory (Burke, 1945) and the philosophy of history as it is with normal science. Translating this interpretive framework into the language of normal science, the dependent variable would be competence acquisition. In the case of pollution prevention in electric generation, this variable is the capacity to meet the demands of new environmental requirements by changing fuels at the source rather than relying on expensive and unwieldy add-on devices (scrubbers). This capacity is stimulated by a combination of external, macro-system factors residing in the political/legal and market contexts, and by a combination of internal micro-system factors residing in the firm.

Thus, in normal science terms, this case yields the following hypothesis:

1. the more government sets up a teleological structure of goals and end points, the more likely there is to be competence acquisition by firms;
2. the more the market fits an evolutionary pattern of variation, selection, and retention, the more likely there is to be competence acquisition by firms;
3. the more firms search for talent, technology, and ideas outside themselves, the more likely they are to acquire competencies when government sets up a teleological structure and the market fits an evolutionary pattern; and
4. the more firms can harmonize what they learn externally with what they know internally, the more likely they are to acquire competencies when government has this structure and the market this pattern.

Further research might turn our interpretive theory into a variance theory and test it in a different context to determine how generalizable the results are. The challenge would be to find the right setting for such a test, to operationalize the variables, and to determine how in combination they produce the predicted results.

Implications for practice

For government the implications of these findings are that it should set goals, take actions to reach them, monitor progress, and modify what it does based on what it learns. Markets need to approach ideal conditions, and when they stray from these conditions government needs to correct them. Government should try to assure freedom to enter and forge relationships, many buyers and sellers, mobility of resources, and good information about options. The more a society approaches such ideals, the greater the degree to which individual firms should have opportunities to develop distinct competencies. A key is that the government has to provide the dialectical goad to accelerate market processes and it has to guarantee that conditions approaching pure markets exist.

These conditions are the necessary, but not sufficient conditions, for competence acquisition. Another critical condition is that firms take advantage of the opportunities. For firms the implications of our research are the two routes to seizing these opportunities. One is an external path of purchasing talent, technology, and ideas in outside markets. It was illustrated by BN. Another is an internal route of harmonizing what a company knows inside the organization. It was illustrated by GE. Both paths were used by both companies, but BN relied more on the external processes and GE more on the internal ones.

Acquiring a distinctive competence involves both these external and internal elements. It is a long-term accumulation process made up of socially complex learning where coordination across organizational boundaries and bargaining about internal roles play a part (Russo and Fouts, 1996). This process consists of novel problem solving, looking toward the future, and positioning and repositioning the organization in accord with changing economic, political, technical, and social conditions. It means elaborating on knowledge and techniques which derive from relationships with outside entities and harmonizing them with internal organizational capabilities and resources. Especially for a firm as large and as well endowed as GE, internal harmonization is as viable and important a route to strategic advantage as looking outside. Competence acquisition, then, can be derived from both market and hierarchical processes (Williamson, 1996). It can be both purchased and produced. External and internal paths to its acquisition play an important role (Godfrey and Gregersen, 1997).

In sum, competency acquisition is a social process consisting of complex learning across organizational boundaries. It depends on competitive markets and government. It relies on there being many innovations in different sectors and on corporate managers who gain competitive advantage by melding these innovations in ways that meet social needs. The creative tension between government and markets often drives change. The process of competency acquisition requires that many elementary social forces operate at very high levels, a condition which cannot be expected in all situations. It also requires that managers be ready to seize the opportunities offered by these dialectical forces.

ACKNOWLEDGEMENTS

This paper was prepared with assistance from the Management Institute for Environment (MEB) and Business under a grant from the Environmental Protection Agency (EPA). The authors take full responsibility for the views expressed, and these views should not be construed in any way as representing either those of the MEB or the EPA. Ben Davis served as a research assistant on this project. Michael Russo commented on an earlier draft. Anonymous referees for this journal were very helpful in providing insights and guidance. Sumit Mujamdar pointed us to sources on the utility industry of which we had been unaware. Vern Ruttan helped deepen our understanding of the innovation literature.

REFERENCES

Abbott, A. (1990). 'A primer on sequence methods', *Organization Science*, **1**(4), pp. 375–392.

Abbott, A. (1992). 'From causes to events', *Sociological Methods and Research*, **20**(4), pp. 428–455.

Ackerman, B. and W. Hassler (1981). *Clean Coal/Dirty Air*. Yale University Press, New Haven, CT.

Afuah, A. (1998). *Innovation Management*. Oxford University Press, New York.

Anderson, J., D. Brady and C. Bullock (1978). *Public*

Policy and Politics in America. Duxbury Press, North Scituate, MA.
Amit R. and P. Schoemaker (1993). 'Strategic assets and organizational rent', *Strategic Management Journal*, **14**(1), pp. 33–46.
Astley, W. (1985). 'The two ecologies: Population and community perspectives on organizational evolution', *Administrative Science Quarterly*, **30**, pp. 224–241.
Bailey, F. and G. Benson (1989). *Trains: The Magazine of Railroading*, November, whole document.
Barney, J. (1986a). 'Organization culture: Can it be a source of sustained competitive advantage?', *Academy of Management Review*, **11**(3), pp. 656–665.
Barney, J. (1986b). 'Strategic factor markets: Expectations, luck, and business strategy', *Management Science*, **32**(10), pp. 1231–1241.
Barney, J. (1991). 'Firm resources and sustained competitive advantage', *Journal of Management*, **17**(1), pp. 99–120.
Benson, J. (1977). 'Organizations: A dialectical view', *Administrative Science Quarterly*, **22**, pp. 1–21.
Bernstein, M. (1955). *Regulating Business by Independent Commission*. Princeton University Press, Princeton, N.J.
Braybrooke, D. and C. Lindblom (1970). *Strategy of Decision*. Free Press, New York.
Brumagim, A. (1994). 'A hierarchy of corporate resources'. In J. Dutton and P. Shrivastava (eds), *Advances in Strategic Management*, Vol. 10A. JAI Press, Greenwich, CT, pp. 81–112.
Bryner, G. (1987). *Bureaucratic Discretion: Law and Policy in Federal Agencies*. Pergamon Press, New York.
Bryson, J. and T. Hostager (1986). 'Poetics and strategic management', Discussion Paper #59, Strategic Management Research Center, University of Minnesota.
Burgelman, R. (1984). 'Strategy making and evolutionary theory', Stanford University Research Paper No. 755.
Burke, K. (1945). *A Grammar of Motives*. Prentice-Hall, New York.
Burlington Northern (1994). *1OK Report*. Securities and Exchange Commission, Washington, DC.
Chakravarthy, B. (1996). 'Competing in the infocom space: In search of a new strategy framework', unpublished manuscript, University of Minnesota, Carlson School of Management, Minneapolis, MN.
Chamberlain, N. (1968). *Enterprise and Environment*. McGraw-Hill, New York.
Collins, J. C. and J. I. Porras (1994). *Built to Last: Successful Habits of Visionary Companies*. Harper Business, New York.
Coser, L. (1956). *The Functions of Social Conflict*. The Free Press, New York.
Dahl, R. and C. Lindblom (1976). *Politics, Economics, and Welfare*. University of Chicago Press, Chicago, IL.
Davis, K. (1977). *Discretionary Justice*. University of Illinois Press, Urbana-Champaign, IL.
Dye, T. (1978). *Understanding Public Policy*. Prentice-Hall, Englewood Cliffs, NJ.
Eisenhardt, K. (1989). 'Building theories from case study research', *Academy of Management Review*, **14**(4), pp. 532–550.
Fiorino, D. (1995). *Making Environmental Policy*. University of California Press, Berkeley, CA.
Freeman, H., T. Harten, J. Springer, P. Randall, M. Curran and K. Stone (1992). 'Industrial pollution prevention: A critical review', *Journal of the Air and Waste Management Association*, May, pp. 618–656.
Friendly, H. (1962). *The Federal Administrative Agencies: The Need for Better Definition of Standards*. Harvard University Press, Cambridge, MA.
Friedman, M. (1972). *Capitalism and Freedom*. University of Chicago Press, Chicago, IL.
Friedman, M. (1979). *Free to Choose*. Avon Books, New York.
Galunic, C. and S. Rodan (1998). 'Resource recombinations in the firm', *Strategic Management Journal*, forthcoming.
Geffen, D. and A. Marcus (1995a). 'Competitive implications of environmental regulation in the electric utility industry', Management Institute for Environment and Business, World Resources Institute (WRI), Washington, DC.
Geffen, D. and A. Marcus (1995b). 'A case study of Carolina Power and Light', Management Institute for Environment and Business, World Resources Institute (WRI), Washington, DC.
General Electric (1997). *Annual Report*. Securities and Exchange Commission, Washington, DC (Internet site http://www.ge.com/annual96/share.htm#growth).
Gersick, C. (1991). 'Revolutionary change theories: A multilevel exploration of the punctuated equilibrium paradigm', *Academy of Management Review*, **16**, pp. 10–36.
Gioia, D. and E. Pitre (1990). 'Multiparadigm perspectives on theory building', *Academy of Management Review*, **15**(4) pp. 584–600.
Gladwin, T. (1993). 'The meaning of green'. In J. Schoft and K. Fischer, (eds.), *Environmental Strategies for Industry*. Island Press, Washington, DC, pp. 37–61.
Godfrey, P. and H. Gregersen (1997). 'Where do resources come from? A model of resource generation', *Academy of Management Proceedings*, Boston, MA, pp. 21–25.
Gollop, F. and M. Roberts (1983). 'Environmental regulations and productivity growth: The case of fossil-fueled electric power generation', *Journal of Political Economy*, **91**(4), pp. 654–674.
Green K. and I. Miles (1996). 'A clean break? From corporate research and development to sustainable technological regimes'. In R. Welford and R. Starkey, (eds.), *Business and the Environment*. Taylor & Frances, Washington, DC, pp. 129–144.
Grinstein, G. (1993). C.E.O. of Burlington Northern Inc., Interview. *Siemens Review*, May, reprint courtesy of Burlington Northern.
Hall, R. (1993). 'A framework linking intangible resources and capabilities to sustainable competitive advantage', *Strategic Management Journal*, **14**(8), pp. 607–618.
Hamel, G. and C. K. Prahalad (1994). *Competing for*

the Future. Harvard Business School Press, Boston, MA.

Hannan M. and F. Freeman (1977). 'The population ecology of organizations', *American Journal of Sociology*, **82**, pp. 929–964.

Hart, S. (1995). 'A natural resource based view of the firm', *Academy of Management Review*, October, pp. 986–1014.

Henderson, R. and I. Cockburn (1994). 'Measuring competence? Exploring firm effects in pharmaceutical research', *Strategic Management Journal*, Winter Special Issue, **15**, pp. 63–84.

Holmes M. and S. Poole (1990). 'Longitudinal analysis'. In B. Montgomery (ed.), *Studying Interpersonal Interaction*. Guilford, New York, pp. 286–302.

Jaffe, A., S. Petersen, P. Portney and R. Stavins (1995). 'Environmental regulation and the competitiveness of U.S. manufacturing', *Journal of Economic Literature*, **33**, pp. 132–163.

Jones, C. (1970). *An Introduction to the Study of Public Policy*. Duxbury Press, Belmont, CA.

Jones, C. (1975). *Clean Air: The Policies and Politics of Clean Air*. University of Pittsburgh Press, Pittsburgh, PA.

Kash, D. (1989). *Perpetual Innovation*. Basic Books, New York.

Kogut, B. and U. Zander (1992). 'Knowledge of the firm, combinative capabilities, and the replication of technology', *Organization Science*, **3**(3), pp. 383–397.

Kuehn, S. (1993). 'Utility plans take shape for title IV compliance', *Power Engineering*, August, pp. 19–26.

Lado, A., N. Boyd and P. Wright (1992). 'A competency-based model of sustainable competitive advantage: Toward a conceptual integration', *Journal of Management*, **18**(1), pp. 77–91.

Lado, A. and M. Wilson (1994). 'Human resource systems and sustained competitive advantage: A competency based perspective', *Academy of Management Review*, **19**(4), pp. 699–727.

Landy M., M. Roberts and S. Thomas (1990). *The Environmental Protection Agency: Asking the Wrong Questions*. Oxford University Press, New York.

Lenz, R. T. (1980). 'Strategic capability: A concept and framework for analysis', *Academy of Management Review*, **5**(2), pp. 225–234.

Lindblom, C. (1977). *Politics and Markets*. Basic Books, New York.

Lowi, T. (1979). *The End of Liberalism*. Norton, New York.

March, J. and H. Simon (1958). *Organizations*. Wiley, New York.

Marcus, A. (1980). *Promise and Performance: Choosing and Implementing an Environmental Policy*. Greenwood, Westport, CT.

Marcus, A. (1981). 'Policy uncertainty and technological innovation', *Academy of Management Review*, **6**(3), pp. 443–448.

Marcus, A. (1984). *The Adversary Economy: Business Responses to Changing Government Requirements*. Greenwood-Praeger, Westport, CT.

Marcus, A. (1996). *Business and Society: Strategy, Ethics, and the Global Economy* (2nd ed.). Irwin Press, Chicago, IL.

McGrath, R. G., I. MacMillan and S. Venkatraman (1995). 'Defining and developing competence: A strategic process paradigm', *Strategic Management Journal*, **16**(4), pp. 251–275.

McIlvaine Company (1995a). 'Gold dust', *Air Pollution Management Newsletter*, July, No. 206, Northbrook, IL.

McIlvaine Company (1995b). 'FGD and DeNOx', *Air Pollution Management Newsletter*, May, No. 205, Northbrook, IL.

Merrill Lynch (23 August 1993). *U.S. Utility Industry: Measuring Competitive Risk*. Merrill Lynch, New York.

Miller, D. and J. Shamsie (1997). 'The resource-based view of the firm in two environments', *Academy of Management Journal*, **39**(3), pp. 519–543.

Mitnick, B. (1980). *The Political Economy of Regulation*. Columbia University Press, New York.

Nahapiet, J. and S. Ghoshal (1997). 'Social capital, intellectual capital, and the creation of value in firms', *Academy of Management Proceedings*, Boston, MA, pp. 35–39.

Nelson, R. and S. Winter (1982). *An Evolutionary Theory of Economic Change*. Harvard University Press, Cambridge, MA.

Pettigrew, A. (1985). 'Examining change in the long-term context of culture and politics'. In J. Pennings *et al.* (eds.), *Organizational Strategy and Change*. Jossey Bass, San Francisco, CA, pp. 269–317.

Porter, M. (1980). *Competitive Strategy*. Free Press, New York.

Porter, M. and C. Van der Linde (1995). 'Green and competitive: Ending the statement', *Harvard Business Review*, **73**(5), pp. 120–134.

Powell, T. (1995). 'Total quality management as competitive advantage', *Strategic Management Journal*, **16**(1), pp. 15–37.

Prahalad, C. K. and G. Hamel (1990). 'The core competence of corporations', *Harvard Business Review*, **69**(3), pp. 79–91.

Preston, L. and J. Post (1975). *Private Management and Public Policy*. Prentice-Hall, Englewood Cliffs, NJ.

Prudential Securities (30 May 1993). *Competitive Risk Study—Electric Utilities*. Prudential Securities, New York.

Prudential Securities (24 September 1995). *Competitive Risk Study—Electric Utilities*. Prudential Securities, New York.

Reed, R. and R. DeFillippi (1990). 'Casual ambiguity, barriers to imitation, and sustainable competitive advantage, *Academy of Management Review*, **5**(1), pp. 88–102.

Reinhardt, F. (1991). 'Acid rain: Burlington Northern, Inc. (A)', Harvard Business School, case 792018.

Rogers, E. (1983). *Diffusion of Innovations* (3rd ed.). Free Press, New York.

Russo, M. and P. Fouts (1996). 'A resource based perspective on corporate environmental performance and profitability', *Academy of Management Journal*, **40**(3), pp. 534–560.

Ruttan, V. (1997). 'Induced innovation, evolutionary theory, and path dependence: Sources of technical change', *Economic Journal*, **107**(444), pp. 1520–1530.

Ruttan, V. and Y. Hayami (1984). 'Toward a theory of induced institutional innovation', *Journal of Development Studies*, **20**(4), pp. 203–223.
Sansom, R. (June 1990). 'Energy Ventures Analysis, Inc.', *Review of Powder River Basin Coal Supply*, unpublished report.
Sanchez, C. (1995). 'Environmental regulatory impact and firm level innovation: A study of electric utilities' responses to the Clean Air Act Amendments of 1990', unpublished PhD dissertation, Department of Management, Southern Illinois University.
Selznick, P. (1957). *Leadership in Administration*. Harper & Row, New York.
Shrivastava, P. (October 1995). 'The role of corporations in achieving ecological sustainability', *Academy of Management Review*, pp. 936–960.
Stigler, G. (1965). *Essays in the History of Economics*. University of Chicago Press, Chicago, IL.
Torrens, L. and J. Plaft (January 1994). 'Electric utility response to the Clean Air Act Amendments', *Power Engineering*, pp. 43–47.
Tushman, M. and E. Romanelli (1985). 'Organizational evolution: A metamorphosis model of convergence and reorientation', *Research in Organizational Behavior*, **7**, pp. 171–222.
U.S. Department of Energy (1989). *Estimation of Coal Reserves by Coal Type, Heat, and Sulfur Content*. Energy Information Administration, DOE/E[A-0529, U.S. Government Printing Office, Washington, DC.
U.S. Department of Energy (1993a). *Electric Power Annual*. U.S. Government Printing Office, Washington, DC.
U.S. Department of Energy (1993b). *Electric Plant Costs and Power Production Expenses 1991*. Energy Information Administration, U.S. Government Printing Office, Washington, DC.
U.S. Department of Energy (1994a). *Clean Coal Technology Demonstration Program, Program Update 1993*. DOE/FE-0299P, March, U.S. Government Printing Office, Washington, DC.
U.S. Department of Energy (1994b). *Cost and Quality of Fuels for Electric Utility Plants 1993*. Energy Information Administration, DOE/EIA-01 91 (93), U.S. Government Printing Office, Washington, DC.
U.S. Department of Energy (1994c). *The Clean Coal Technology Program—Lessons Learned*. Assistant Secretary for Fossil Energy, DOE/FE-031 P, July, U.S. Government Printing Office, Washington, DC.
U.S. Department of Energy (1994d). *Inventory of Power Plants in the United States 1993*. Energy Information Administration, DOE/EIA-0095(93), December, U.S. Government Printing Office, Washington, DC.
U.S. EPA (1989). *The NAPAP Emissions Inventory* (Version 2). November, U.S. Government Printing Office, Washington, DC.
U.S. EPA (1992). *The 1990 Clean Air Act-Implementation*. Publication EPA430/F-92/016 & 01 9, December, U.S. Government Printing Office, Washington, DC.
Usher, A. (1954). *History of Mechanical Inventions* (2nd ed.). Harvard University Press, Cambridge, MA.
Van de Ven, A. (1993a). 'The emergence of an industrial infrastructure for technological innovation', *Journal of Comparative Economics*, **17**, pp. 338–365.
Van de Ven, A. (1993b). 'A community perspective on the emergence of innovations', *Journal of Engineering and Technology Management*, **10**, pp. 23–51.
Van de Ven, A. (1992). 'Suggestions for studying strategy process', *Strategic Management Journal*, Summer Special Issue, **13**, pp. 169–188.
Van de Ven, A., H. Angle and M. Poole (1989). *Research on the Management of Innovation*. Ballinger/Harper & Row, New York.
Van de Ven, A. and M. Poole (1995). 'Explaining development and change in organizations', *Academy of Management Review*, **20**(3), pp. 510–540.
Vig, N. and M. Kraft (eds.) (1990). *Environmental Policy in the 1990s*. CQ Press, Washington, DC.
Walley, N. and B. Whitehead (1994). 'It's not easy being green', *Harvard Business Review*, **72**(3), pp. 46–52.
Ward, B. (1979). *The Ideal Worlds of Economics*. Basic Books, New York.
Williamson, O. (1996). *The Mechanisms of Governance*. Oxford University Press, New York.
Winter, S. (1987). 'Knowledge and competence as strategic assets', *The Competitive Challenge*. Center for Research in Management, Berkeley, CA, pp. 159–184.
Wolf, C. (1988). *Markets or Governments*. MIT Press, Cambridge, MA.
Yin, R. (1989). *Case Study Research* (revised ed.). Sage, Newbury Park, CA.