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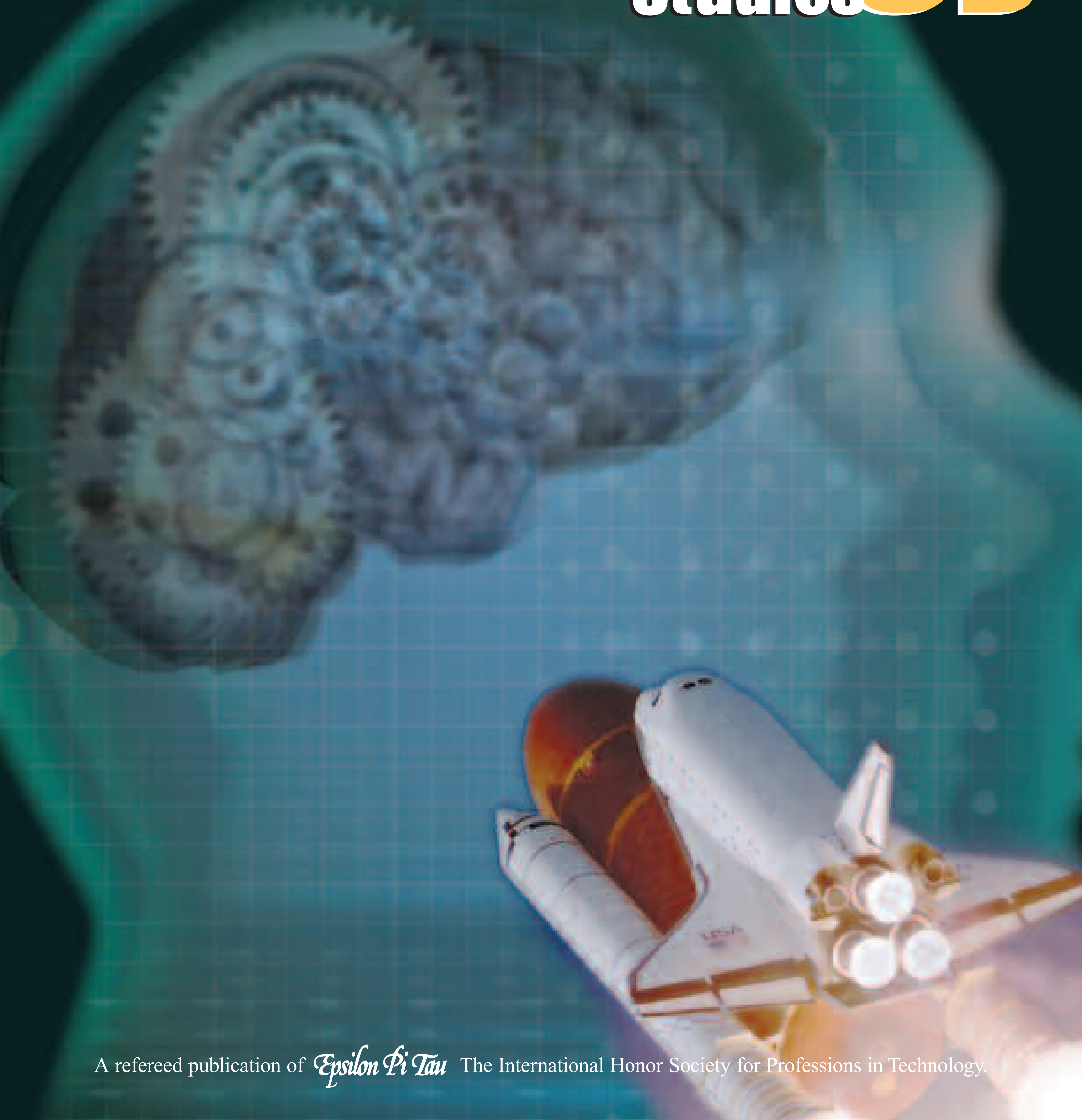

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The Pedagogy of Technology Integration

Mabel CPO Okojie, Anthony A. Olinzock, and Tinukwa C. Okojie-Boulder

Abstract

The problem of integrating technology into teaching and learning process has become a perennial one. Common excuses for the limited use of technology to support instruction include shortage of computers, lack of computer skill and computer intimidation. While these could affect the success of technology integration, it should be acknowledged that the degree of success teachers have in using technology for instruction could depend in part on their ability to explore the relationship between pedagogy and technology. The article shows that technology integration is narrowly perceived and that such a perception might hinder teachers' understanding of the scope of technology in education. Technology integration should be considered along with issues involved in teaching and learning. Such issues include developing learning objectives, selecting methods of instruction, feedback, and evaluation and assessment strategies including follow-up activities. Technology used for teaching and learning should be considered an integral part of instruction and not as an object exclusive to itself. Viewing technology integration from a wide perspective will provide teachers with the necessary foundation to implement technology into the classroom more successfully.

Introduction

This article discusses the narrow perception of the term "technology integration" and considers that such a perception is likely to result in a poor use of technology for instructional purposes. The scope of technology integration is examined with a view of showing its relationship with pedagogy**.** It should be noted that technology, which is used to facilitate learning, is part of the instructional process and not an appendage to be attached at any convenient stage during the course of instruction. Technology integration not only involves the inclusion of technical artifacts per se, but also includes theories about technology integration and the application of research findings to promote teaching/learning. It is not restricted to the mechanical application of various new computer hardware and software devices during the process of instruction. It should include the strategies for selecting the desired technologies, skill to demonstrate how the selected technologies will be used, skill to evaluate such technologies, as well as the skill to customize the use of such technological skills in a way that addresses instructional problems. The decision on the selection and use of technology for instruction should be made at the onset – when the instruction is being prepared, not in the middle or at the conclusion of the instruction. The objective and method of instruction including technology and outcomes of instruction should be specified at the planning stage. This point is illustrated by Diaz & Bontembal (2000):

> Using technology to enhance the educational process involves more than just learning how to use specific piece of hardware and software. It requires an understanding of pedagogical principles that are specific to the use of technology in an instructional settings…Pedagogy-based training begins by helping teachers understand the role of learning theory in the design and function of class activities and in the selection and use of instructional technologies. (pp. 2 and 6)

The relationship between instructional technology and pedagogical concepts is considered with a view of assisting teachers to recognize the impact of such a relationship in an educational inquiry. Technology integration is complex and is made up of processes of interconnected activities. The essence of this article is to explore those processes and to encourage teachers and those connected with technology integration to be reflective practitioners.

The Scope of Instructional Technology

Technology in education is commonly defined as a technical device or tool used to enhance instruction. According to Lever-Duffy, McDonald, and Mizell (2005) "educational technology might include media, models, projected and non-projected visual, as well as audio, video and digital media." These authors claim that some "educators may take a narrower view" and are likely to "confine educational technology primarily to computers, computer peripherals and related software used for teaching and learning" (pp. 4, 5). This definition does not take into consideration the pedagogical principles upon which the application of various technologies into educational inquiry are based. Such a definition is narrow because it isolates technology from pedagogical processes that it is intended to support. It does not connect instructional technology with the learning objectives, methods of instruction, learning style and pace of learning, assessment and evaluation strategies, including follow-up procedures. Specifically, technology integration should incorporate the technological skill and ability to use pedagogical knowledge as a base for integrating technology into teaching and learning. This implies that teachers should develop strategies to motivate students to keep them focused as the instruction progresses and to consider that different students prefer different learning styles and that they learn at different rates.

It is important that teachers use a variety of teaching methods, and students must be taught to use the newly acquired knowledge and skill as well as to critically evaluate and modify such knowledge. In other words, teachers should be able to engage students in an exploratory learning experience which is designed to stimulate thinking. According to Bruner (1966), the essence of teaching and learning is to help learners acquire knowledge and use the knowledge they have acquired to create other knowledge. Bruner eloquently states:

> To instruct someone ... is not a matter of getting him to commit results to mind. Rather, it is to teach him to participate in the process that makes possible the establishment of knowledge. We teach a subject not to produce little living libraries on that subject, but rather to get a student to think mathematically for himself, to consider matters as an historian does, to take part in the process of knowledge-getting. Knowing is a process not a product. (p. 72)

This can imply that teaching software skills without consideration to the basic foundation knowledge that justifies their application is likely to result in rote memorization of disjointed information on various technologies used. Ausubel (1978) claims that this type of teaching method is likely to lead to forgetfulness.

In a broad sense, technology integration can be described as a process of using existing tools, equipment and materials, including the use of electronic media, for the purpose of enhancing learning. It involves managing and coordinating available instructional aids and resources in order to facilitate learning. It also involves the selection of suitable technology based on the learning needs of students as well as the ability of teachers to adapt such technology to fit specific learning activities. It calls for teachers' ability to select suitable technology while planning instruction. It also requires teachers to use appropriate technology to present and evaluate instruction as well as use relevant technology for follow-up learning activities. Such a broad definition of technology in education will help teachers develop a rational approach toward technology integration.

Problems of Technology Integration

The study of Leh (2005) reveals that teachers admitted "they did not resist technology per se but agreed that they could not fully integrate it into their own practices because of the organizational, administrative, pedagogical, or personal constraints" (p. 19). Leh claims that the teachers acknowledge, "technology was more of a problem with multiple facets rather than a solution …" (p. 19). Defining instructional technology in broad spectrum helps educators, especially inexperienced teachers, understand the pedagogical issues to be considered when using technology to enhance the process of teaching and learning. Leh also calls for the "the national organizations involved in teacher standards to recognize that teachers need to … develop a foundation upon which to build their understanding of technology integration (p. 46). Bosch & Cardinale (1993) maintain that while it is important for teachers to be provided with technological skill, it is also important to educate them on how to use that skill to support learning. Infusing technology into a curriculum is less likely to make an impact on students' learning if technology is not considered as a component of instruction. Technology should not be treated as a separate entity but should be considered as an integral part of instructional delivery. The teacher should be able to assess the appropriateness of any technology used for teaching and learning in relation to specific instruction. The teacher should also consider how the technology selected fits into the objective of the lesson, methods of instruction, evaluation, feedback and follow-up initiatives. Such consideration will provide teachers the opportunity to reflect on their practice and reduce the tendency to integrate technology into teaching and learning in a mechanistic way. Fletcher (1996) has provided an interesting scenario to show that technology integration should be grounded in sound educational practices:

> When you go to the hardware store to buy a drill, you don't actually want a drill, you want a hole, they don't sell holes at the hardware store, but they do sell drills, which are the technology used to make holes. We must not lose sight that technology for the most part is a tool and it should be used in applications which address educational concerns. (p. 87)

In teaching and learning, technology should be applied as a process rather than as a single, isolated and discrete activity. The *American Heritage Dictionary* defines process as "a series of actions, changes, functions bringing about a result." Technology in education is not a mere object to be introduced into teaching and learning activities at will without considering basic principles of learning and sound teaching methodology. Therefore, to assume that educational technology is an object that can be used and detached at any time is a false assumption because educational technology is not applied in a vacuum. It is guided by learning principles about how individuals learn and how they retain the knowledge and skill they have acquired. It is also based on the students' expectations of the outcome of learning and how the outcomes could be applied to enrich practical life experiences. Therefore, technological application should be based on sound teaching and learning principles to avoid teaching hardware and software technologies in an isolated manner. Technologies used for instructional delivery should form part of the cohesive components of instruction; they should not be detachable objects.

An ongoing action research project has shown that most in-service teachers have a narrow view of technology integration. When they were asked to briefly state why they need to apply technology in their teaching, most of the student teachers (70%) maintain that it is a tool for instruction; they fail to relate it to pedagogy or identify how it will help them to improve their teaching or facilitate learning. An educator who does not understand the purpose of technology integration or how it could be applied is less likely to achieve success in a technology-based learning environment. Eby (1997) warns that "technology could not support learning without teachers who know how to use it and integrate it into subject-specific area." Means (1994) points out that technology training must go beyond focusing on the acquisition of technical skills but attention should be given "to the instructional strategies needed to infuse technological skills into the learning process" (p.92). Yao and Quang (2000) argue that technology training tends to focus on computer applications such as word processing, spreadsheets and databases. Technology for teaching and learning should be part of the instruction milieu and not be added as an afterthought activity. Sprague et al. (1998) argue that using technology for instruction should include mastery of the techniques to apply it to teaching.

Relationship between Technology in Education and Pedagogy

A major part of the problem related to technology integration is that most educators have not addressed the pedagogical principles that will guide their use of technology for teaching and learning. The intricate relationship between technology and pedagogy has not been adequately explored. As teachers explore the process of technology integration and search for ways that it can be effectively accomplished, they will develop the rationale to examine the appropriateness of the technologies they are using and whether such technologies are compatible with their lesson plan and learning outcomes. The process of exploring the relationship between technology in education and pedagogy will encourage critical thinking on the part of teachers as they practice technology integration. Mezirow (1990) argues:

> That thinking critically involves our recognizing the assumption underlying our beliefs and behaviors. It can give justifications for our ideas and actions. Most important, perhaps, it means we try to judge the rationality of these justifications. (p. xvii)

The words of Alfred Kyle, a Dean of Engineering, are very insightful in discussing critical and reflective teaching (in Schon, 1987). Dean Kyle maintains that "we know how to teach people to build ships but not how to figure out what ships to build" (p.11). Accordingly

Ripley (2001) explains that what the Dean of Engineering is conveying is for "students to learn how to determine which ships to build while they master shipbuilding skills. He hopes that students will progress toward becoming reflective practitioners who think and rethink their positions and assumptions …" (p. 19). By the same token, it is hoped that instructors will develop similar awareness by becoming critical thinkers and reflective teachers as they engage in technology integration.

The authors of this paper have observed that during the course of their teaching, education students were asked to discuss why they would like to use technology for teaching and learning. A great majority of them said that they use technology (more specifically computers) for instruction because it helps teachers to teach and students to learn. This response is too general and does not convey an in-depth understanding of technology integration. These students fail to articulate in any meaningful way how technology can be used to improve learning. Their response does not capture the intricate relationship between pedagogy and technological resources. Lack of appropriate guidelines limit teachers' use of technology for instruction, and limits their desire to explore the use of technology beyond basic applications. Weizenbaum (1976) argues that "computers can be a powerful metaphor for understanding many aspects of the world." However, he states "it enslaves the mind that has no metaphors and few resources to call on—the mind that has been educated with only facts and skills" (p. 51). It is important that practicing teachers and in-service teachers recognize that technology in education is considered part of pedagogy.

Bazeli (1997) is critical of the way technology is used for instruction. She believes implementing technology in the classroom is time-consuming and teachers do not have the time to involve students at the planning stage of technology integration. Bazeli asserts that when students participate in the planning and implementation stages of technology integration "the burden is lifted from the teachers and the learning process becomes collaborative, with the teacher assuming the role of facilitator rather than a disseminator of information. Further, as students are actively involved in planning and implementing technology production, they gain critical thinking and problem-solving skills along with curricular learning." She maintains that "unfortunately, the computer is often perceived as a separate entity, not an integrated part of the curricular areas of the school" (p. 201).

Technology should be implemented in the classroom only if its role in a given instruction is determined along with pedagogical issues related to a given instructional task. The role of technology in education can only be determined if teachers who implement technology at the classroom level are involved in technology decision-making because teachers have the responsibility of facilitating instruction. Okojie et al. (2005) argue that school administrators make decisions about technology training without consulting teachers who will integrate technology into instructional process. Teachers who are in a better position to articulate their needs and identify their weaknesses have minimal input in planning the technology training they receive. Thus, technology integration training becomes a general identification of various hardware and software technologies, which does not address specific learning problems nor pinpoint the way technology can be used to improve instruction (p. 5). Pierson (2001) recognized that "society has embraced computer technology and allowed it to reinvent the ways in which we create, find, exchange, and even think about information. Unable to ignore such deeply permeating innovation, school districts often bow to societal pressure to fund technology without having a thoughtful plan for implementation" (p. 413). Gunter (2002) argued that students learn computer skills in isolation of the curriculum structure. Topper (2005) believes that "for teachers to use technology in support of their teaching, and to see it as a pedagogically useful tool, they must be confident and competent with the technology they are planning to use (p. 304).

It is important that teachers recognize that a relationship exists between technology in education and pedagogical decision-making. According to Anderson and Borthwick (2002) research evidence shows that "participants whose technology instruction was integrated in their methods course reported more frequent use of technology for both teacher productivity and student projects during both on-campus courses and their first year of actual classroom teaching" (p. 5). There is no blueprint for technology integration, however, it is suggested that effort be made to link technology for instruction to all levels of pedagogical processes and activities as described next.

- Identifying learning objectives in a technology-based instruction requires teachers to select and/or adapt instructional technology to match the objectives based on the students' needs.

- Presenting instruction using technology as part of the instructional process requires teachers to choose the methods that are relevant to the objectives, the technology selected, learning styles, modes and pace of learning.

- Evaluating technology-based instruction requires teachers to select appropriate evaluation techniques that are relevant to the objectives, methods of instruction, and to technologies that have been used.

- Designing follow-up activities using technology requires teachers to select appropriate follow-up materials that are relevant to the objectives of the instruction and technologies that are accessible to the students as well as easy to use.

- Developing course enrichment materials using technology requires teachers to provide opportunity for students to explore issues related to the course materials and to provide them with the opportunity to select and analyze course enrichment materials using technology in ways that broaden their problem-solving skills.

- Locating sources for additional instructional materials using technology requires teachers to use the internet and multimedia networks to develop additional learning materials and expand instructional resources aimed at broadening the knowledge and the skill gained.

- Designing a dynamic classroom using technology requires teachers to provide a learning environment that is colorful, engaging, exciting, interactive and energetic as a way of encouraging students to venture into the world of technology and to discover knowledge for themselves.

Conclusion

The essence of this article is to provide insight on how teachers can improve their use of technology to support instruction. It explores pedagogical issues that are relevant and need to be considered in order to successfully apply technology into teaching and learning. It is important that educators perceive technology in education as part of the pedagogical process. This article also recognizes the relationship between pedagogy and technology in education. It is necessary that teachers understand the pedagogical principles that govern the application of technology into teaching and learning. Suggestions are made on how to improve technology integration. Educators are encouraged to view technology integration from a wider perspective and be reflective in their teaching as they use technology to support and facilitate instruction. Technology integration should be considered as part of the process of instructional preparation. Instructional technology should be identified at the planning stage just as the students' readiness is assessed, lesson objectives identified, methods of presenting are established, and evaluation strategies are determined. Follow-up activities should also be established at the planning stage. Poor implementation of technology integration is likely to affect the desired outcome.

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Technological Systems and Momentum Change: American Electric Utilities, Restructuring, and Distributed Generation Technologies

Richard F. Hirsh and Benjamin K. Sovacool

"To draw attention today to technological affairs is to focus on a concern that is as central now as nation building and constitution making were a century ago. Technological affairs contain a rich texture of technical matters, scientific laws, economic principles, political forces, and social concerns."

—Thomas P. Hughes, 1983

The American electric utility system has been massively transformed during the last three decades. Viewed previously as a staid, secure, and heavily regulated natural monopoly, the system has shed elements of government oversight and now appears to be increasingly susceptible to terrorist attacks and other disruptions. Overturning the conventional wisdom of the 1960s and 1970s, dependence on large-scale generation plants and high-voltage transmission networks now seems to decrease reliability of the system. The same hardware also subjects utility companies to pollution concerns at a time when environmental sustainability has become a serious political and economic issue worldwide. Clearly, much of the formerly sound thinking about the utility system has been overturned. But new thinking has evolved as well. For example, many people have begun advocating the use of small-scale, decentralized technologies known collectively as distributed generation (DG), which offers hope that the electric utility system may become more resilient and environmentally friendly in the near future.

This article examines the reversal of almost a century of momentum in the electric utility system. To do so, it employs the nonengineering version of the systems approach, which has proven useful for analyzing sociotechnical enterprises. As a subtheme, the article explores long-term and cross-industry trends in the use of technologies; in particular, it notes that industrial use of large-scale technologies, which provide great economies of scale, may have reached limits in certain fields, such that small-scale technologies may have become better suited for use. As another subtheme, the article underscores the importance of nontechnical (i.e., social) action in the development of technologies. In the American utility system, the unintended consequences of an obscure law passed in 1978 spurred deregulatory efforts in the 1990s and the development of commercially viable renewable energy and distributed generation technologies. The encouragement of these environmentally preferable and DG facilities continued during the political chaos that emerged early in the twenty-first century, when utility restructuring became questioned in many states.

Using the Systems Approach to Understand Technological Change

To help understand the historical development of electric utilities, one can fruitfully use the "systems approach" that Thomas Hughes originally developed for the social sciences. In his seminal *Networks of Power: Electrification in Western Society* (Hughes 1983) and other works, Hughes argues that the generation, transmission and distribution of electricity occurs within a technological system. That system extends beyond the engineering realm, and it includes a "seamless web" of considerations that can be categorized as economic, educational, legal, administrative, and technical. Large modern systems integrate these elements into one piece, with system-builders striving to "construct or ... force unity from diversity, centralization in the face of pluralism, and coherence from chaos" (Hughes 1987, 52). If the managers succeed, the system expands and thrives while, simultaneously, closing itself. In other words, the influence on it of the outside environment may gradually recede because the system has expanded its reach to encompass factors that might otherwise alter it (Hughes 1987, 52).

Hughes's systems approach also employs the notion of momentum, which *Networks of Power* describes as a mass of "machines, devices, structures" and "business concerns, government agencies, professional societies, educational institutions and other organizations" that "have a perceptible rate of growth or velocity" (Hughes 1983, 15). In fewer words, Hughes defines momentum elsewhere as a "mass of technological, organizational and attitudinal components [that tend] to maintain their steady growth and direction" (Hughes 1989, 460). The system's tendency to continue along a given path results from the actions of numerous stakeholders, such as educational and regulatory institutions, the investment of billions of dollars in equipment, and the work and culture of people working within an industry. In concert, these elements promote business as usual and the outward show of a large degree of momentum. Furthermore, Hughes explains that system momentum can be aided through the use of "conservative" inventions, i.e., new technologies that preserve the existing system. Managers of the system obviously prefer to maintain their control of affairs and, while they may seek increased efficiencies and profits, they do not want to see introduction of new and disruptive "radical" technologies. As an example, Internet telephony and cell phones may be viewed today as radical inventions by managers of the traditional wired communications network.

To summarize, Hughes's approach suggests that systems develop through human managers' control of elements to exploit the existing social environment. Systems acquire momentum, and they resist alteration as they mature. Momentum, however, is not the equivalent of determinism (which holds that either social or technical factors are exclusively responsible for technological development) or autonomy (which suggests that technologies achieve a level of action independent of human contexts). Rather, momentum in systems—even those having high momentum—can sometimes be altered through "a confluence of contingency, catastrophe and conversion," as Hughes puts it (1989, 470-471). Through their institutions and actions, humans may play a role in changing momentum, difficult as that may appear in many situations. But such was the case in the American electric utility system.

Origins and Growth of Momentum in the Electric Utility System

The electric utility system began to gain momentum early in the twentieth century. It did so largely as power company managers took advantage of incrementally improving technology. Adopting alternating-current (AC) transmission and steam-turbine technologies, early utility entrepreneurs quickly found they could emulate trends in other industries, most notably by increasing the scale of their business. Economist Alfred Chandler (1977) has shown how the railroad industry served as the epitome of modern enterprises that exploited new technologies to expand their scale and scope. In the process, railroad companies eliminated regional competition and gained panoptic political and economic power, while also earning the contempt of many of their customers. Similarly, through the use of transformers made available in the late 1880s, AC transmission allowed companies to distribute high-voltage power over long distances. And in the first decade of the twentieth century, utility managers began employing compact steam turbines (connected to generators) as prime movers that further encouraged centralization, because the new machines offered tremendous economies of scale. Put simply, as the turbines produced larger capacities of power, the unit cost of electricity declined over a wide range of output. Taking actions that would be imitated by other electrical entrepreneurs, Samuel Insull embraced alternating current and steam turbines for his small Chicago Edison Company. When he took over the firm in 1892, Chicago claimed 20 competitive electric supply firms. By 1907, Insull employed the new technology and consolidated them into the renamed "Commonwealth Edison Company," a virtual monopoly in the city and its environs (Hughes 1983, 208).

Steam turbine-generators and alternating-current technologies became the core conservative technologies of the utility system, allowing it to produce increasing amounts of power at lower unit cost. Developed for utility use by companies such as Westinghouse and General Electric, the technology showed improvements mainly in two criteria. First, manufacturers designed steam turbines using new metal alloys that could endure higher temperatures and pressures, thus yielding better thermal efficiencies. While Thomas Edison's pioneering 1882 power station (which used reciprocating steam engines) converted just 2.5 percent of a raw fuel's energy into electricity, steam turbines improved over the years to achieve a conversion efficiency of about 40 percent in the 1960s, though the average plant demonstrated an efficiency of about 33 percent (Figure 1). At the same time, manufacturers exploited new knowledge about metallurgy to produce turbines and generators that became ever-larger and took advantage of economies of scale. Following installation of a 5-megawatt (MW) steam turbine in 1905, for example, Samuel Insull's firm procured 12-MW machines in 1911 (Insull 1915, 430). More powerful equipment followed: Insull's company

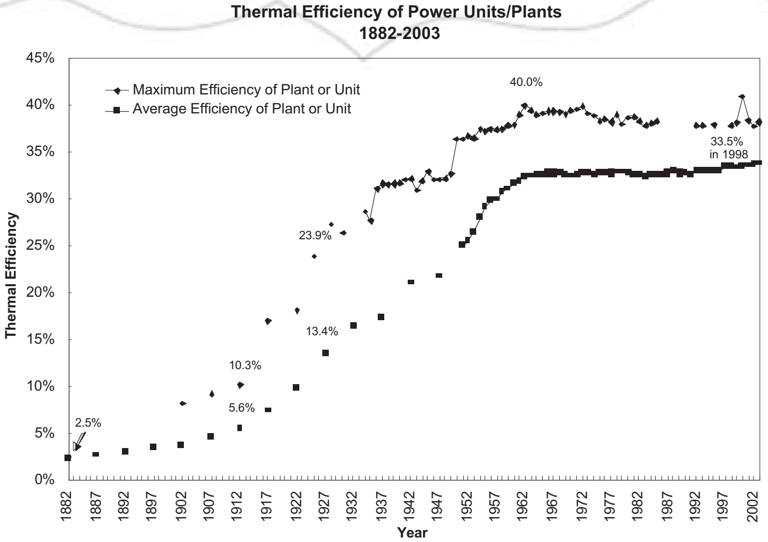

Figure 1. Data from Edison Electric Institute 1988, Electric Light and Power, and U.S. Department of Energy 2004.

employed a 208-MW unit in 1929. After the Great Depression, other American utilities bought units that reached 1,000 MW in 1965 and 1,300 MW in 1972.

The growth in scale of electric utility technology parallels trends in other industries. As in the manufacturing of automobiles and consumer durables and in service industries and sanitation, managers employed technologies that reduced unit costs, increased efficiency, and added to profitability as the scale of operations increased (Melosi 2000; Noble 1999). Some of the scale efficiency occurred for "simple" laws of mathematics and engineering. For example, as the circumference of a pipe that feeds a steam turbine increases by a factor of three, the volume of steam passing through it increases by a factor of nine. In other words, for a modest increase in material inputs (and costs), the industrialist obtains disproportionately large outputs (Hirsh 1989, 41). More gains emerge when realizing that many other costs decline as scale increases. Instead of employing two small steam turbines, along with the associated equipment and personnel needed to operate them, a utility could build one large turbine. The power output is equivalent, but at lower unit cost.

Because of associated improvements in transmission, distribution, and control equipment, the use of more fuel-efficient and larger turbine-generators boosted the industry's total factor productivity—a measure of overall operating efficiency (Kendrick 1961; Kendrick 1973). In everyday terms, higher productivity meant declining costs and prices. While residential customers in 1892 paid about 544 cents per kilowatt-hour (kWh) (in adjusted 2004 terms), they only paid 10 cents for the equivalent amount of electricity in 1970 (Edison Electric Institute 1988; Edison Electric Institute 1997; U.S. Department of Energy 2005a). Since lower prices and the availability of attractive electrical appliances stimulated demand, consumption jumped at a 12 percent annual growth rate from 1900 to 1920 and at a 7 percent average annual rate from 1920 to 1973 (Landsberg and Schurr 1968).

While the use of conservative, incrementally improving technologies contributed to the utility system's growing momentum, so did nontechnical elements. By focusing attention on such elements, Hughes's system approach helps us understand that technology evolves in a social milieu. Perhaps most surprisingly, the creation of regulatory oversight of the utility industry contributed significantly to momentum. As academics and politicians began to realize during the Progressive era in American politics, which lasted from about 1896 to the beginning of World War I, certain types of businesses appeared unable to operate within the traditional competitive market environment: they required construction of capital-intensive facilities that limited the number of rivals to those few that could secure financing. Meanwhile, competition among firms had already led to political corruption in attempts to win franchise rights from city leaders. These businesses, such as railroads and the increasingly large electric power companies, constituted “natural monopolies”—businesses that offered services most efficiently and cheaply only if they remained free from competition (Hirsh 1999, 17-18). Regulation became viewed as a popular approach for gaining the benefits of large-scale companies while protecting the public from potential abuses. In other words, the existence of natural monopolies seemed to call for the regulatory commission as a new, socially valuable institution.

While casual observers might assume that industrial tycoons would resist government regulation, Samuel Insull and other prescient managers realized that regulation actually could help them to consolidate a fledgling industry. As early as 1898, Insull argued that government oversight would confer legitimacy to power companies as natural monopolies and, as important, it would enable utilities to reduce their cost of financing by lessening the risk incurred by investors. Regulation would also protect utilities from attempts at municipal takeovers (Insull 1915, 34).

Government oversight of utilities added to system momentum, ironically by giving utility managers a large measure of control. Because regulators guaranteed an almost certain income stream and financial viability, utilities benefited. Moreover, regulation offered the appearance of watchful supervision without really providing much, thereby providing a large degree of clout to utility managers. With the end of the Progressive era, state regulators received little attention from the news media or state legislators, which provided few resources to combat the utilities’ well-paid lawyers and consultants. Meanwhile, utility managers courted regulators, and they publicly exaggerated the positive role that regulators played in maintaining a successful large-scale enterprise. Regulators did little to disabuse the public of this notion. They happily went along with the charade because they enjoyed the little prestige and power they acquired by being associated with an industry that provided declining prices for an increasingly necessary commodity (Hirsh 1999, 41-46). In short, utility managers had “captured” the regulatory apparatus, which contributed to their control of a system that had developed growing momentum (Stigler 1971; McCraw 1984).

Beyond regulators, utility managers won the support of other stakeholders who sought to keep the system moving in the same direction and with continuously increasing mass and velocity. Investment bankers constituted one supportive party as they profited from supplying money for the capital-intensive industry. They also helped create holding companies, which offered power company managers access to financial resources and professional management expertise. Manufacturers of electrical equipment further contributed to momentum because they flourished monetarily when utility companies expanded and required more advanced technologies. To train utility executives and middle-managers, educational institutions (starting with MIT and Cornell University) fashioned degree programs for electrical engineers and also became tacit contributors of momentum. Utility customers, meanwhile, appeared happy, as electrification benefited people with higher material standards of living and a sense of social progress (Hirsh 1989, 26-35). They did little to impede the growing momentum and, through their increasing purchases of electricity, added to it.

By the 1920s (and continuing into the 1960s), the utility system had gained a huge amount of momentum. Serving as an integral part of the infrastructure that enhanced industrial productivity and made the “good life” possible, the system employed incrementally improving and conservative technologies. Moreover, utility managers gained control of the system by capturing the regulatory framework and by winning support from financial, industrial, educational, and consumer stakeholders—all of whom seemed to reap tangible benefits (Hirsh and Serchuk, 1996). On the surface, it appeared that little could alter the system’s trajectory.

Momentum Change Begins

The first challenge to continuously building momentum in the electric utility system arose in the 1960s and 1970s. In a process that has been called “technological stasis,” the industry witnessed the apparent end of productivity-enhancing technological improvements. For a host of managerial and technical reasons, the thermal efficiency of steam turbine-generators stopped improving. Though some plants reached efficiencies as high at 40 percent, they also proved to be highly unreliable, which made them unattractive to managers who sought to keep plants online as long as possible. As bad experience grew with these highly efficient plants, managers stopped ordering them, remaining satisfied with the less-efficient, but more trustworthy units (Hirsh 1989, 89).

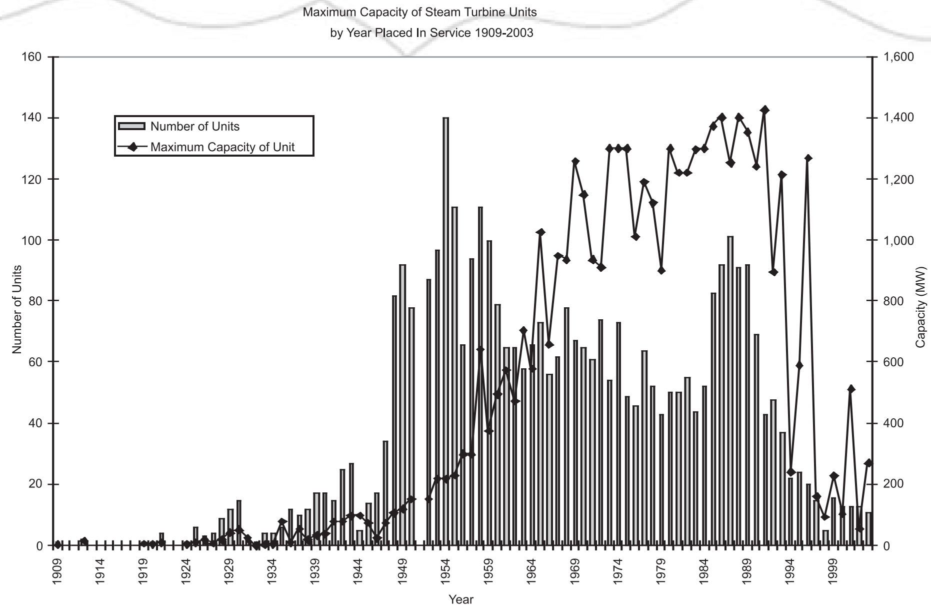

Figure 2. Data from U.S. Department of Energy 2003.

Soon thereafter, technological stasis occurred again, this time as utilities sought to build ever-larger, higher-capacity power plants. As units grew to exceed 1,000 MW in the 1960s and 1970s, utilities also discovered operational problems as turbine blades suffered distortions and as furnace problems and other defects hampered the units' performance (Figure 2). Despite the desire to attain increased economies of scale, especially in light of the industry's inability to reach higher thermal efficiencies, managers stepped back from the largest units and settled for smaller, proven units. The problem became increasingly serious in light of the 1973 "energy crisis," which caused fuel to become more expensive. In previous decades, the improvement of power-producing technologies had mitigated increased costs in building materials and labor, allowing the industry to reduce the price of its product. But because of technological stasis—along with greatly increased borrowing rates for an industry that consumed vast amounts of capital—power companies soon found themselves uncharacteristically requesting rate hikes from utility commissions (Hirsh 1989, 111). Additionally, the higher prices created antipathy among customers who previously supported the structure of the utility system. More tangibly, higher prices motivated customers to purchase less power: for a few years after the onset of the crisis, electricity consumption actually grew at negative rates, while the longer term annual growth rate (from 1973 to 2003) dropped to about 2.4 percent (Figure 3).

Politics and System Momentum

The havoc on the American economy wreaked by the energy crisis spurred policy makers to take action. On the federal level, President Carter made energy policy his first major initiative. Among a set of five laws proposed by Carter and passed by Congress (albeit in greatly diluted form), the Public Utility Regulatory Policies Act (PURPA) of 1978 had the most far-reaching—and least intended—consequences for power companies. It spurred creation of radical technologies; it began the process of deregulation; and it challenged the control held by power company managers. In the process, the law helped change the momentum of the utility system.

Superficially, PURPA appeared to pose little threat to utility companies. But one obscure portion of it offered incentives for the use of efficient cogeneration power plants. These small units often produced less than 100 MW of power—about 10 percent of what utility-owned nuclear and fossil units churned out—and they burned coal, natural gas, garbage, or biomass. The resulting heat first produced electricity using a traditional steam turbine. But instead of dumping the low-pressure steam into the environment, as was common practice for utility power plants, cogenerators employed it for industrial processes. In other words, small cogeneration plants obtained double duty from raw fuel in the form of two valuable products (electricity and process steam), yielding an

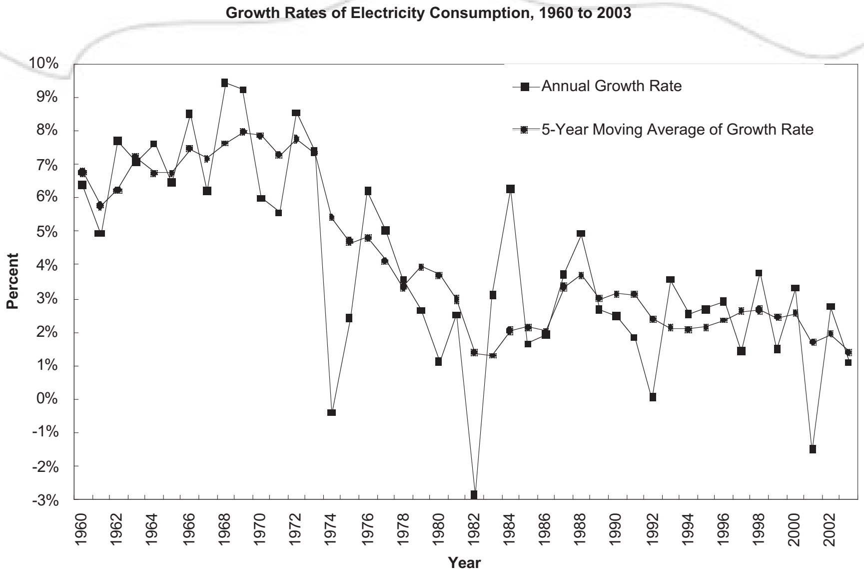

Figure 3. Data from U.S. Department of Energy 2004.

overall thermal efficiency rate of 50 percent or higher. (Compare this figure to the 40 percent optimum achieved by utility power plants.) Because of this feat, cogeneration plants frequently matched the economic viability of utility units and became increasingly popular, even at their relatively puny scale. Growing from a small percentage of American electric capacity in 1980, cogeneration facilities accounted for 39 percent of capacity in 2002 (Electric Power Supply Association, 2005).

A related provision of PURPA also spurred research on environmentally preferable technologies that used water, wind, or solar power to produce electricity. More successful than anyone originally anticipated, PURPA prompted work that cut the cost of power produced by solar photovoltaic panels by about 70 percent between 1980 and 1995 (Sheer 2001; Clayton 2004). More significantly, it contributed to work that lowered the cost of power produced by wind turbines; by 2002, the average cost of wind-produced electricity dropped to under 5 cents per kWh, a cost that compared favorably with electricity produced by conventional utility plants burning natural gas or coal (Smith 2004; American Wind Energy Association 2005).

These smaller-scale generation technologies challenged the established paradigm of the utility industry (and many other industries) that previously relied on large-scale equipment to produce economies of scale. Now, it appeared, power plants producing modest amounts of electricity proved economically viable. Moreover, since they were smaller, they required less time to build, and they put less capital at risk during a period of rapid price inflation. Finally, they matched the slower growth rate of consumption more appropriately: with growth rates remaining under 3 percent per year, consumers needed smaller increments of power to match their demand. Had utilities continued to build their traditional behemoths, huge chunks of power would remain unused when the plants were completed. Small scale, indeed, looked beautiful.

In the parlance of Hughes's approach, these small-scale technologies constituted radical technologies that helped alter the utility system's momentum. They did so by enabling competition for the traditional power companies—at least in the generation sector—and by eroding the control held by utility managers. No longer the sole producers of electricity, power company executives watched as industrial firms (employing cogeneration facilities) and renewable energy entrepreneurs sold competitively priced electricity.

This unintended experiment with competition suggested to influential regulators and legislators in the 1980s that more competition would benefit stakeholders in the electric utility industry. (Not coincidentally, competition had already begun in the airline, telecommunications, and natural gas industries.) Some academics and politicians wondered if utility regulation still had merit, seeing that a traditional justification of government oversight—the fact that power companies constituted natural monopolies—no longer appeared valid. After all, if nonutilities could produce power as cheaply as could utilities, then the big power companies no longer deemed recognition as natural monopolies. And if they were not natural monopolies, they no longer deserved special status as noncompetitive entities that required regulation (Hirsh 1999, 119-142). Why not permit increased competition to thrive outside the realm of the PURPA-inspired generation companies?

Already feeling their control of the system threatened by pressures resulting from implementation of PURPA, utility managers had more to fear. After the Gulf War focused attention again on the cost and security of energy supplies, Congress passed the Energy Policy Act of 1992. The legislation sought to employ competitive forces to increase domestic fuel production and to improve the efficiency of energy use. One provision gave states the option of opening up their transmission network to use by competitors. The network would serve as a common carrier so any electricity producer could sell power to any customer. Essentially, the law gave states the right to begin competition on the retail level. During the late 1990s, several states (with California being among the first) passed legislation that established competitive retail frameworks for power. By September 2001, 23 states (and the District of Columbia) had passed similar legislation, while regulatory bodies in several other states had reduced their oversight and had introduced market forces into the system.

The restructuring process, stimulated by PURPA and pursued by advocates of market forces, meant that momentum in the utility system had been altered, largely because utility managers lost control of “their” system. For almost a century, managers commanded the huge-scale, incrementally improving conservative technologies that produced and distributed electricity. But in recent decades, they began facing competition from entrepreneurial companies that employed small-scale fossil fuel and renewable energy technologies. In 1992, nonutility companies controlled 1.5 percent of the nation’s total power capacity; that number rose to 34.7 percent in 2003 (U.S. Department of Energy, 2005b). In addition, power company managers lost the benefit of traditional regulation, which protected companies from competition on the basis of their claim—now challenged—to natural monopoly status. At the same time, managers lost support from those stakeholders who previously buttressed them: financiers, equipment manufacturers, and educational institutions adapted to the changing environment and found new opportunities serving the needs of the growing number of nonutility companies. Employing the terms of the systems approach, then, the sociotechnical elements that had previously contributed to utility system momentum no longer had the same speed nor direction.

Assuming some of the political and economic power that managers once held, other stakeholders began making new waves. Environmental advocates, for example, gained impressive standing in the legislative process that led to creation of restructuring laws. While supporting deregulation in general, they fought for (and in many cases won) provisions in laws that guaranteed funding for renewable energy and energy-efficiency initiatives. In California’s version of restructuring, for example, utilities earned the right to receive payment from customers for building what turned out to be expensive power plants during the era of regulation, but which would have little economic value in an era of competition (called “stranded” assets). But environmental advocates won provision for expenditures on energy efficiency work, renewable energy technologies, and for development of research on new technologies that had not yet shown commercial viability (Hirsh 1999, 258).

The Promise of Decentralized Electricity Generation

As stakeholders began renegotiating their positions in an altered utility system, the California electricity crisis of 2000 and 2001 created a sense of chaos. Subsequent blackouts in the Midwest during 2002 and in the Northeast and Canada during 2003 contributed further to that disharmony. In California, where one utility declared bankruptcy as a result of the crisis, the state suspended competition altogether and expanded its control of the wholesale market. Such events caused policy makers in other states to reconsider their previous enthusiasm for restructuring and to slow down plans to introduce market forces. At the same time, the Federal Energy Regulatory Commission proposed new initiatives in response to the 2003 blackout that may give it greater control over the increasingly fragile-looking transmission grid. That grid has witnessed serious underinvestment since the 1990s as utility companies and nonutility entrepreneurs remained concerned in an uncertain policy setting about how the grid will be employed and which stakeholders will profit from its use (Rigby 2003).

The unsettled state of affairs in the power system has provided opportunities for advocates of environmentally-friendly and distributed-generation technologies. Taking advantage of the flux within the utility system, especially in states with strong traditions of politically astute environmental advocates, activists won passage of laws for funding of renewable energy and small-scale generation technologies. Customers paid into "public benefit funds" (also known as "system benefit funds") regardless of which company (a traditional utility or nonutility company) provided them with electricity (Clean Energy States Alliance, 2004). And in eighteen states (plus the District of Columbia), advocates convinced legislators to enact laws creating "renewable portfolio standards" that required all competitive power companies to produce (or to purchase) a certain amount of power coming from small-scale, renewable resources. The laws created a market for environmentally preferable technologies and spurred research and development of them so they become more economically viable even without government incentives. In Texas, a law (signed by Governor George W. Bush in 1999) required 2,000 MW of renewable energy to be constructed by 2009 (Wiser and Langiss, 2001). By the end of 2004, producers had already installed 1,293 MW, most of it consisting of competitively priced wind turbines (Garman 2005).

The state-supported move toward small-scale generation technologies reflects the erosion of the conventional paradigm of providing power through large, centralized power generators. Traditionally, policymakers emphasized using the discipline of power engineering to focus on expanding generating capacity to meet aggregated demand at the lowest cost. This approach relied on large plants because utility managers believed that bigger facilities offered lower fixed costs and were better driven by economies of scale (Capehart, Mehta, and Turner 2003; Lovins et al. 2002).

By contrast, an emerging paradigm of distributed generation emphasizes decentralized, modular, and on-site production of electricity. Proponents of DG argue that small, local plants (often having capacities of between 5 and 30 MW) are frequently less expensive, more efficient, more reliable, more flexible, and less damaging to the environment than large utility-owned power plants that burn fossil fuels. Since many renewable energy technologies—such as wind turbines and photovoltaic systems—are smaller and decentralized, they serve as examples of DG technologies. Even generation equipment that employs fossil fuels, such as natural gas and coal, can be considered valuable DG resources, especially when they exploit waste heat generated through combustion or fuel conversion. These comprise cogeneration plants (also known as combined heat and power [CHP] facilities) like those encouraged by PURPA. They may also include very small steam turbines known as micro-turbines that produce power in the range of 25 to 500 kW while also recycling waste steam for water or space heating needs (Capehart 2003). Phosphoric acid fuel cells have become popular too. Being pursued by public benefit funding programs in some states, the devices (which are being tested in 200 kW to 11 MW sizes) take in hydrogen-rich fuel and create electricity through a chemical process rather than by combustion, yielding few particulate wastes (Yacobucci and Cutright, 2004). The process also generates heat, which can be used as a profitable by-product. Beyond these DG technologies that offer high efficiencies are modular internal combustion engines that run on diesel fuel or gasoline. In their smallest incarnations (about 1 kW), they provide backup power for homes and recreational vehicles. In larger increments, they supply power for hospitals and commercial venues. Generally speaking, DG technologies can be employed in isolated "islands"—independent of the transmission grid—or attached to it, in which case they serve as small power units that contribute power to it.

Consumer advocates who favor DG point out that distributed resources can improve the efficiency of providing electric power. They often highlight that transmission of electricity from a power plant to a typical user wastes roughly 4.2 to 8.9 percent of the electricity as a consequence of aging transmission equipment, inconsistent enforcement of reliability guidelines, and growing congestion (Silberglitt, Ettedgui, and Hove 2002; Lovins 2002). At the same time, customers often suffer from poor power quality—variations in voltage or electrical flow—that results from a variety of factors, including poor switching operations in the network, voltage dips, interruptions, transients, and network disturbances from loads. Overall, DG proponents highlight the inefficiency of the existing large-scale electrical transmission and distribution network. Moreover, because customers' electricity bills include the cost of this vast transmission grid, the use of on-site power equipment can conceivably provide consumers with affordable power at a higher level of quality. In addition, residents and businesses that generate power locally have the potential to sell surplus power to the grid, which can yield significant income during times of peak demand.

Industrial managers and contractors have also begun to emphasize the advantages of generating power on site. Cogeneration technologies permit businesses to reuse thermal energy that would normally be wasted. They have therefore become prized in industries that use large quantities of heat, such as the iron and steel, chemical processing, refining, pulp and paper manufacturing, and food processing industries (International Energy Association 2002, 41-49). Similar generation hardware can also deploy recycled heat to provide hot water for use in aquaculture, greenhouse heating, desalination of seawater, increased crop growth and frost protection, and air preheating (Kleinbach and Hinrichs 2002, 311).

Beyond efficiency, DG technologies may provide benefits in the form of more reliable power for industries that require uninterrupted service. The Electric Power Research Institute reported that power outages and quality disturbances cost American businesses $119 billion per year (Hinrichs, Conbere, and Lobash 2002). In 2001, the International Energy Agency (2002) estimated that the average cost of a one-hour power outage was $6,480,000 for brokerage operations and $2,580,000 for credit card operations (44). The figures grow more impressively for the semiconductor industry, where a two-hour power outage can cost close to $48,000,000 (Lin 2004). Given these numbers, it remains no mystery why several firms have already installed DG facilities to ensure consistent power supplies.

Perhaps incongruously, DG facilities offer potential advantages for improving the transmission of power. Because they produce power locally for users, they aid the entire grid by reducing demand during peak times and by minimizing congestion of power on the network, one of the causes of the 2003 blackout (Congressional Budget Office 2003). And by building large numbers of localized power generation facilities rather than a few large-scale power plants located distantly from load centers, DG can contribute to deferring transmission upgrades and expansions—at a time when investment in such facilities remains constrained (International Energy Agency 2002; Pepermans 2003). Perhaps most important in the post-September 11 era, DG technologies may improve the security of the grid. Decentralized power generation helps reduce the terrorist targets that nuclear facilities and natural gas refineries offer, and—in the event of an attack—better insulate the grid from failure if a large power plant goes down (Friedman and Homer-Dixon 2004).

Environmentalists and academics suggest that DG technologies can provide ancillary benefits to society. Large, centralized power plants emit significant amounts of carbon monoxide, sulfur oxides, particulate matter, hydrocarbons, and nitrogen oxides (Kleinbach and Hinrichs 2002, 249). The Environmental Protection Agency has long noted the correlation between high levels of sulfur oxide emissions and the creation of acid rain. Because they concentrate the amount of power they produce, large power plants also focus their pollution and waste heat, frequently destroying aquatic habitats and marine biodiversity (Kleinbach and Hinrichs 2002, 307-308). On the other hand, recent studies have confirmed that widespread use of DG technologies substantially reduces emissions: A British analysis estimated that domestic combined heat and power technologies reduced carbon dioxide emissions by 41 percent in 1999; a similar report on the Danish power system observed that widespread use of DG technologies have cut emissions by 30 percent from 1998 to 2001 (International Energy Association 2002, 92). Moreover, because DG technologies remain independent of the grid, they can provide emergency power for a huge number of public services, such as hospitals, schools, airports, fire and police stations, military bases, prisons, water supply and sewage treatment plants, natural gas transmission and distribution systems, and communications stations (Liss 1999). Finally, DG can help the nation increase its diversity of energy sources. Some of the DG technologies, such as wind turbines, solar photovoltaic panels, and hydroelectric turbines, consume no fossil fuels, while others, such as fuel cells, microturbines, and some internal combustion units burn natural gas, much of which is produced in the United States. The increasing diversity helps insulate the economy from price shocks, interruptions, and fuel shortages (Herzog, Lipman, and Edwards 2001).

Although estimates vary, total-customer owned generation of distributed resources remains comparatively small, although it is expected to grow rapidly. The Energy Information Administration classified only 0.5 percent of electricity generation in 2000 as “nonutility” generation while noting that cogeneration systems in industrial sectors produced 3.6 percent of electricity for their own use (Congressional Budget Office 2003). However, an Electric Utility Consultants (2004) study concluded that distributed generation units—classified as decentralized generators between 1 and 60 MW—provide an aggregate capacity of 234 gigawatts (GW) through approximately 12.3 million units. (The total capacity of American power plants in 2003 was 948 GW). The American Gas Association (2000), meanwhile, predicted that renewable energy technologies will provide over 15 percent of electricity in the United States by 2020, and the U.S. Department of Energy’s Energy Information Administration (2000) projected that distributed generation technologies will likely surpass 25 percent of electricity generation by the same year.

Regardless of these projections, proponents of distributed generation caution that DG technologies are not designed or intended to replace the power grid. The United States Combined Heat and Power Association notes that DG facilities could not reliably serve as substitutes for all large, centralized power plants since they cannot meet all customers’ needs (especially customers in urban areas with severe land, permitting, and citing constraints) (Fallek 2004). The American Wind Energy Association (2004) adds that wind turbines will primarily augment, rather than replace, the grid.

As compelling as DG appears, the transition to a new paradigm that employs it widely will not necessarily occur smoothly due to a host of social, technical, and political impediments. By far the largest social constraint consists of the belief that renewable energy systems and decentralized units have higher operating costs than large centralized facilities. As a result, many policymakers and consumers believe that renewable technologies have not become cost competitive with traditional fossil fuel sources of electricity (Pepermans 2003; Colorado Renewable Energy Society 2002). In addition, the financial payback period for renewable energy systems still appears too long for fiscally conservative customers. Businesses often look for two to three year timeframes for obtaining a positive cash flow after making capital investments. Yet wind turbines require about six to nine years for payback, and their installation sometimes suffers from long project lead times, lack of suitable service infrastructure, and poorly developed sales channels (Rendon 2003; Liss 1999).

The biggest technical impediment consists of connecting DG technologies to the grid. This interconnection challenge really constitutes a set of related smaller problems: voltage control (keeping voltages within a certain range), the balancing of reactive power (using power to regulate the flow of alternating current to maintain proper grid synchronization), and safety (ensuring the adequate protection of people working on the grid) (International Energy Agency 2002, 73-75). Currently, those using DG technologies often depend on custom-designed electronics packages to solve these problems. The great expense in developing such packages obviously creates a disincentive for new users (Ostergaard 2003; Pepermans 2003).

Perhaps more significant are the challenges relating to regulatory and political inertia within the United States. Lingering monopoly rules and discriminatory rate structures still create political obstacles towards investing in DG technologies. Customers who seek to use DG often face high exit fees imposed by utilities that seek to recover stranded costs. Further giving an unfair advantage to existing producers, utilities and other owners of old coal-fired power plants have won exemption from 1970 Clean Air Act. These “grandfathered” plants can often operate more cheaply than any type of new generation technology. They therefore enjoy an artificial advantage over some DG technologies, which must meet current and future environmental standards (Casten 1998, 203; Meyer 2003).

Conclusion

The tentative move toward DG represents a somewhat paradoxical return to the electric utility industry’s roots. Thomas Edison inaugurated the industry in 1882 when he supplied direct-current (DC) power to a host of nearby businesses in the financial district of New York. Because DC power could not be transmitted over long distances, Edison hoped to sell small-scale generation equipment to commercial customers (such as hotels and industrial firms) that had large demands for electricity. Individual homeowners would be served by small power stations like Edison's original, which would be dotted throughout cities at regular intervals. This model, of course, became displaced by one that employed large centralized power stations to create huge amounts of power sent over alternating-current transmission networks. Overcoming the problem of limited distance distribution posed by Edison's DC arrangement, the AC approach lent itself better to the economies of scale that became apparent in generating equipment over the next eight decades.

But even consideration of a return to the use of distributed generation resources highlights the significant change in momentum that has occurred within the electric power system. Unlike in the period from the early twentieth century to the 1970s, the technological basis for the system remains in flux today: large-scale generation and transmission technologies no longer offer prized economic benefits, and they recently have begun to be seen as security and reliability threats to a society that increasingly depends on electricity. The experience contains parallels with other industries that once valued large scale. In the steel, biotechnology, agriculture, microelectronics, pharmaceutical, and mining industries, companies have recently employed small-scale technologies to gain increased flexibility, security, and lower costs.

The utility system's momentum has been altered by more than the shift away from traditional large-scale technologies. It has also been changed by those who wield economic and political power. As utility managers lost the benefit of state regulation, which previously guaranteed their companies' status as natural monopolies, they found themselves competing with entrepreneurs who employed small-scale technologies. Simultaneously, other supporting stakeholders (i.e., financiers, equipment suppliers, academic institutions, and politicians) abandoned their former allies, realizing that they could benefit from making alliances with new players in the system. As utility managers lost control over the system, new players, such as environmental advocates and policy makers, sought to advance their own (and different) visions of a utility paradigm. During the chaotic first years of the twenty-first century, the old and new stakeholders have not yet reached consensus for a new paradigm for the utility system. In such an untidy environment, advocates of distributed-generation technologies have seen opportunities to redirect the system's momentum.

If nothing else, this study of the American electric utility system demonstrates that systems with momentum do not carry that momentum indefinitely. Evolving systems are not, as Hughes (1983) pointed out, "driverless vehicles carrying society to destinations unknown and perhaps undesired" (462). Rather, human stakeholders play important roles in channeling momentum. Though they may not always realize the consequences of their actions—contributing to forces that alter momentum in unanticipated ways—people remain at the core of technological systems because of their concern for political control, influence, money, and power. This conclusion suggests the value of the systems approach for teaching about technology and society in school at several levels. In particular, the approach reveals the subtle and explicit interdependency of hardware and nontechnical elements in modern society.

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One Man One Vote: Trust between the Electorate, the Establishment, and Voting Technology

Laurie Robertson

Election Day 2004: A voter arrives in person to a polling location, which although a temporary setup projects an image of impartial integrity. Bland signage, temporary tables, voting machines and other election paraphernalia turn a school gymnasium or a civic center into a sacred space. Upon entering the polls a voter approaches a table where a series of rituals (e.g., appropriate identification, verbal affirmation of name and residence) verify his or her registration and identity. After the officials perform a mysterious rite with the poll book, the voter is provided with a sacred token, be it a paper polling pass or a DRE smart card, and is admitted to vote. The voter exchanges the sacred token with an official who escorts the voter to the hallowed machine with allows him to perform the holy rite of democracy – voting. Ordained election officials protect the integrity and sanctity of the machines and space throughout the day and it is these officials who perform the all-important, but private ceremony, of the tally and report of the votes. After this official sanctification, the results are publicly ordained and once again the “voice of democracy has spoken.”

Of course, voting realities are much messier than this idealized account promulgated by the electoral establishment. The seminal image of

Election 2000 was the Florida election official behind a magnifying glass examining a circa-1960s mainframe computer punch card with Republicans and Democrats arguing the legal fine points about hanging chads. For the electoral establishment, which presents itself as a protector of voting integrity, it was a retro-embarrassment. It was "obvious" to legislators, lawyers, and election officials that "obsolete" voting technology had failed and the perpetuation of American Democracy required a massive technological upgrade. As a result, in 2002, Congress passed the Help America Vote Act (HAVA), which provided over $325 million for states and localities to upgrade their current "presumably obsolete" voting technologies. For technological advocates "modern" electronic voting equipment, many designed using banking's "familiar" automated teller machine (ATM) paradigm, would solve many if not most of Election 2000's technological problems.

However, most academic and popular post-Election 2000 critiques (especially the many electronic voting accounts) focused on voting technology and overlooked the fact that voting machines and systems are technologically-situated. Technological advances completely outside the electoral realm can significantly impact the perceived "trustability" of a voting technology. For example, in the late 1800s, mechanical lever machines were introduced as a "state-of-the art" advance from handwritten ballots to "solve" the problem of human interpretation and ballot box tampering. With the emergence of mainframe computers in the 1960s, mechanical lever machines seemed "old-fashioned" and "state-of-the-art" optical and punch card technology offered a modern mechanism to rapidly process results and "solve" human calculation errors. Now with widespread personal computing and banking automated teller machines, the mainframe technologies that epitomized Florida 2000 seem antique and the rush is on to replace them with more "accurate" state-of-the-art electronic voting technology.

Historically any U.S. voting technology is burdened from its very inception with the expectation of technologically ensuring voting integrity. Beginning with Thomas Edison in 1869 and continuing today, numerous U.S. manufacturers have produced machines and systems to "protect the voter from rascaldom" (Phillymag). Voting is an officially sanctioned social activity/ritual in a technologically-focused nation, so U.S. voters arrive at the polls expecting that voting technology will ensure that their vote "counts."

But no matter what voting technology is used, any election system must be approachably voter friendly while simultaneously satisfying hard technical criteria such as system reliability and availability, integrity, data confidentiality, operator authentication, and system accountability (Mercuri, 33-34). Forgotten in the post-Election 2000 rush to modernize is the perception risk inherent in any technological transition. Even "primitive" election techniques such as paper ballots bear the imprimatur of established voting technology. In the case of electronic voting machines, voters and election officials must gain confidence and comfort with the new technology. Until that occurs, the number of voting errors (probably mostly unintentional) may actually increase. For example, the Caltech/MIT Voting Project statistically analyzed voting results in all U.S. counties that changed their voting technology between 1988 and 2000 and found that only optically scanned ballots offered similar rates of reliability (as measured by residual voting) as lever machines. Despite their ballyhooed promises, Direct Recording Electronic (DRE) machines performed equivalently well as "discredited" punch cards and significantly worse than paper ballots (Alvarez). Conduct this transition in an environment of electoral and media hysteria and it is not surprising that public confidence in the establishment is shaken.

The mantra of the U.S. voting establishment is "One man, one vote," so it is understandable that voting machines are the lightening rods for electoral integrity, but voting is a process performed and administered by humans. No matter what voting technology is used, cumulatively individual mistakes and misperceptions can undermine voter confidence. Electronic voting machines may be problematic, but so are the other election technologies. There will never be a perfect election, but perception is everything. Today, voter concerns regarding electoral integrity are epitomized by not only by past (e.g., punch cards) but current (e.g., DREs) computerized voting technologies. Voters want to believe that their vote counts and that it is counted properly. Post-Election 2000, the election establishment is under increasing scrutiny and technology alone will not solve the problem.

Ironically the current electronic voting hysteria focuses on one of the more trustworthy components – the technology of voting. Individual voting technology, such as lever machines, punch cards, and DRE may be problematic, but they are only a part of an underlying electoral establishment. It is here that numerous new technological issues emerge. Voters need to believe that their vote actually "counts" otherwise they will not bother to participate. Procedural rituals such as voter registration, poll-side voter identification, and official ratification are designed to create trust in the overall voting establishment. The modern U.S. voting establishment bases its legitimacy by pre-qualifying and registering acceptable voters prior to an election, then on election day publicly verifying their acceptability prior to permitting them to anonymously vote, then performing elaborate official post-electoral rituals to reconcile any voting discrepancies. This admirable Norman Rockwell-type portrayal was never attainable but especially not in this post-Election 2000 world. Although most electronic voting accounts focus on technological disenfranchisement, there are numerous other non-DRE means by which a voter may end up disenfranchised and most do not involve technology.

Underlying the United States voting process/establishment there is a fundamental paradox – a citizen must personally publicly certify his or her identify prior to being permitted to vote anonymously. Consequently, any U.S. electoral mechanism be it manual or electronic, is expected to produce an official trusted auditable record of anonymous votes cast by approved voters. In the idealized election establishment world, jurisdictions vet, pre-approve and publish on approved voters on registration roles; on Election Day officials challenge prospective voters to validate their legitimized identity and if approved the individual voter is allowed to vote anonymously. Over time, various registration voting and validation rituals have evolved – from the registration oath (even if administered in a grocery store by a League of Women Voters' representative) to the name and address declaration at the precinct poll books.

Successful voter registration is a critical entry point for voting in most U.S. jurisdictions. Voters who identify themselves, affirm their eligibility, and declare their intent to vote are added to the election rolls from which poll books are produced containing lists of the approved voters for an election. Poll books in most jurisdictions serve as the primary gatekeepers for voting. Affirmed voters listed in the book are permitted to vote and the overall experience is positive; but for unlisted voters the experience may quickly degenerate into a frustration of potential disenfranchisement. Even in today's post-1960s Civil Rights and Election 2000 environment, the electoral landscape consists of a mind-numbing number of widely-varying state and local procedures to handle not only routine but especially anomalous voting circumstances. Given this patchwork of voting laws and procedures it is not surprising that many denied voters are left with the impression their right to vote was unfairly denied.

Although most jurisdictions use computers to maintain their voter registration lists and produce their poll books, technology is not usually at fault here. Typically, an individual doesn't appear in the poll book because he or she moved and didn't update their registration, he or she didn't register in time, or he or she hadn't voted for a significant period of time and were dropped from the rolls. These long-standing factors are social not technological; however, recently Federal legislation has muddled the situation and introduced unanticipated technological consequences. Today, a registered voter may requested to produce an "H" (the Arlington County Virginia code for post-Help America Vote Act [HEPA] registered voters) acceptable form of identification; and here Federal and state laws regarding acceptability vary considerably. For example, Virginia state law accepts employer photo identification as an affirmation of identity; while other states and Federal (HEPA) standards disallow it. Given these continuing jurisdictional inconsistencies it shouldn't be surprising that individual disenfranchisement persists in electoral debate. The question to be asked is how much is intentional and how much is inadvertent.

Elections are administered by a small core of professionals who oversee a large army of volunteers that provide not only labor but the personal face of the electoral establishment. These well-intentioned volunteers, with their varying experiences, temperaments, and abilities are provided with rudimentary training, then officially sanctioned and thrown together to administer an election. Their personal demeanor and decisions can significantly affect whether a voter feels enfranchised or not. Unfortunately training for these volunteers is woefully inadequate. Many jurisdictions conduct two- to four-hour classes for the poll workers in which they try to cram in basic election logistics, machine and polling place operations, and procedural checks and balances, but with so much to cover there is little time to assimilate the material. Furthermore, on Election Day these individual volunteers, who may or may not know each other, are thrown together and expected to operate as a team. The election establishment could easily improve the quality of its volunteer workforce by conducting more hands-on training and training precincts staff together.

In the post-Election 2000 climate, voters are extremely sensitive to perceived improprieties and any non-routine event can be cause for suspicion. Although most voting is routine (i.e., voter is verified, voter is admitted, voter votes), there are also anticipated non-routine events (e.g., special registration codes). Some jurisdictions provide election officials with "What If" reference sheets to assist in these non-routine situations while others rely upon individual judgment. As a result, a given situation (e.g., voter does not have appropriate identification) may be handled differently by different volunteers in different jurisdictions. For example, at one precinct a voter without identification may be denied entry, at another given a provisional ballot, while at a third given an affirmation of identity form. These inconsistencies are primarily inadvertent but they undermine the public's confidence in the electoral system. The election establishment could easily improve the consistency of non-routine events by providing poll workers with standardized state-wide reference sheets.

Voting technology was a prominent Election 2004 focus. In the wake of Florida's spectacular Election 2000 meltdown and numerous reports of pre-Election 2004 technological failures, voters entered the polls extremely sensitive to any hint of disenfranchisement. Many jurisdictions had used the post-Election 2000 Congressional HAVA money infusion to upgrade their voting machines to more modern technology, but for their voters this was the first election using new "state of the art" technologies such as computerized touch screen Direct Recording Entry devices. Due to this combination of voter technological unfamiliarity and hysterical pre-election publicity. The electorate voted warily. Sensitized to and "educated" about numerous "short-comings" of DRE technology, voters in Election 2004 came to the polls anticipating technological disenfranchisement. Congress and the electoral establishment pursued technological fixes, but slighted the social environment and implications of their deployment. The electoral establishment needs to recognize that most voters are not familiar with the full body of election procedure and how non-routine events may be perceived by the average voter in line. For example, Virginia law allows a physically disabled voter to vote outside the polls and in Arlington, this requires disconnecting a DRE device and taking it outside; this is in fact an anticipated non-routine event (in fact poll workers were trained on it), but in my precinct it caused considerable concern for several voters waiting in line. The election establishment could easily allay voter concerns by providing simple signage for non-routine events (e.g., signage for "Curbside Voting" or for routine poll book codes such as "H" means they registered after HAVA) would greatly alleviate many voters' post-Election 2000 concerns.

For Langdon Winner, technologies embody their politics and no technology is more political than election machines; however there is a significant inverse difference – while Winner sees politics embodied by technologies, voting machines are technologies encumbered by politics. U.S. voters go to the polls expecting that the U.S. voting establishment has provided them with a technological voting system that will ensure their votes are counted. When the system fails, as so many modern technologies do, the first inclination is to blame the technology. Voting machines are only a part of the overall electoral system but they are the most visible, attracting the focus of the both the popular press and academics.

As a technology, voting machines – from "obsolete, problematic" punch cards to "modern, unreliable" computer devices – have become the poster-children for post-Election 2000/2004 voting controversies, but as this article has shown despite their popular prominence voting machines are only a technology situated within an electoral infrastructure. While voters and the popular press obsess about new or obsolete voting technology, the overall establishment remains pretty much unchanged; consequently, it should not be unexpected to read about controversies in Election 2008.

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The Epistemic Value of Cautionary Tales

William M. Shields

> *Twice in NASA history, the agency embarked on a slippery slope that resulted in catastrophe. Each decision, taken by itself, seemed correct, routine, and indeed, insignificant and unremarkable. Yet in retrospect, the cumulative effect was stunning. In both pre-accident periods, events unfolded over a long time and in small increments rather than in sudden and dramatic occurrences. NASA's challenge is to design systems that maximize the clarity of signals, amplify weak signals so they can be tracked, and account for missing signals. For both accidents there were moments when management definitions of risk might have been reversed were it not for the many missing signals – an absence of trend analysis, imagery data not obtained, concerns not voiced, information overlooked or dropped from briefings. A safety team must have equal and independent representation so that managers are not again lulled into complacency by shifting definitions of risk . . . Because ill-structured problems are less visible and therefore invite the normalization of deviance, they may be the most risky of all.*
> – Vol. I, Section 8.5, *Report of the Columbia Accident Investigation Board* (August 2003).

For those involved in any way with the creation and management of modern technology, the report on the loss of the space shuttle *Columbia* (NASA 2003) should be required reading. Technically accurate and devoid of hype or newsroom exaggerations, the report's spare prose offers a warning that should shake both young engineers learning their trade and their older counterparts who may have drifted into management and finance. In the densely-packed pages of the report, we read of a faulty design never corrected, of precursor events that came to be accepted as ordinary, of many chances to assess the damage to the spacecraft left lying on the table, of warning voices ignored in the name of pushing ahead with the mission, and of the many counterfactual cases that might have led to a lost spacecraft but a living crew.

The cautionary tale has become something of a cottage industry in the past decade. To be sure, there has been plenty of material for these publications: Bhopal, Chernobyl, *Exxon Valdez*, Three Mile Island, and *Challenger* have entered the lexicon as virtual synonyms for "disaster." One of the more readable and fascinating of the cautionary-tale collections is *Inviting Disaster* by James Chiles (2001). Of the cautionary tales Chiles tells, I have personal knowledge only of Three Mile Island, and as to TMI his work is accurate. Most of the stories make chilling reading, yet not because of the deadly outcome. They are chilling because of their "disaster-waiting-to-happen" atmosphere. My own favorite is "The Really Bad Day," the story of American Airlines pilot Bryce McCormick attending training school as an introduction to the new DC-10 jumbo jet. In the course of inspecting the new airliner's cargo bay, McCormick observed that the triply-redundant hydraulic systems for the aircraft's control surfaces all ran in the same area of the cargo hold, and due to the aircraft's immense size, there were no manual backups. In terms of safety engineering, he had stumbled on a "common mode failure" that made him nervous. That nervousness led him to teach himself to fly the huge airliner by balancing engine power, simulating the loss of all control circuits. This new skill very soon became the only safety feature standing between total disaster and a safe if shaky landing. This story contains a least two valuable lessons: the ease with which well-intentioned design can be defeated by human error; and compensation for that critical error by another individual's powerful sense of personal responsibility.

After thirty years in the nuclear industry, both commercial and defense, I need very little convincing that cautionary tales of this kind are important. Much of my career has been focused on protecting nuclear materials from the consequences of fire. The near-disaster that was my first exposure to a cautionary tale was a dangerous fire at TVA's Browns Ferry Nuclear Station in 1985. (NRC 1975) This fire heavily damaged the plant's control systems, and a meltdown was averted only by a combination of human action and conservative design. The fire was started by a candle held inside a wall to look for ventilation leaks. A taper candle and the human being holding it nearly melted down the core of a nuclear generating station. Ten years and uncounted millions of dollars later, U.S. nuclear power plants had been redesigned and rebuilt to prevent and mitigate fires.

Let me return now to the *Columbia* report. This was indeed an "accident waiting to happen." All of the elements were there: faulty design, failure to thoroughly consider the worst-case consequences of the design flaw, refusal to take actions to assess the possible damage after launch, decision to go ahead with reentry without any knowledge of the condition of the spacecraft. These elements can all be thought of as arrows or vectors, converging on a single event that cost the lives of the crew, destroyed the spacecraft, threatened the survival of the space station, and heavily damaged the reputation of NASA. Those vectors were created and aimed by *individuals* as well as management practices and organization charts, though we hesitate to assign personal blame for loss of life. Strangely, in the United States we seem more than willing to fix blame on individuals (e.g., the Enron executives) when mere money is lost. I don't believe anyone has been charged with negligence as a result of *Columbia*'s needless destruction.

Of what value are these cautionary tales? Do we read them with fascination just to experience the sense of relief that "It wasn't me" or "It wasn't my fault?" If so, then we gain no real value from them. They need to be read for more than that, and whatever that "more" is, it needs to be incorporated into engineering curricula, drummed into the heads of all technologists, and perhaps made the basis for Enron-like prosecutions of individuals. How do I as an engineer know when I may be participating in a cautionary tale *as it is unfolding*, and what can I do as a responsible human being to make a difference in the outcome? It is not enough, it seems to me, to argue that meeting a code of ethics is the limit of our responsibilities. That is not to dismiss the codes; they are important in their own sphere of relevance. But no code of engineering ethics imposes the generalized burden of watching for the precursors of failure and taking timely actions (even at the cost of career damage) to change the course of events.

Perhaps the fundamental difficulty in learning from cautionary tales of man-caused disasters is epistemological: what kind of *knowledge* do these tales constitute? As engineers and scientists, we are most comfortable thinking in a straightforward causal fashion, i.e., if I do X the likely result is Y. If I provide the code-required safety margin for structural strength of a steel beam, the likely result is that the beam will remain intact following an earthquake. Most engineers who have to consider safety are also comfortable with what is termed "failure modes and effects" analysis. If the beam does fail in an earthquake, what else will happen? How many beams must remain intact before structural collapse follows?

Cautionary tale scenarios involve a different kind of causality. In analyzing technology-related disasters after the fact, we find ourselves examining causal sequences that had no apparent connection to one another. For example, one causal factor may be a component part that was properly procured according to the correct specification. How could that be a cause? Because it may turn out that the specification itself is not adequate given an unanticipated series of events. Foam regularly broke off the shuttle booster tank and struck the vehicle on ascent, causing some minor tile damage. After a number of such occurrences, NASA managers assumed that the vehicle was built sturdily enough to withstand these impacts, without really considering what might happen if the impact occurred in a slightly different way. On the *Columbia* mission, the foam punched a hole in the wing rather than damaging a few tiles. The result was catastrophic failure once the decision was made to land without examining the hull.

Let me give another illustration from my own field of fire protection engineering. In July of 1998, a team of trained workers was preparing to conduct preventive maintenance on Idaho National Laboratory's Engineering Test Reactor. The high-voltage equipment to be serviced was located in a large room protected by a total deluge carbon dioxide suppression system, automatically actuated by a modern fire control panel. Naturally the power to the area was to be cut off before the work began. The workers entered the area with portable lights powered by long cables from an adjacent area. When they were in position to begin work, the power to the area was shut off, momentarily plunging the room into darkness. Before the workers could turn on their portable lamps, the CO-2 system discharged without warning, creating total whiteout conditions as the gas condensed into snow. Visibility fell to zero. Some workers near the exit door managed to escape before breathing the gas. One worker held his breath but ran the wrong way, ending up at a locked door. He smashed a glass pane with his hand, severely lacerating his arm, then passed out. Several other workers collapsed before reaching the exit. Those who made it out found they had no breathing air equipment available; it had to be obtained from a cabinet some distance away that was found to be locked. By the time breathing air could be brought back to the area, one trapped worker had died. But for the selfless actions of fellow workers and others who were nearby, there could have been many more fatalities.

What went wrong? The CO-2 system had been disabled by a software command entered into the fire control panel. Why had it discharged instantly when power to the fire control panel was shut off? The system was designed to give an audible alarm 30 seconds before discharge; no alarm had sounded. This question turned out to be very difficult to answer, but eventually the cause was found. The alarm panel was equipped with batteries, and automatically switched to that power source when line power was lost. But in that short space of time while battery power was being activated, the panel's circuitry sometimes, but not always, generated an activation pulse that went directly to the CO-2 system's control valve, bypassing the alarm/delay circuit. This event was very hard to duplicate because the panel did not send a spurious pulse in every case of power transfer.

This was a subtle failure mode. But is that what *really* went wrong in this cautionary tale? Would replacing the control panel be a suitable response? The fatality was also caused by an excessive reliance on the fire control panel, by a lack of planning for the eventuality of a system discharge, and by the failure of anyone to take a truly cautious attitude toward what was clearly a life-threatening hazard. The result was that workers had been placed in an unfamiliar room filled with CO-2 discharge heads isolated from pressurized tanks by a single valve controlled by computer software and circuitry. All of the "arrows" were pointing in the same direction, turning what should have been a routine electrical project into a disastrous situation depriving one man of his life and threatening many others. The post-accident report (DOE 1998) identified all of these factors, of course, and recommended specific and appropriate changes. But my point in relating this story is to ask the epistemic question: what kind of knowledge was needed a day before this fatal accident occurred to prevent it from happening, and what might cause that knowledge to be actionable. It is a strange sort of knowledge and not at all what engineers are used to dealing with, because it cannot be read in a textbook, calculated from an equation, or even acquired by reading cautionary tales. Perhaps *knowledge* is not the right word: what is needed is more a form of intuition arising from a suitable combination of attitude, assignment, experience, and technical understanding. This is not "quality assurance" or "discipline of operations," because these functions tend to be controlled by consensus standards and practices. Decisions to launch the space shuttle and to permit its reentry are tightly constrained by myriad procedures, checkpoints, concurrences and the like. Unfortunately, the end-oriented pressure of unrelated causes can overwhelm these well-intended precautions.

In cautionary tales, what we see is a causal sequence in which many unrelated factors seem to converge, almost conspire, to bring about an unexpected and usually undesirable result. The individual factors are *not* the common cause events engineers are trained to look for, such as the multiple redundant hydraulic systems running right alongside each other in a aircraft. As in the case of the *Columbia*, we see *after the fact* a combination of largely independent causes involving hardware, systems, operations, and human judgment. For this reason, the more typical responses to cautionary tales often do not prove effective in doing much more than preventing that particular event sequence from occurring again.

I am well aware that some critics of complex technological systems urge that we look for new, less complex forms of technology that will somehow be less vulnerable to failure. Unfortunately, these well-meaning suggestions are misguided. Nearly all of the cautionary tales I have studied do not reveal a pattern of complexity as the principal cause of calamity. We are not defeated by complexity itself, nor are complex systems necessarily more hazardous than simple ones. Claims that we have overreached ourselves, that our technologies have become inherently uncontrollable and hence dangerous, are in my view groundless. There is no turning back to a simpler time, because the history of technology shows that earlier eras were in no measurable way more benign in terms of human safety. Carriages with spindly wooden wheels drawn by teams of massive horses threatened both riders and pedestrians. Sailing across huge spans of ocean in wooden ships bearing cloth sails was frightfully hazardous. Those beautiful, romantic steamboats ended many lives when their primitive boilers exploded. We will not find greater safety in a strategic retreat to less complex technologies.

We do need, however, to raise our level of thinking about the ways the modern technological systems can fail us and do harm, even after we have provided what we believe to be a conservative design and have tried to behave in ways we imagine to be safety conscious. Specifically, we need to learn new ways to approach the causality reflected in the cautionary tales of our times, to go beyond narrow, event-driven technical fixes and organizational changes. It will not be enough to approach the problem as one of design: the best design can always be defeated by human error and unusual circumstances. We will never succeed in preventing *Columbia* or TMI-type accidents by better design practices alone. Design fixes will prevent the accident that has already happened, but they will not anticipate or prevent a different cautionary tale from being entered into.

I believe that we need to develop a heuristic methodology that teaches us to think in somewhat teleological terms, as if we are looking backwards from a potential catastrophic event to see how current actions and events may be contributing to an as-yet-unrealized accident sequence. We have to find the vectors that point toward the unexpected failure before they are allowed to converge and reinforce each other. In short, we need to develop a sense of when "an accident is waiting to happen." This is easy enough to say, but very hard to do. Thinking in this backwards fashion is not part of our training and in a sense is counterintuitive. How can we evaluate what we are doing in light of an end-state that we cannot fully specify?

Time and effort will be needed to work out a methodology of this kind. One step has already occurred, at least to a degree. There is a growing literature on cautionary tales that provides valuable case studies. (Dörner 1989; Duffey 2003; Perrow 1999; Sagan 1993; Tenner 1996) More needs to be done, to be sure, and at a level of technical sophistication that is meaningful for engineers and other technologists. The *Columbia* report sets a high but not unattainable standard. We need to study all of the unexpected causal chains, all of the events that seem to have confounded our ability to design and operate technological systems safely.

The next step is to work this line of inquiry into our academic institutions, where teachers and students alike may have the time, energy, intellectual prowess, and objectivity needed to make progress. I am proud to report that my alma mater, MIT, now offers a course to engineering students entitled " Colossal Failures in Engineering." The course is focused on:

> Case studies of known "colossal failures" from different engineering disciplines. Includes the collapse of the World Trade Center, the *Columbia* Space Shuttle accident, and the melt down at Chernobyl. Basic engineering principles are stressed with descriptions of how the project was supposed to work, what actually went wrong, and what has been done to prevent such failures from reoccurring.

This is headed in the right direction, but we must be cautious about being too quick to find "what went wrong" and "what can be done to prevent it." It is easy for engineers in particular to seek the single, dominant "cause" and then identify a "fix." Preventing the same failures from occurring is generally not that difficult once the analysis is done. I would like to see courses like this focus on how those involved with the colossal failure might have anticipated it and then prevented it. We want to learn how to close the barn door *before* the horses get out.

Any methodology we might come up with must be tested, of course, in the real world of engineering design and management of complex systems. This means taking the bold step of embedding in our technological infrastructure an intuitive, somewhat teleological function, assigned to highly-trained and experienced persons whose sole responsibility is to search out "accidents waiting to happen." Perhaps this notion would not meet with much resistance, as it sounds like—though it is not—a somewhat more fancy version of quality assurance. The hard part is ensuring that those who design, build and manage complex technological systems listen and respond to the voice of the Cautionary Tale Division. Consider: it would have taken only one NASA senior manager to demand that *Columbia*'s true condition be ascertained before ordering the reentry.

What I am arguing for, in the end, is a new approach to the managing of technological risk, one that can identify a dangerous condition caused not by a single error in design or maintenance but by factors that may appear on the surface to be unrelated. If such an approach can be found, it must then be embedded in the management systems we use to control our most complex and hazardous technologies, from the space shuttle to the electric power grid. The cumulative impact of decisions made by individual managers are the divider between safety and disaster. These decisions can and should be informed, and when needed deflected, by the analytical capability of seeing *when* we are in a cautionary tale before the "accident waiting to happen" is upon us.

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The High-Level Radioactive Waste Policy Dilemma: Prospects for a Realistic Management Policy

Constantine Hadjilambrinos

Introduction

Since the dawn of the atomic age, the United States and every other nation that has chosen to use nuclear power have created hazardous substances that have the capacity to outlast human civilization, and possibly even the human species, and the potential to devastate the environment. The management of these substances that make up what has been termed high-level radioactive waste (HLRW) has presented a set of technical and socio-political challenges that are matched by few, if any, other science and technology policy issues. For the purposes of this discussion, high-level radioactive waste consists of spent fuel from civilian and military reactors, as well as transuranic waste which comes primarily from the fabrication of nuclear weapons. The most serious of these challenges stem from the fact that this type of waste is extremely harmful to all life and will remain so (and, therefore, must be secured) for a period of time that is beyond anything in human experience (at least 10,000 and, possibly, more than 1,000,000 years). The time frame over which the waste will remain dangerous depends on its composition and, to some extent, on the definition of what constitutes a dangerous level of radioactivity. In terms of spent reactor fuel, composition is a function of the type of reactor and on whether or not re-processing takes place.

U.S. policy for the management of HLRW has focused on long-term (permanent) containment which still has many technical and policy issues to overcome. This focus has been to the detriment of medium-term containment—in fact, existing U.S. law explicitly prohibits the federal government from developing an interim (e.g., medium-term) repository for HLRW before a permanent disposal facility is operational. Medium-term containment presents technical and policy challenges that are inherently much easier to address than permanent disposal. This article argues that without a coherent national policy for medium-term containment, the U.S. HLRW management system is compromised, and the risks to human health and the environment are made higher than they need be.

Problems Inherent in the Permanent Isolation Option

The focus of national HLRW management policy on permanent isolation of this waste from the environment has been long standing. As early as 1956, when the nation's civilian nuclear power program was little more than a research effort, the U.S. Atomic Energy Commission (AEC) promulgated regulations that, in effect, required all highly radioactive wastes to be permanently removed from the environment (Hewlett, 1978). The scientific consensus at the time was that geologic disposal (a method whereby stable geologic formations constitute the final barrier to waste dispersal into the biosphere) was the only realistic disposal method offering the possibility of permanent isolation. This consensus was expressed in a report prepared by the National Research Council of the U.S. National Academy of Sciences (National Research Council, 1957).

In accordance with the findings of this report, the AEC began the search for an appropriate site in which to construct the first permanent geologic repository for spent fuel from civilian nuclear power plants (none of which yet existed)—a search that continues a half century later. The quest for a permanent geologic repository site which was begun by the AEC and was continued by its successor agencies, the Energy Research and Development Administration (ERDA, extant from1974 to 1977) and, since 1977, the Department of Energy (DOE), faced several setbacks over the years. The investigation covered numerous sites in 36 states but failed to identify a single suitable location. The failure was in some cases due to the clearly inappropriate characteristics of the geology of the site, but was more often due to political opposition which made it impossible to even begin to study a site's geology in any detail (Easterling and Kunreuther, 1995, pp. 26-34).

The setbacks in the search for a geologic repository site led to the consideration of other possibilities, still, however, with the purpose of permanent disposal. Consideration was given to deep sea disposal, extraterrestrial disposal, and conversion of radionuclides to stable nuclides

(Hewlett, 1978, Hadjilambrinos 1999). Each of these options presented its own set of difficult challenges, but they were afforded serious consideration because they offered the possibility of reducing domestic political opposition to HLRW disposal efforts.

Deep sea disposal proposals envisaged burial of the waste in sub-seabed geologic formations. This meant that this option was essentially a variant of geologic disposal. As such, its primary advantage was that it would remove the waste a safe political distance from any voting constituency's "back yard." While offering a few technical advantages, it presented additional technical problems (such as the need for special emplacement technologies) and policy dilemmas (such as restrictions imposed by international treaties) which made it impractical as an alternative to geologic disposal on land (Miles, Lee, and Carlin, 1985).

In the mid-1970s, disposal in space was considered to be a viable option for the disposal of some of the most hazardous components of spent nuclear fuel: the actinides (NASA 1973-1974). Thus, this option would necessitate significant processing of HLRW and would not eliminate the need for terrestrial disposal of the remaining components of the waste. A 1982 study concluded that at least 750 space shuttle flights would be needed to carry even the significantly reduced volume of actinide waste into space, and it also estimated that the risk of a catastrophic shuttle accident would be very small (about 1 in 2,000 launches) and the risk of release of waste material would be negligible: about 1 in 100 million (Rice, Denning, and Friedlander, 1982). The accident that destroyed the space shuttle *Challenger* in January 1986 (after only 24 shuttle missions) cast serious doubts on the basic premise these calculations were based upon. The *Columbia* accident, seventeen years and 87 shuttle missions later, along with NASA's inability to achieve the launch rate for space shuttles that was projected in the early 1980s, essentially removed extraterrestrial disposal of any portion of HLRW from any realistic consideration in the foreseeable future.

The third option studied as an alternative to land-based geologic disposal, the conversion of radionuclides to stable nuclides, could be considered the ultimate "technological fix" to the HLRW disposal problem because it would actually eliminate this type of waste. However, the processes to this end that have been studied thus far have only been able to eliminate miniscule amounts of HLRW, and most have generated a significantly greater volume of intermediate and low level radioactive wastes (Lenssen, 1991). Despite some recent advances in this area, no proposed method has been shown to be even close to becoming feasible at the necessary scale (International Atomic Energy Agency, 2000).

As none of these three options proved to offer a viable alternative to land-based geologic disposal, the search for a geologic repository site by the AEC, ERDA and, finally, DOE continued. However, political opposition thwarted the efforts of four consecutive administrations to identify an appropriate site and, in 1982, the U.S. Congress took action to resolve the HLRW disposal issue. With the passage of the 1982 Nuclear Waste Policy Act (NWPA), the nation's commitment to geologic disposal was not only reaffirmed, but actually codified into law. The NWPA directed the DOE to investigate a variety of sites throughout the U.S. for their potential to host a geologic HLRW repository. The law assigned the responsibility for drafting the radiation release standards to which any proposed repository would have to abide to the Environmental Protection Agency (EPA), and gave responsibility for repository licensing to the Nuclear Regulatory Commission (NRC). The law required the DOE to investigate sites throughout the nation and propose a list of six candidate sites, three of which were to be in the eastern half and three in the western half of the U.S., to Congress which would select one site in each half of the country for the development of two HLRW repositories.

This attempt, however, to cut through the political quagmire by an exercise of political will did not produce the anticipated results. Pursuant to the directives of the NWPA, in 1983, the DOE selected nine locations in six states for consideration as potential repository sites. Each of these sites had been the subject of study already for a number of years. However, the investigation of multiple sites facilitated the coalescence of political opposition that became strong enough to stall the process. Consequently, after five years of no progress, Congress intervened again, passing the 1987 Nuclear Waste Policy Amendments Act (NWPAA). This law ended the investigation of multiple sites by directing the DOE to study only Yucca

Mountain, Nevada, for the purpose of determining whether or not the site geology is unsuitable for hosting a permanent HLRW repository. Changing the objective of the site characterization study from determining the suitability of the site to determining whether it is unsuitable essentially eases the burden of proof. In the first instance, it is necessary to positively prove that releases of radioactivity will remain within the limits set by the EPA. In the second instance, it is only necessary to show that there is no evidence that the EPA standard will be violated.

Status and Prospects of Yucca Mountain

The NWPAA succeeded in overcoming the political opposition to the site selection process by effectively isolating the Nevada Congressional delegation. Nevertheless, as the DOE focused its investigation on Yucca Mountain, a number of problems began to crop up that slowed down the process of developing a permanent geologic repository at this site.

The 1982 NWPA assigned the EPA the responsibility for drafting the radiation release standards with which any proposed HLRW repository would have to abide (the 1987 Amendments did not change this situation). When the EPA released its draft set of standards for public comment in 1983, it was criticized by the majority of the scientific community for trying to impose a threshold of safety that, given the high uncertainty of any prediction pertaining to a 10,000 year framework, would be impossible to meet. The proposed EPA standard was based on limits to exposure to radioactivity set by the Clean Water Act. Furthermore, the EPA required that these limits not be exceeded at any point in time within 10,000 years of the time the repository were to become operational. Instead of questioning the efficacy of a permanent geologic repository, however, the community of experts demanded that the standards be lowered to make such a repository feasible. In this case, the "community of experts" comprises of scientists whose areas of expertise are the most pertinent to the investigations necessary for the development of a geologic HLRW repository. While some propose that the opinion of these experts should bear the most weight in advising policymakers, others argue that this segment of the scientific community has the greatest vested interest in the development of a repository. Notwithstanding this criticism, in 1985 the EPA promulgated a set of standards that were not substantially different from its original proposals. As this meant that a permanent repository would be impossible to license, the Yucca Mountain project was thrown into disarray (Hadjilambrinos, 1999). Opponents of the project used the EPA standards to delay the process, while proponents, including the community of experts continued to argue that the standards were unnecessarily strict. The deadline set in the NWPA (and left unchanged in the 1987 Amendments) for the repository to become operational and the DOE to begin receiving HLRW from the nation's nuclear power plant operators—January 1, 1998—became increasingly difficult and, ultimately, impossible to attain.

In the end, the repository proponents, arguing that the level of acceptable risk should be defined on the basis of supposedly "objective" scientific analysis, rather than through open public debate, succeeded in their effort to convince policymakers to intervene. Regulatory relief was provided the DOE through the1992 National Energy Policy Act, in which Congress directed the EPA to draft site-specific regulations (i.e., regulations that would only apply to the proposed Yucca Mountain repository) based on "reasonable" standards that would be recommended by the National Academy of Sciences (Energy Policy Act, 1992, § 801). Pursuant to this act of Congress, the National Academy of Sciences issued its recommendations in 1995, in the form of a report of a specially formed committee of the National Research Council (the Academy's research arm) (National Research Council, 1995), and the EPA began the process of drafting regulations once again.

Soon after the release of the National Academy of Sciences' report, a potentially serious flaw with the Yucca Mountain site surfaced. In late April 1996, DOE released a report by Los Alamos National Laboratory researchers that documented elevated levels of Chlorine-36 in five of the geologic faults that exist within the proposed repository site. These elevated Chlorine-36 levels could only have come from the atmospheric nuclear tests conducted in the Pacific Ocean in the 1950s (the radioactive chlorine isotope was created through the activation of seawater salt by nuclear explosions). In order to travel in less than 50 years to the depths of 600 to 1,000 feet below the surface where it was discovered , this radioactive isotope had to have been carried there by water flowing rapidly downward from the ground surface. This finding posed a serious threat to the Yucca Mountain project because the DOE's own siting guidelines, and the Nuclear Regulatory Commission licensing regulations, required a site to be disqualified if it were shown that groundwater travel time through the repository to the accessible environment (e.g., the aquifer) is "less than 1,000 years along any pathway of likely and significant radionuclide travel." (10 CFR 960.4-2-1-d, in Department of Energy, 2001) The DOE argued that the elevated Chlorine-36 levels did not necessarily violate the siting guidelines, and that, furthermore, in light of the National Academy of Sciences' recommendation that standards for the proposed Yucca Mountain repository be based on limiting *risks* to individuals of adverse health effects from radioactivity releases from the repository, rather than limiting radioactivity releases themselves, the existing suitability guidelines would have to be modified. DOE's claim that the presence of Chlorine-36 did not exempt the Yucca Mountain site under its original suitability guidelines was based on an interpretation of "groundwater travel time" as an average flux, i.e., sum of travel times for a "discrete segment of the system." DOE, calculating average and median travel times for the entire system, estimated groundwater travel time to be no shorter than 8,000 years. See response to Comment EIS001020 / 0001, Final Environmental Impact Statement, Vol. III, Part 2, Section 4.2 (3547). Nevertheless, the U.S. Nuclear Waste Technical Review Board (NWTRB) considered the matter serious and recommended the DOE conduct further studies of water flow through rock fissures (Nuclear Waste Technical Review Board, 1997). The Board was created by the 1987 Nuclear Waste Policy Amendments Act as an independent federal agency for the purpose of evaluating the technical and scientific validity of the DOE's studies of Yucca Mountain. Consequently, the DOE contracted with the U.S. Geologic Survey (USGS) for an independent study to confirm or refute the findings pertaining to Chlorine-36.

Technical problems combined with budget levels that were too low for planned development activities forced the DOE to push back once again from 1998 to 2001 the important milestone of an official site suitability recommendation. Assuming that the Yucca Mountain site would be suitable, the projected date for completion of the repository was the year 2010.

The EPA, after a long drafting process, released its final, site-specific radiation protection standards in June 2001 (40 CFR 197 in Environmental Protection Agency, 2001). The standards essentially had three distinct parts:

1. A risk-based standard applied to a "critical" individual (termed "Reasonably Maximally Exposed Individual"—RMEI) living in the vicinity of the repository. This required that the health risk to such an individual not exceed a certain allowable level at any time over the 10,000 years following closure of the repository.

2. A standard for a stylized human intrusion scenario involving a single borehole drilled into the repository, penetrating a single waste package, at a point in time after the waste containers have began to disintegrate. This standard replicates the RMEI standard for this special case.

3. A groundwater protection standard requiring the DOE to demonstrate that there is a reasonable expectation that, for 10,000 years of undisturbed performance of the repository, releases of radionuclides will not cause the level of radioactivity in the groundwater to exceed the current limits established by the Safe Drinking Water Act.

Following the release of the EPA standards, the DOE promulgated its final site-specific suitability guidelines (10 CFR 963 in Department of Energy, 2001). Under these guidelines, the DOE may determine that the site is suitable for the hosting of a permanent HLRW repository if it meets the EPA's pre-closure and post-closure requirements as described in that agency's site-specific safety standards. The DOE would use safety analyses to show that the pre-closure criteria are met, and total system performance analyses to show that the post-closure criteria have been met for 10,000 years. It should be noted here that the total system performance analysis (TSPA) method makes it unnecessary to show explicitly that natural geologic barriers play a major role in containing the disposed HLRW. Instead, it relies on both natural and engineered barriers to limit radioactivity releases with in the levels established by the EPA, without distinguishing the level of protection provided by each type of barrier. According to some analysts, the move to TSPA and away from specific geologic criteria (such as those contained in the DOE's original *general* guidelines) to determine site suitability cast in doubt the fundamental assumptions that underlie the concept of a geologic repository. The NRC also published its final licensing rule for the Yucca Mountain repository in 10 CFR 63, incorporating the provisions in the EPA standard (Nuclear Regulatory Commission, 2001).

These developments allowed the DOE to complete the final environmental impact statement for the proposed repository, concluding that there was no evidence that the Yucca Mountain site would be unsuitable (Department of Energy, 2002). Pursuant to this finding, on February 14, 2002, then Secretary of Energy Spenser Abraham forwarded to President George W. Bush his official recommendation that Yucca Mountain be approved as the site for development of a HLRW repository, in accordance with Section 114(a)(1) of the 1982 NWPA. On February 15, 2002, President Bush submitted to Congress his recommendation that the Yucca Mountain site be developed. The State of Nevada exercised its right to veto the President's recommendation by submitting to Congress a "notice of disapproval" on April 8, 2002 (Gwinn, 2002). On July 9, 2002, Congress passed a joint "resolution of repository siting approval" overriding Nevada's veto and approving the Yucca Mountain site for a repository, despite numerous concerns about remaining technical problems, including better understanding of the behavior of the natural components of the repository system, the implications of the presence of Chlorine-36, possible volcanic action consequences, issues pertaining to corrosion of the waste canisters, etc. These problems have been identified by various actors in the Yucca Mountain suitability debate, including the NWTRB (Nuclear Waste Technical Review Board, 2002, 2003, and 2004). The President signed the joint resolution on July 23, 2003, clearing the way for the DOE to begin the process of obtaining approval from the NRC to begin construction of the repository.

With legislative action once again clearing the way, the HLRW repository at Yucca Mountain, Nevada, appeared to be on track to meet the goal of being ready to accept waste in 2010. The DOE announced its plans to submit a license application to the NRC some time in 2004 for construction authorization and Congress supported these plans by approving budget increases for the Yucca Mountain project of 22% for 2003 and 26% for 2004. However, 2004 was marked by a series of setbacks. Congress appropriated only $572 million instead of the $880 million requested by the DOE for 2005 in order to support the license application to the NRC (this was a slight decline over the previous year's appropriation). This forced the DOE to move its target date for the license application to 2006, making completion of the repository before 2012 impossible. More important, however, in July 2004, the District of Columbia Circuit Court of Appeals struck down important provisions of the EPA safety standards for Yucca Mountain, as well as related provisions of the NRC licensing rule, finding that the 10,000-year compliance period upon which both sets of rules are based "is not 'based upon and consistent with' the recommendations of the National Academy of Sciences." (U.S. Court of Appeals, 2004) The Academy of Sciences' report had recommended a standard based upon the time at which radiation doses from the repository reach their peak:

> We believe the compliance assessment is feasible for most physical and geologic aspects of repository performance on the time scale of the long-term stability of the fundamental geologic regime—a time scale that is on the order of 10^6 [one million] years at Yucca Mountain—and that at least some potentially important exposures might not occur until after several hundred thousand years. *For these reasons, we recommend that compliance assessment be conducted for the time when the greatest risk occurs, within the limits imposed by long-term stability of the geologic environment.* (National Research Council, 1995, pp. 6-7)

Since "peak risks might occur tens to hundreds of thousands of years or even farther into the future" (National Research Council, 1995, p. 2), standards extending the compliance period to the time of likely peak exposure are more difficult to develop, and much more difficult to comply with (in fact, in its rationale for choosing a 10,000-year compliance limit, the EPA argued that determining compliance beyond that time frame would likely be impossible). For example, the EPA states: “we are unaware of a policy basis that we could use to determine the ‘level of proof’ or confidence necessary to determine compliance based upon projections of hundreds-of-thousands of years into the future.” (Environmental Protection Agency, 2001, p. 32097) and “As IAEA noted, beyond 10,000 years it may be possible to make general predictions about geological conditions; however, the range of possible biospheric conditions and human behavior is too wide to allow ‘reliable modeling’” (Environmental Protection Agency, 2001, p. 32099). Thus, the court decision may well make the Yucca Mountain repository (and possibly *any* geologic repository) impossible to license.

While it is possible that legislative action could again rescue the Yucca Mountain project—by, for example, codifying the 10,000-year regulatory period into law—such action may be politically untenable. On the one hand, the repeated Congressional actions, always favoring the development of a HLRW repository at Yucca Mountain increasingly lend credence to the criticism that the policy objective is *not* the safe disposal of this type of waste (and certainly not finding the *safest* location and means for disposal), but disposal at Yucca Mountain regardless of the environmental and health risks. On the other hand, the elevation of Nevada Senator Harry Reid to the position of Senate Minority Leader following the 2004 elections may well have shifted Nevada’s political position in Congress from a state of weakness to one of strength. Congressional intervention is made even less likely by the recent revelations that one or more USGS employees may have falsified data used to support the recommendation for the selection of Yucca Mountain (Struglinski, 2005; Werner, 2005). Thus, after twenty years of research, close to $10 billion expended, and four acts of Congress, the prospects for building a geologic HLRW repository in the U.S. are at the very least highly uncertain.

Dry Cask Storage: from Stopgap to Viable Alternative for HLRW Management

While progress in developing a permanent geologic repository in the U.S. has time and again ground to a halt, the nation’s nuclear power plants have been facing serious spent fuel storage problems. When the DOE declared that it would be unable to begin accepting HLRW on the mandated deadline of January 1, 1987, several nuclear power plants had been in operation for 20 years or more, and their spent fuel cooling pools were running out of space. As problems with the proposed Yucca Mountain repository continued to mount, nuclear power plant operators were forced to begin exploring alternatives to permanent disposal—and a practical and relatively inexpensive solution has emerged: dry cask storage.

Dry cask storage allows spent fuel that has already been cooled in the spent fuel pool for at least one year to be removed from the pool and be stored in a container that can provide adequate shielding. Spent fuel assemblies are dried and placed inside a container called a cask. The casks are typically steel cylinders that are either welded or bolted closed. The steel cylinder provides a leak-tight containment of the spent fuel which is surrounded by inert gas. Each cylinder is then surrounded by additional steel, concrete, or other material to provide radiation shielding to workers and members of the public. The NRC reviews and licenses the cask designs and issues permits for dry cask storage facilities.

The first operating license for a dry storage installation was issued in 1986 for the Surry nuclear power plant in Virginia, and today there are approximately thirty approved dry cask storage facilities throughout the U.S. (Nuclear Regulatory Commission, 2003). Each of these facilities is located at a reactor site (all but two are at commercial reactor sites), and most consist of a concrete slab upon which the casks are vertically placed in the open air (some facilities consist of above-ground concrete or steel structures and the casks are placed inside, either vertically or horizontally).

As completion of the Yucca Mountain repository is pushed further into the future and may even become unfeasible, and as spent fuel storage pools at more reactor sites are filled to capacity, the prospect of proliferation of dry cask storage sites is growing. With 72 commercial power plant sites in 33 states, more than half of which are currently approaching the capacity limits of their storage pools, it is not difficult to postulate that 50 or more dry cask storage facilities will exist throughout the U.S. by the end of the decade. If the problems of developing Yucca Mountain become insurmountable, then it is very likely that these facilities, which were meant to be temporary, will have to continue holding waste for an indefinite amount of time (Wald, 2004). Both of these prospects present important policy challenges that the U.S. government's single-minded, narrow focus on geologic disposal has made it impossible to solve.

The policy challenges that dry cask storage presents as it becomes the *de facto* HLRW disposal option for the medium term (25 to 100 years), stem from a number of potential problems:

- The proliferation of storage sites presents monitoring challenges with attendant security and environmental safety implications. These challenges are magnified significantly by the prospect that increasing number of sites will be "orphaned" as the nuclear power plants to which they are attached are decommissioned (some, such as the Maine Yankee site are already "orphaned"). Costly site protection and monitoring activities will have to continue indefinitely without attendant revenue-producing activities. How will safety and security vigilance be assured for each site over time?

- The ongoing development of dry cask storage sites with a multitude of different cask designs poses possible environmental risks that may make the exercise of other options in the future difficult. Most cask designs are not transportable. This means that for waste to be transported either to a permanent repository or interim storage facility, it must be transferred from the casks to special transport vessels. However, the extraction of waste from the casks may be risky. In order to maintain shielding, the waste will most likely have to be extracted under water. Cask-stored waste is hot enough to vaporize water virtually upon impact. The resulting steam may cause damage to the stored spent fuel assemblies, may cause explosions, or may carry dangerous radionuclides as it is vented. Steam would make even routine maintenance of the casks difficult. With transportation from cask sites being riskier, more complicated, and, therefore, more expensive than directly from storage pools, consolidation of a large number of sites to a few may become unfeasible.

- Is the development of numerous storage sites going to be acceptable to the public, both at each site and at-large? What are the socio-political implications of this option? Alternatively, the development of one or a small number of central storage sites, while making the management of the waste simpler, will also have to contend with the issue of public acceptance, as well as with issues of transportation planning and safety.

The environmental, security, economic, and socio-political issues arising from dry cask storage have been ignored because this option for managing the nation's HLRW has been overshadowed by the apparently all-consuming efforts to develop a permanent geologic repository. Thus, the emergence of dry cask storage as the *de facto* interim and, possibly, indefinite-term HLRW management policy, has been characterized by an ad-hoc approach that highlights the drawbacks of this option. Nevertheless, intermediate and long-term dry cask storage appears to meet many of the criteria for a truly effective HLRW management policy that have been proposed by several analysts (Shrader-Frechette, 1993; Easterling and Kunreuther, 1995; Flynn, et al., 1995; Hadjilambrinos, 2000). Dry cask storage is a monitored, retrievable waste management strategy that permits flexibility of options as better techniques are developed in the future. It also allows future generations to participate in the decision-making process—an approach that is ethically preferable to geologic disposal, assuming adequate resources are set aside to finance the ongoing management activities. Dry cask storage cannot be ignored any longer. A policy debate must be initiated for the purpose of determining how this option should be implemented in order to meet two very important objectives:

1. Address the nation's need for interim storage of HLRW in the most effective way; and

2. Provide at least a backup solution for the disposal of HLRW waste.

This policy debate is necessary to alleviate the problems inherent in the ad-hoc exercise of the dry-cask storage management option. For example, even if a decision about consolidation into one or a small number of sites is not made immediately, such consolidation can nevertheless be facilitated by selection of transportable cask designs (a few such designs exist and have been used in some sites). The specification of cask design characteristics clearly requires regulatory action, and such action clearly would be much more beneficial if it considered the full range of possibilities of dry cask storage as a HLRW management option.

The unwillingness up until now of policymakers to even consider the full range of possibilities of dry cask storage, as well as of other flexible waste management alternatives for high-level radioactive waste is not in the public interest. No reason for it can be found other than that the development of credible alternatives to geologic disposal for the long-term management of HLRW may pose a threat to the speedy development of a geologic repository. In fact, the history of policy action in the U.S. suggests that the construction of such a repository is a goal in itself, and is tied to the prospect of further development of nuclear power in this nation. Recognition of this fact, and divorce of the issue of future nuclear power development from the issue of management of the HLRW that has been and will be generated by *existing* nuclear power plants can only facilitate the development of effective management options for this waste.

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The Societal and Ethical Implications of Nanotechnology: A Christian Response

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Just about every magazine on the newsstands has featured nanotechnology in the past year or two. These articles usually speak of nanotech as the latest emerging platform technology that will substantially transform our material and social world, just as electricity and nuclear science did previously. It will create faster and smaller computers, allow us to combat all sorts of diseases, manufacture new stronger and lighter materials, and save our natural environment. The articles speak of the ways it will change how just about everything is designed and made and in the process change our entire world: not just the physical but the social and ethical aspects as well.

What is usually not mentioned in these articles is reference to the fact that nanotech could be the first platform technology to offer significant opportunities to include discussions of the social and environmental concerns in its development. Usually, it is not until a technology is well established that its social and ethical implications become known (Collingridge, 1980, pp.17-18). The National Science Foundation claims that with nanotechnology there is much "more opportunity to integrate the societal studies and dialogues from the very beginning and to include societal studies as a core part of the National Nanotechnology Initiative investment strategy" (Rocco and Sims, 2001, p. 2). The end result is that the development of nanotech may not be left solely to the experts. The public may play a greater role than it previously has.

Nanotech and SEIN

The government acknowledged the importance of this new platform technology in January 2000 when President Clinton (White House, 2000) established the National Nanotechnology Initiative (NNI), a federal program to coordinate funding of nanotech research and development. He justified the money by claiming nanotech promises to build materials ten times the strength of steel at a small fraction of its weight, to shrink all information in the Library of Congress into a device the size of a sugar cube, and to detect cancerous tumors when they are only a few cells in size.

Many go beyond this extensive vision to claim working on the atomic and molecular level will offer the opportunity to solve all of humanity's basic problems. In fact, one of the popular ways to present nanotech is to ask the audience to list the most pressing current and future global challenges that have potential technological fixes and then to claim nanotech will solve every one of them. Of course, no one mentions the potential social and ethical impacts of this new technology.

The government provided the opening for the greater community to become involved when it passed *The 21st Century Nanotech Research and Development Act of 2003*. That act stipulates all federally funded research should include provisions for dealing with the social consequences of the work. The Societal and Ethical Implications of Nanotechnology section (SEIN) of that bill provides for 1) regular and ongoing discussions that involve the public, 2) involvement of social scientists and ethicists in setting the goals and priorities in federal research, and 3) assurances that efforts will be made to distribute the benefits of the technology to all Americans. The act provides an opportunity for community involvement from the very beginning and at many points of access along the line as this technology is developed.

Although this would seem a tremendous breakthrough in a democratic society, there has been very little discussion of it. Nobody seems too excited about soliciting the public's participation. Perhaps this reflects a belief that nobody really cares or perhaps it represents an effort to maintain things the way they are. If the public is not involved, those with power can keep control. Undoubtedly, others believe public participation would bring confusion, because the larger community does not have the special knowledge required.

It is true that the larger community does not share a common story and thus does not posses common values by which to evaluate technological issues. However, the public is composed of many constituent communities that possess more than a common zip code that can be used to group them for marketing purposes. These constituent communities share common stories and values. Their coming together in conversation is essential in addressing the common good of the larger community. This seems to be the objective of SEIN's provisions, and we believe this has to be the goal of any democratic society.

A Role for Religion?

One of those constituent communities that have something to offer is religion. As part of the larger community, religion has historically provided ethical guidance and addressed social change. At the present time, it appears the larger community is willing to listen again to what it has to say.

In this article, we shall speak of the Christian Church as a representative of religion in general in order to simplify our argument. Like society as a whole, religions do not share a single story. However, they do all draw on many similar assumptions. What we have to say about Christianity can be applied in some degree to other religious communities. We would urge that all religious communities have a right to have a role in the discussion.

To date the Christian Church has pretty much ignored the great influence of technology on society. She has addressed issues rather passively as they have been forced upon her, but has not regarded these important enough to involve much time by her leading theologians. Much of the work done has been in secular schools rather than church seminaries. This has meant that the Church has found it difficult to offer a united voice in technological times. At times, various church bodies have parted company and gone in completely opposite directions when forced to respond to technological advances.

A good example is the official response to the development of a safe contraception. When Goodyear and Hancock introduced the vulcanization of rubber in 1843, allowing good cheap, reliable condoms, the world finally had a good method of contraception with far-reaching consequences. The responses of the Lutheran and Roman Catholic churches moved in completely different directions. That separation has grown wider through each development up to and including the introduction of the pill in 1960. The Roman Catholics argued from the traditional natural law theory, insisting that the function of sexual intercourse is solely for the procreation of children. The Lutherans, on the other hand, took the current situation into consideration and modified the traditional doctrine. They introduced the expression of mutual love as a second function for intercourse. As a result, the Lutherans have accepted "artificial" contraception, while the Roman Catholics have rejected it as "unnatural" (Foltz, 1986).

Regardless of the official Church doctrinal response to this and other technological innovations, surveys for some time have shown the actual practice of laity in both bodies is virtually the same (Coffey, 1998, Hartman, 1998). Some see this as evidence of the demise of religious influence in a technological society, claiming as technology advances religion recedes. However, many others argue lay people are doing a better job wrestling with the demands of modern