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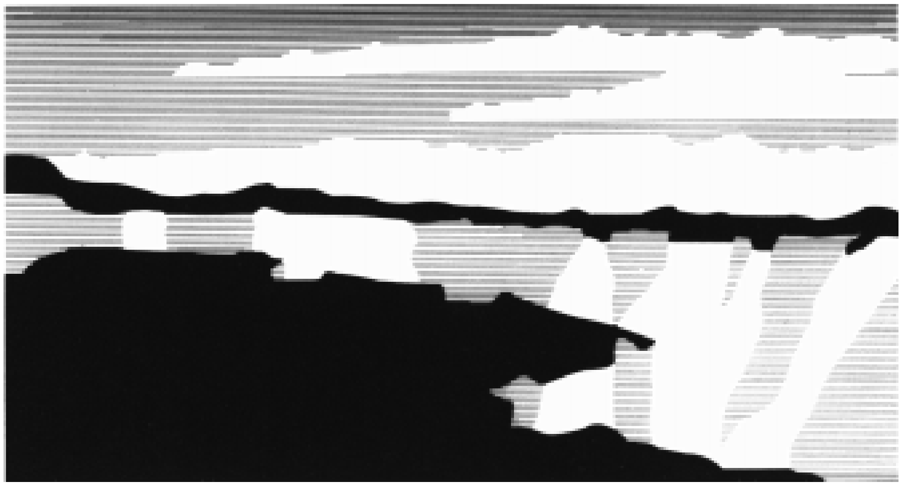

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An Interpretation of Technology Diffusion Patterns for the U.S. Department of Energy's Environmental Management Program

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1. INTRODUCTION

For the last decade since the end of the Cold War, the U.S. Dept. of Energy's (DOE) mission has shifted focus to include environmental restoration of the many sites around the country contaminated by the waste products of over 50 years of weapons production. This is commonly referred to as the "environmental legacy of the Cold War." Many of the cleanup problems are complex, challenging, and expensive. Not all the solutions are known. On the basis of the use of existing technologies and cleanup approaches, the cost estimate for cleaning up the DOE's 130 sites is on the order of $250 billion over the next 75 years [1].

Since 1989 the DOE has promoted a Technology Development program designed to encourage innovative approaches to cleanup, enhance technical performance, and reduce costs. However, the DOE's Environmental Management Technology Development Program (EM-50) has been challenged to justify expenditures of over $2.5 billion dollars in development money over the last eight years, when only $300 million dollars has been estimated in savings to date. Expenditures have been easier to measure than cost savings because there has not been a consistent mechanism thus far to track technology deployments over time.

Partially in response to this challenge to show accountability to U.S. taxpayers, the current DOE administration has implemented a new approach to accelerate deployment of some of the promising innovative technologies that have reached an advanced stage of maturity in the development process. This plan is called Accelerated Site Technology Deployment (ASTD), formerly the Technology Deployment Initiative (TDI). In addition, the administration is attempting to integrate cleanups at the major DOE sites within the relatively short time period of 10 years. The framework for effecting this approach to cleanup at DOE sites is called Accelerating Cleanup: Paths to Closure [1], formerly known as the 2006 Plan.

2. OBJECTIVES OF THE PAPER

The purpose of this paper is to provide a response to the general question as to why there has been so little actual application of new environmental technologies to on-the-ground cleanup. There are two sides to the issue that may at first seem unrelated, but taken together provide both a tactical and theoretical response to the question.

EM-50 has provided a tactical response to the challenge of showing that expenditures in technology development are justified by implementation of its ASTD program. ASTD provides a fiscal incentive for the major DOE facilities to effect remedial actions using new technologies. The purpose of the ASTD is to demonstrate to stakeholders, including U.S. Congress and concerned citizens, that environmental costs can be reduced and site cleanup accelerated by substituting new technologies for established baseline methods.

The theoretical side looks at how historically, the substitution of new technologies for old in any given industry follows well-documented principles of diffusion; therefore, the aggregate adoption of new environmental technologies is predictive. It is not within the scope of this paper to accurately quantify the equations that result in the mathematical description of the S-shaped diffusion curve, but the overall concept of the innovation-development process is an important clue in understanding why new EM-50 technologies are not already in more widespread use.

3. THE PROCESS OF TECHNOLOGY TRANSFER

When several technologies vie to address the same problem, why do few succeed and many fail? The innovation-development process consists of all the decisions and activities, and their impacts, that occur from recognition of a need or a problem, through research and development and commercialization of an innovation, through diffusion and adoption of the innovation by users, to its consequences [2]. Experience has shown that adoption by users is not based on cost effectiveness or performance alone. It is a complex process that involves a great deal of interpersonal communication exchanges over an extended period of time.

The DOE defines technology transfer as the process by which technology, knowledge, or information developed in one organization, in one area, or for one purpose is applied or used in another organization, or area, or for another purpose. In the Office of Environmental Management (EM), a more applied definition is used because EM activities are focused on transferring successful technology to industry and acquiring technology from industry to strengthen the technology base needed to address EM environmental activities.

From an EM perspective, then, technology transfer is the process of moving developed, demonstrated, and compliant technology from one facility to another, or in the EM case, moving technology from the public sector (DOE R&D facilities) to the private sector (industry), while maintaining compliance. Successful technology is moved across the weapons complex among different sites with similar contamination problems for application and, finally, to users in DOE environmental restoration and waste management, the environmental management industry, other agencies, and state and local governments for U.S. and international environmental restoration and waste management applications. In addition, EM brings private sector technology into the Department for testing and evaluation to identify the best available technology for cleanup.

3.1 The Role of Perception and Organizational Culture in Adoption of New Technologies

A technology "demonstration" is one of the last stages that a new process must go through in order to show viability. (These stages of technology development have been quantified by McCown, 1997 [3]). However, a successful demonstration does not automatically lead to eventual deployment. Further use of the technology is often hindered by perceptions of risk on the part of the user. Types of risk can include programmatic, economic, regulatory, or technical. A technology demonstration is for the supposed benefit of the appropriate DOE decision maker, who can then apply the new technology to reduce costs and accelerate cleanup. But the real end user of the new technology is typically a DOE site manager or environmental restoration contractor who is responsible for a particular release site or geographic region.

This end user is often an engineer hands-on type whose motivation for using a new technology may be entirely different than that of a DOE-EM Washington bureaucrat. The mere term, "demonstration," may be negatively perceived by the site manager because it implies a test of something (usually highly technical) that may have worked on a laboratory bench top, but is most likely not ready for prime time in the field. "Pilot tests" are often regarded with skepticism because scaleup of physical/chemical processes is typically nonlinear, making it difficult to predict how a new technology will transition from the development to the deployment stage. In short there is a wide gap in organizational culture that exists between the person responsible at field level for cleanup and the decision maker at DOE headquarters trying to prevent budget cuts.

3.2 Other Barriers to Technology Transfer and Commercialization

Major obstacles to technology transfer have been well documented in the literature [4, 5]. The study "Barriers to Environmental Technology Commercialization," [Berkey, et al., 1995] identifies the following obstacles to successful adoption of innovative cleanup technologies:

- cumbersome DOE contracting/procurement requirements;
- potential liability exposure for developers;
- inadequate articulation of DOE technology needs or market size;
- lack of adequate DOE site characterizations;
- insufficient technology performance or cost data;
- lack of performance-based standards that can encourage new technologies;
- inconsistent, multi-level permitting process;
- "not-invented-here" mindset within DOE;
- pronounced lack of entrepreneurial management;
- lack of adequate development funding;
- market uncertainty due to changing requirements and priorities;
- lack of consistent regulatory enforcement;
- limited technology applications for private sector;
- lengthy and uncertain commercialization pathway, and

- lack of strong linkage between technology developments efforts and technology deployment efforts.

It is beyond the scope of this paper to address each of these barriers in detail. Although all are valid and merit discussion, it is the last item, the weak link between development and deployment, that the ASTD seeks to strengthen.

4. ASTD PROVIDES INCENTIVE TO TECH TRANSFER

Typically, between the stages of advanced development and predeployment is where critical financial support for further technology development breaks down. The gap in funding occurs when the federal funding program considers a technology "too applied" for additional funding and industry considers the technology "too embryonic" (pre-venture capital stage) to adopt. This funding gap in the technology development cycle has been described as the "Valley of Death" [6] (see Figure 1).

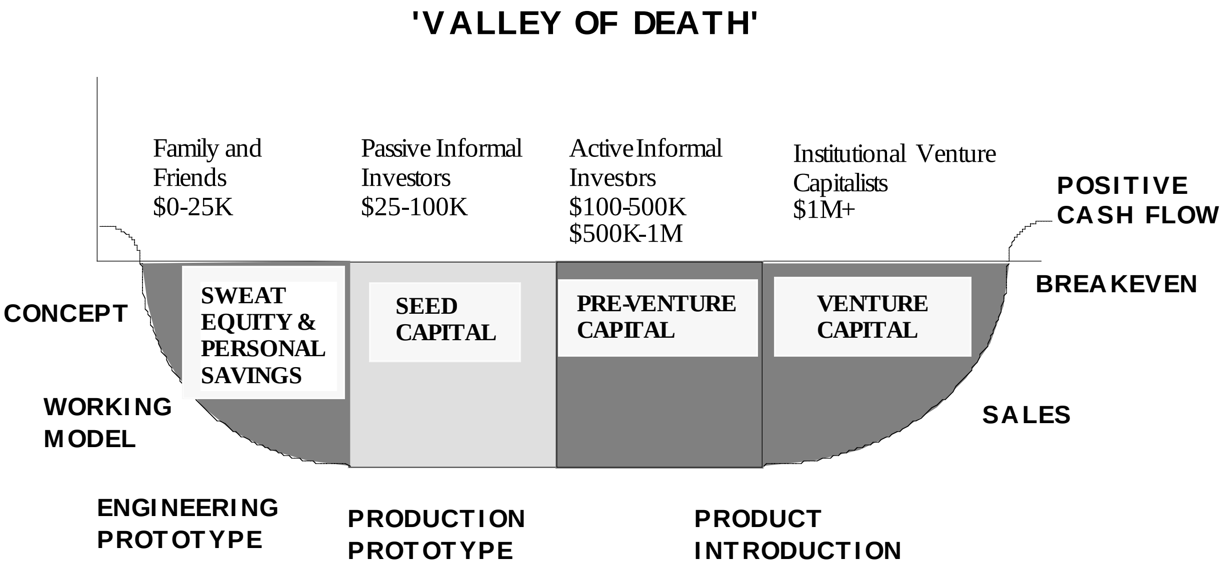

Figure 1. The so-called Valley of Death refers to the federal "funding gap" between technology development and technology deployment (source: "From Invention to Innovation," U.S. DOE, May 15, 1991).

ASTD is an attempt to bridge the funding gap by providing to the sites a fiscal incentive to deploy new technologies for cleanup. This is accomplished through a fund set up by EM-50 to share in the initial costs of deployment with the participating sites. Distribution of ASTD funds are contingent upon submission of a successful proposal. Only technologies that have been previously demonstrated at the field scale are eligible to be included in proposals.

If selected, ASTD funding makes possible the deployment of the technology at the initial site. Subsequent cost savings accrued by using the new technology are allowed to be kept in that site's environmental program; hence, an economic incentive exists for both program offices and field sites. For example, if Los Alamos National Laboratory (LANL) had budgeted $15 million to remediate actinide-contaminated soils using the conventional method of excavation and disposal, but instead was awarded ASTD money to deploy a new soil sorting/soil washing system that would accomplish the same objective for $5 million, then the resulting $10 million in savings would be available for LANL to use in other areas, further accelerating cleanup at the site [7].

Each ASTD proposal is judged on the basis of technical merit, business/management approach, stakeholder/regulatory approval, and life-cycle cost. In addition , each proposed technology must demonstrate that it:

- supports the ASTD mission to reduce costs, accelerate site cleanup, and enhance achievement of 2006 Plan goals;
- provides for multiple applications of the technology;
- demonstrates cost savings and high return on investment over the baseline method;
- accelerates a referenced baseline schedule;
- is deployable (i.e., technically feasible at field scale);
- is supported by joint funding provided by the proposing organization.

Finally, the proposal must include a letter of commitment from the initial site where the technology is to be deployed, as well as letters of interest from other DOE sites where the technology is applicable.

The EM program expects to receive a total of about 150 proposals, primarily from the top 10 major laboratories (including LANL and Sandia). Of these, maybe 18 or 20 will make the final cut. ASTD funding levels for each proposal are expected to be in the $1 – $5 million range (FY98); one might think of it as subsidized venture capital.

Optimistically, one would hope that even if only a handful of ASTD proposals are actually funded, the primary, and one hopes lasting, purpose of the exercise is to open up the channels of communication among R&D labs, technology developers, DOE program offices, and end users. By requiring the end user's written interest in adopting the technology at the beginning of the project, and providing the user a financial incentive, the ASTD attempts to increase the degree of influence of personal communication channels. This facilitates knowledge awareness and promotes understanding of the relative advantage of the new technology. Costly delays in bringing the technology to market are thus reduced.

5. HISTORICAL PERSPECTIVE: A Look at Other Industries

Some of the major barriers to technology transfer and commercialization have been identified, and the ASTD program has been discussed as a potential means to facilitate deployment of new, cost-effective technologies in the field. How do technology deployment opportunities within DOE compare to those in the private sector? Historical records illustrate that considerable time and effort is expended to achieve tech transfer in other industries compared to the DOE. There is an underlying assumption in government that because DOE is both the supplier and the consumer of innovative technology, the innovation-development process should happen instantaneously. However, data collected from other industries support the fact that the technology transfer process consists of time-consuming, predictable, and quantifiable steps in a well-documented diffusion cycle.

5.1 The S-shaped Diffusion Curve

One of the most basic tenets about technological adoption and market penetration is that it involves a well-documented diffusion process. Initially, an older technology has the advantage because it is well understood, its reliability is usually high, users have confidence in its applications, and both equipment and knowledgeable operators are readily available. Any new technology is unfamiliar, its reliability is questionable, and its supporting equipment and trained staff are scarce. As the initial problems are overcome, communication spreads knowledge awareness about the technology, the rate of adoption increases, and substitution of the new technology for old tends to proceed exponentially during early years. The rate of substitution only slows after very rapid growth, when the older technology presents fewer and fewer opportunities for replacement.

This process produces the well known concept of the S-shaped curve used in forecasting diffusion of innovative technologies over time. The Pearl curve and the Gompertz curve represent the two most common variants on a quantitative model of this process [8]. The parameters of these curves and therefore the future rate of technological substitution have been shown to be estimable from the growth rates in only the first few percentage points of market penetration by a new technology. For example, Marchetti (1983) [9] found in a study of automobile adoption in nine countries that the rate of adoption had been fixed by the time the automobile reached a market penetration of only 1%. The Pearl curve is the more appropriate model in our case because, unlike the Gompertz curve, past adoption practices influence future adoption rates.

The Substitution Model of Technological Change developed by John Fisher and Robert Pry (1971) [10] shows that the aggregate adoption of new environmental technologies is likely to follow the same S-shaped Pearl curve applicable to the substitution of new technologies in many other industries. This model is based on three assumptions [11]:

1. Many technological advances can be considered as competitive substitutions of one method of satisfying a need for another.
2. If substitution has progressed as far as a few per cent of the total consumption, it will proceed to completion.
3. The fractional rate of fractional substitution of new for old is proportional to the remaining amount of the old left to be substituted.

The fraction of market penetration, f, by a new technology is given by:

$$f = 1/2\ [1+\tanh a(t - t_0)] \tag{1}$$

where tanh is the hyperbolic tangent, a is a shape coefficient representing half the annual fractional growth during the early years, t is time, and t_0 is the time it takes to reach 50% market penetration. For many cases in industry, substitution data has been plotted over time to show trends in substitution of one product or technology for another. A convenient, straight-line way of illustrating such data is to plot f/1-f against time on semi-log scale. Figure 2 shows four examples of this type of substitution data. Note that the time between 10% and 50% market penetration, t_0, is approximately 20-25 years in the examples shown.

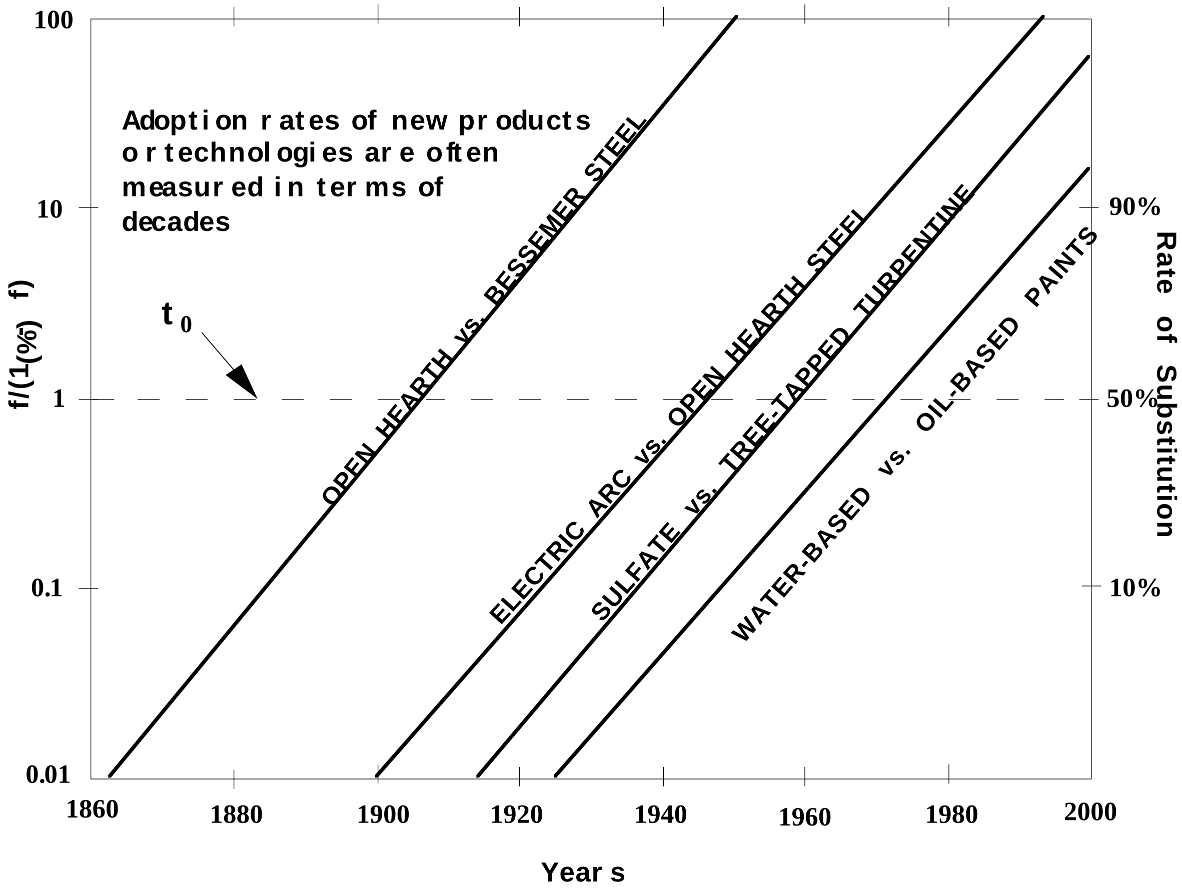

Figure 2. Historical data taken from other industries shows that the rate of substitution of new products/technologies for old follows similar diffusion patterns, and that full market penetration typically does not occur for decades after introduction of the innovation (sources: Illinois Institute of Technology Research Institute, Ceramics Bulletin No. 24, December 1969, and Chemical Economics Handbook, Stanford Research Institute).

Using the same parameters in equation (1) we can develop assumptions about where EM-50 technologies have been and where they are headed based upon this technological diffusion model and fairly sparse initial data. This can enable us to show that the current $300+ million overall savings accrued from the deployment of specific new environmental technologies is perfectly reasonable to expect given our position on the Pearl curve as shown in Figure 3.

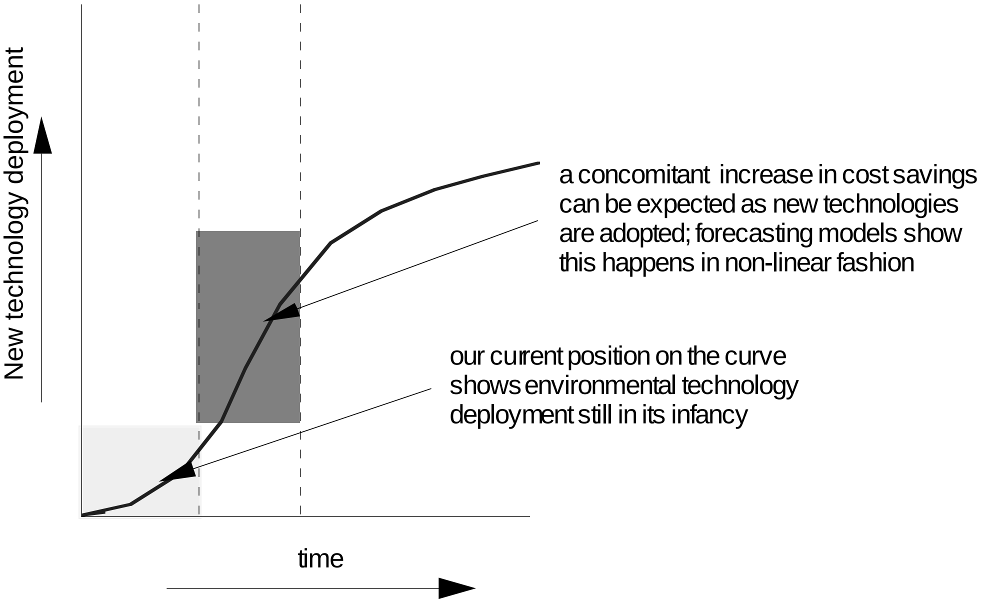

Figure 3. Adoption of new technologies can be generalized across various industries according to an S-shaped curve (Cetron and Ralph, 1983; Rogers, 1995).

If we take our data points as cumulative savings to date of $300 million approximately 8 years after the start of technological development and initial applications, spread the $300 million over time as if it has grown exponentially -- assuming that the new technologies typically save 30% of costs over the old -- then we have now achieved an aggregate market penetration of about 10%. Ultimately, we will be saving 30% of the EM budget (about $2 billion annual savings) as we asymptotically approach 100% penetration, and this yields savings in the $9-$15 billion range over the life of the 2006 Plan horizon, with additional savings in following years.

DOE's Technology Development program cost-savings estimates are usually based on the premise that adoption of innovative technologies is nearly instantaneous upon their successful demonstration. However, from the many studies of diffusion of new technologies documented in the literature, it is clear that adoption by users is not based solely on cost effectiveness or performance alone. A complex communication and adoption process takes place over an extended period of time.

5.2 The Relationship between R&D and Technical Productivity

There are those who criticize the ASTD as a last-ditch effort for DOE's EM-50 to justify its existence. The implication is that the DOE should spend less on R&D and more on cleanup. But again, data from other industries may be used to show that perhaps *more* attention should be paid to R&D. Industries that are in their infancy, those that emphasize growth through innovation, those trying to exploit new market opportunities or specialize in streams of new, high-tech products all make use of relatively high R&D expenditures. The pharmaceutical, computer, chemical, and semiconductor industries spend heavily on R&D, as shown in Figure 4. These are the same industries that enjoy rapid growth in revenues and profits. The converse is found in the commodity producers, metals, food, clothing, housing, and appliance industries. These are mature industries with fewer opportunities for technological innovation, and correspondingly slower growth [12].

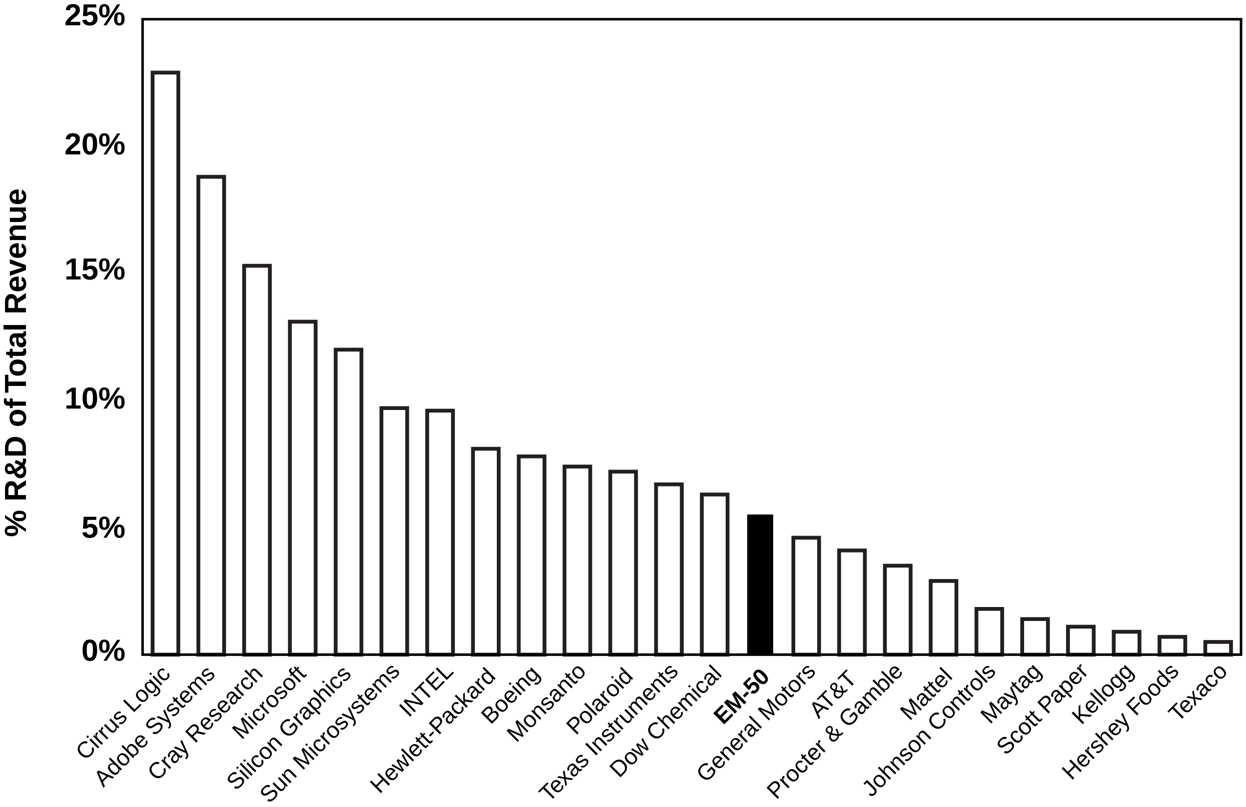

Figure 4. High-tech companies increase productivity by spending more on R&D as a percentage of their total revenue (source: Business Week, July 1995).

One can argue that the DOE EM program is still in its infancy, has highly challenging unsolved technical problems, and numerous opportunities to discover new ways of accomplishing its goals. Thus, EM should be following the high percentage R&D spending policy of its private sector counterparts. Figure 4 shows that EM's 5.5% R&D score is in the middle of the pack, far below the innovative and fast-growing industries of the private sector. The most innovative industries spend more than 10% of their revenues on R&D.

Since one of EM-50’s primary roles is to provide the technology development resources and management to assure that technical productivity increases are achieved, EM needs to take seriously its commitment to R&D in order to meet its projected technical and fiscal goals. Current EM productivity increase assumptions [1] are very optimistic and require a strong technology development effort to make them happen.

6. CONCLUSIONS

I offer the following conclusions from this analysis:

(1) The technology transfer process as applied to the DOE’s EM program is not without problems. Many barriers to technology transfer have been identified, and the DOE has not implemented mechanisms to track successful technology deployments.

(2) Nevertheless, the roughly quantified adoption rate to date supports the idea that the majority of cost savings are still to come as the innovative technologies’ market penetration proceeds in accordance with well-known diffusion patterns.

(3) It is imperative to apply resources to accelerate the rate of diffusion through initiatives such as the Accelerated Site Technology Deployment program. Because the natural diffusion rate of innovative technologies is inherently slow, the implementation of new technologies and their associated cost savings will not be realized within the DOE Paths to Closure planned cleanup schedule without extra efforts to speed deployment.

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