Understanding R&D Investment Trends in Energy-Intensive Industries

Jack Eisenhauer, Energetics, Inc.
Buddy Garland, U.S. Department of Energy, Industrial Technologies Program

ABSTRACT

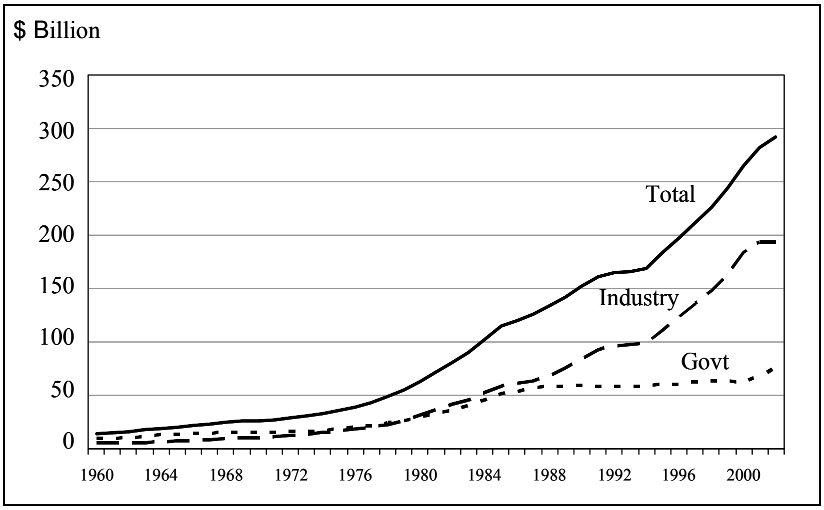
Industry's ability to invest in research and development can have a profound effect on the advancement of technologies that are critical for improving energy efficiency and reducing carbon emissions. National data on private R&D expenditures provide information on overall trends but they may obscure important investment patterns within specific industrial sectors. In the late 1990's, for example, industrial R&D investment grew faster than total economic output and reached an all-time high of $181 billion in 2000. Yet, many energy-intensive industries did not experience such growth in R&D investment and they continue to invest in R&D at much lower rates (1% of sales or less) compared to other industries (3% to 12%). Often, the R&D investments made by these industries give priority to product development rather than energy-related process improvements, even though energy represents a key portion of production costs. Energy-intensive manufacturers often note their inability to invest in energy-related process R&D without government assistance, citing relatively small margins from which to create investment. Understanding this investment environment is important in shaping government policies and programs to maximize energy savings and meet national goals. This paper examines R&D investment trends within energy-intensive industries and attempts to explain the decision process that embodies the ability and/or willingness of these firms to invest in energy efficiency R&D. Based on these findings, the paper proposes recommendations for government R&D investment strategies that will maximize long-term public and private benefits.

The R&D Paradox

The inability or unwillingness of certain industries to invest in R&D during periods of economic expansion is a paradox for government policy makers. Data from the National Science Foundation indicate that national R&D expenditures are at an all-time high ($292 billion in 2002), fueled largely by a surge in industrial R&D expenditures that grew more than six-fold between 1980 and 2002 (Figure 1) (NSF 2003). Industry, which contributed just 31% of national R&D spending in 1964, now provides 66% compared to the federal government's contribution of 26%. Total U.S. R&D expenditures now equal the combined R&D expenditures of Japan, the United Kingdom, Canada, France, Germany, and Italy. High tech exports are up dramatically. By these indications, the U.S. technology environment is robust, driven by industry's investment in research that they seem quite able to provide. This has led some to believe that government support of R&D directed at industrial technologies constitutes 'corporate welfare.'

A careful examination of economic and technology trends reveals a more complex and disturbing picture. Global competition has restructured the economic landscape and has

Figure 1. National R&D Expenditures



Source: NSF 2003

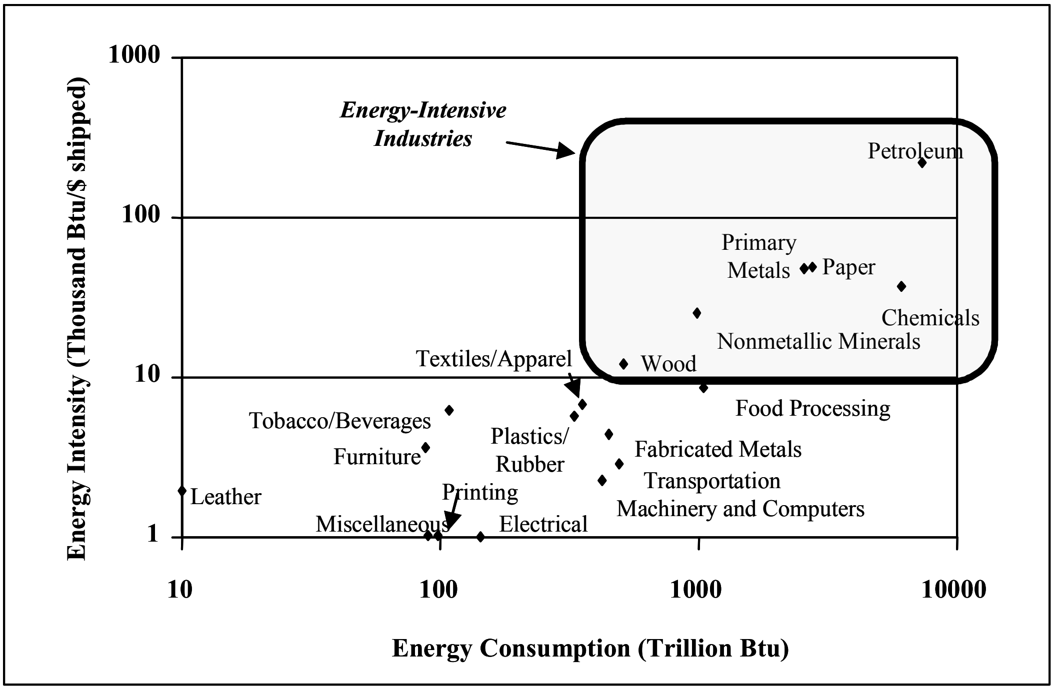
affected individual industrial sectors quite differently. The technology content of all businesses has grown dramatically and has changed the scope, scale, and timing of corporate technology investments. As a result, the composition of industrial R&D has changed over the past decade in both the distribution of investments among sectors and the type of R&D investments made by individual firms.

Energy efficiency improvements generate important private and public benefits. In manufacturing, improving energy efficiency lowers a firm's energy and environmental control costs and frequently improves overall productivity. Energy efficiency also generates significant societal benefits in the form of cleaner air, lower greenhouse gas emissions, and potentially lower product costs. Energy efficiency improvements depend largely on the development and adoption of technologies that require less energy to produce equivalent output. Investment in research and development is critical for stimulating the necessary technology developments that can lead to more efficient manufacturing processes. This is particularly true in the energy-intensive, material processing industries that employ complex process technologies. However, there is mounting evidence that there is severe private underinvestment in R&D for technologies that can improve energy efficiency in industry. If this underinvestment is caused by market failures, the federal government has an appropriate role in providing mechanisms to correct them.

R&D Investment Trends in the Energy-Intensive Industries

A small number of manufacturing industries provide the best opportunities to improve energy efficiency. For example, just six industries, shown in Figure 2, collectively account for 85% of manufacturing energy use and 74% of all industrial energy use. They use large amounts of energy to transform raw materials into higher-value industrial materials and end products. They are also very energy-intensive, using large amounts of energy per dollar of product shipped. Despite substantial efficiency gains over the past 50 years, many of the energy-intensive industries continue to use far more energy than the practical minimum

Figure 2. Industrial Energy Intensity vs. Energy Consumption



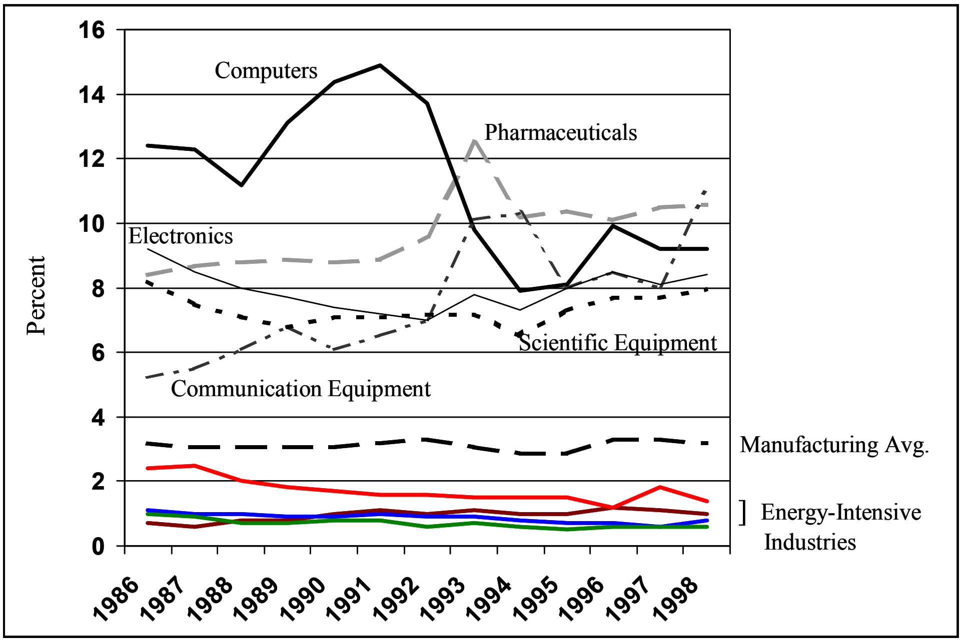
Source: EIA 2001

required for key processes. Such conditions make these material processing industries excellent candidates for additional energy efficiency gains.

In recent years, private R&D investments in the material processing industries have not kept pace with the rest of the economy. From 1994 to 2000, R&D investments by the material processing industries grew by only 0.2% per year compared to 9.9% per year for all of industry. As a result, the portion of total industrial R&D contributed by the material processing industries fell from 10% to 6% (USDOC 2002). Manufacturing R&D as a percent of GDP also declined over this period from 2.6% to 1.6% (NSF 2002). Furthermore, in the period from 1998 to 2000, R&D investment by material processing industries actually *declined* by 3.0% per year. Considering net sales, foreign sales, capital spending, employment, and R&D investment, the material processing industries posted the poorest overall economic performance of all industry groups over this period (USDOC 2002).

One measure of an industry's commitment to R&D is its "R&D intensity," the ratio of corporate R&D spending to sales. Industries with high R&D intensities often have the ability to directly translate R&D results into product improvements, which consumers can easily distinguish (and reward) in their purchasing decisions. By contrast, R&D that improves process technology in a commodity-based industry typically does not change the product, except perhaps its price. As a result, the material processing industries have the lowest overall R&D intensity in the entire industrial sector, with a R&D/sales ratio of about 1% (Figure 3). This compares with an average of 3% for all of manufacturing and is far below the rates of many other industries. These historically low investment rates reflect the use of mature process technologies, relatively low margins for commodity products, competing demands for internal funds, and increasing reliance on technology development from outside the industry.

Figure 3. R&D-to-Sales Ratio in Manufacturing 1986-1998
R&D Funds as a % of Net Sales



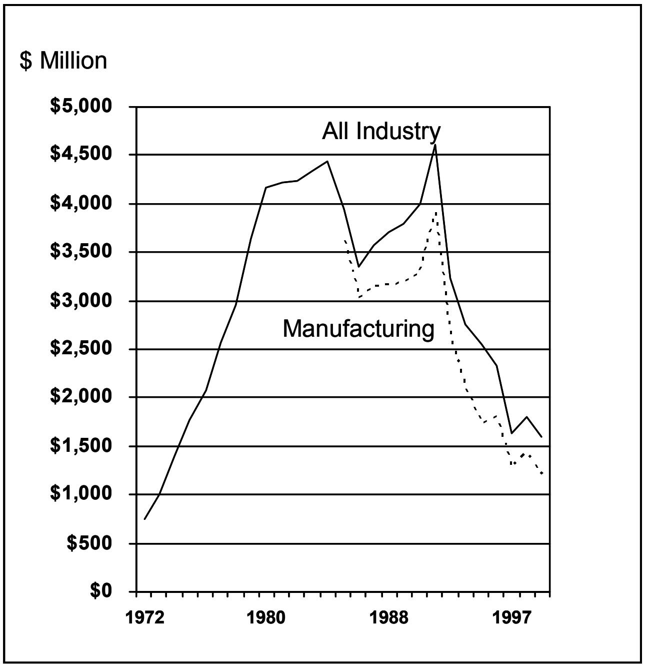
Source: NSF 2002

The National Science Foundation publishes data on industry expenditures for energy R&D (NSF 2002). These data should be interpreted cautiously because they are sparse and energy technologies may be embedded in larger systems and processes. However, the overall investment trend can provide insight into the relative importance of new energy technology in manufacturing over time. As Figure 4 illustrates, expenditures for industrial energy R&D increased rapidly during the 1970's, dipped then rose during the 1980's, and fell dramatically throughout most of the 1990's. Similar trends in U.S. energy R&D have been observed by Garland & Eisenhauer (1996), Dooley (1999), and Margolis & Kammen (1999). As the NSF data indicate, manufacturing expenditures for energy R&D are now at the lowest level since NSF began collecting this data in 1986. Although much of this decline reflects a decrease in industrial energy prices, it also suggests increased competitive pressures in manufacturing, a shift toward less energy-intensive production, and an unwillingness to invest in process-related R&D.

Shifts in R&D Investment Priorities

There is growing evidence that energy-intensive manufacturers have not only limited their overall R&D investment, they have also shifted the focus of their R&D investments to product enhancements and optimization and/or extensions of existing production platforms. These investments generally carry lower near-term risk and provide a higher or at least more immediate return on investment. While many companies in commodity-based industries are not able to distinguish their products to customers, some vertically-integrated companies can and do enhance their products in order to "brand" them and seek higher margins. For example, a flat glass company may add a proprietary reflective coating to its glass to

Figure 4. Industrial Energy R&D Expenditures



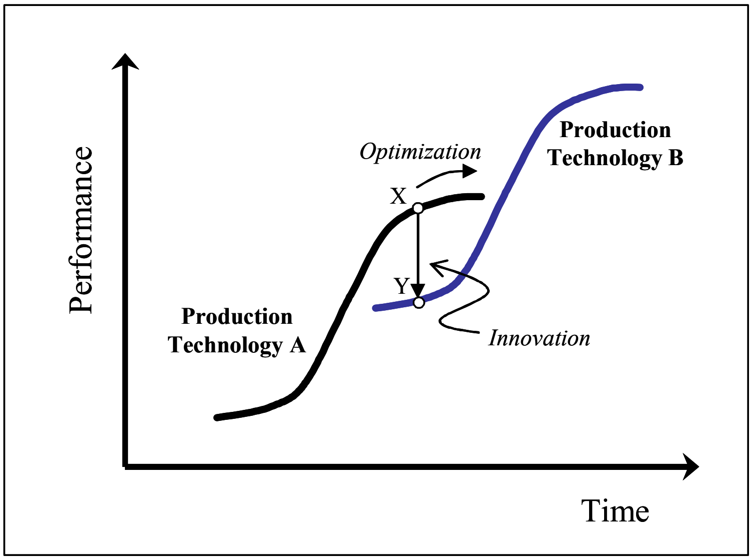
Source: NSF 2002

capitalize on a special market niche. Companies that have the ability to 'move up the value chain' often shift limited R&D resources to focus on product enhancements rather than process enhancements.

For most energy-intensive companies, achieving a cost advantage in the production process is still an important competitive advantage. In today's global economy, U.S. firms often find themselves at a cost disadvantage on labor, materials, energy, and environmental compliance. Many U.S. manufacturers have come to rely on superior production technology to increase productivity and throughput to capture a cost advantage. Process technologies that use less energy per unit of output are logical investment opportunities for energy-intensive industries. For the past twenty years, however, most companies have favored R&D investments that optimize and extend existing technology platforms to achieve incremental benefits rather than explore next-generation technology that could lead to substantial energy benefits. Investment in next-generation process technology is frequently seen by companies as too expensive, too risky, and unlikely to provide adequate returns to the firm.

The choice by a firm to optimize existing production technology or invest in next-generation production technology is shown in Figure 5. Curves A and B represent innovation S-curves for alternate production technologies, which Tassey (1997) calls midlength technology life cycles. Companies at point X on curve A are approaching the mature stage of an existing production technology and must decide whether to invest in further optimization or invest in a new innovative, yet undeveloped, production technology represented by curve B. The optimization strategy generally contains less uncertainty, risk, and cost but yields only small incremental performance improvements. The innovation strategy, which moves the company to point Y on curve B, will ultimately enable large performance improvements but will likely result in a near-term loss of performance.

Figure 5. Production Optimization Versus Innovation



Source: Tassey 2997, Mann 1999

Pursuing this strategy will likely be costly and carry a variety of risks including technical uncertainties and a potential for lost production. Furthermore, individual companies may not have the financial resources or technical capabilities to make this transition. For those that do, it is unlikely they will be able to fully capture the economic benefits of their R&D investment because of technology spillovers to competing firms. This has led many companies in the energy-intensive industries to invest in optimization of existing production technology. Although this may provide the best near-term returns, it tends to decrease R&D investment in the very technologies that can help companies and industries secure a long-term competitive advantage.

These two dominant R&D issues – lower overall investment and a deficiency of next-generation technology investments – suggest dim prospects for future energy efficiency improvements and an uncertain long-term economic outlook for material processing industries.

Private Sector Underinvestment and Market Failures

The foregoing analysis suggests that the energy-intensive, material processing industries are underinvesting in R&D and that the investments made do little to promote major improvements in long-term energy efficiency. Although most company R&D managers understand the inherent tradeoffs between investing in optimization versus innovation, they recognize that their companies are unwilling or unable to commit the technical and financial resources to develop, acquire, or apply unproven, high-risk, and capital-intensive technology.

Tassey (1997) points out that R&D investment decisions are based on a set of complex factors that do not always result in optimal investment decisions. If suboptimal investments persist, as in the case of many energy-intensive industries, market failures may exist. Two factors contribute to R&D underinvestment: risk and appropriability. Risk and uncertainty inhibit investment because the actual or perceived returns may be too low. However, risk and uncertainty in the early phases of process technology development are often intrinsically high because of the complexity of the scientific or engineering challenge (scope) or the magnitude of the investment or capital facilities required (scale). These difficulties are compounded if managers face an array of competing technology options, each with different risk profiles, development cycles, and projected returns.

Appropriability is the ability of a company to capture the economic benefits that result from the "spillover" of knowledge, market, and societal benefits to those who do not participate in the R&D investments (e.g., competing firms, consumers, and citizens). When knowledge and technology cannot be contained, the rewards of R&D investments made by the innovating firm cannot be fully captured because the results are shared by competing firms without compensation. This lowers the return on investment to the innovator or may not even cover the original investment cost. Overall, technology spillover is desirable because it diffuses innovation and leads to greater economic and energy efficiency. Yet, the inability of markets to properly reward innovators stifles investment and precludes technology innovation.

Private R&D investment in energy-efficient process technologies can generate large public benefits because the resulting innovation may reduce pollution, preserve natural resources, lower product costs, and reduce greenhouse gas emissions. Because the social rate of return often far exceeds the private rate of return, companies may underinvest in energy-efficient processes because they cannot capture all the benefits of their innovation through the sale of their products. This type of market failure is frequently cited as a key rationale for government support of R&D (Jaffe 1996).

Even when a new technology is fully developed and ready for deployment, few companies want to be the first to adopt it due to the high first cost of the capital investment and the risk that production will be disrupted. Many corporate managers declare they want to be "the first to be second" in deploying new technology in capital-intensive industries. Often the third, fourth, or fifth installation of a technology can be 30 to 50% less expensive than the first because of increased knowledge and experience of the prior installations.

One forest products industry executive put it succinctly: *"Industries like the forest products industry are reluctant to put in new, potentially highly efficient processes because of the enormous capital intensity of the industry, the often low returns being achieved with these assets, and the risk that these new processes might not work as planned and the compounding risk that that event would have on lost production."* (Raymond 2003)

Options for Public Policy Remedies

When R&D underinvestment is caused by a market failure, there is justification for government involvement to stimulate R&D investment to optimal levels. Over the years, policy makers in many countries have experimented with various approaches to stimulate private R&D to correct market failures. R&D tax credits, for example, are frequently used to increase the overall level of R&D investment. However, when a market failure is specific to an industry or a technology type, general R&D tax credits are inappropriate. These are broad policy instruments that increase all types of R&D investment across many industries. As a result, they may end up subsidizing R&D activities that would have occurred without public support (Tassey 1997). A better approach is to use more precise policy tools that target specific investment barriers. For energy-intensive industries, these barriers include 1) the extensive technical resources required to develop next generation manufacturing processes, 2) the enormous capital requirements for technology development and commercialization, 3) the inherent high risk and uncertainty associated with innovative process technology, and 3) the scarcity of financial resources for long-term process R&D within intensely competitive commodity-based industries.

The purpose of mission-oriented government programs is to maximize public benefit within their mission area. The Department of Energy's Industrial Technologies Program (DOE-ITP) leads the federal government's effort to improve industrial energy efficiency and environmental performance. DOE-ITP maximizes public benefit by decreasing the energy intensity of industry through investments in R&D for high-risk, high-payoff technologies that industry cannot undertake on its own. The program seeks to maximize future energy savings per dollar of government investment. This has prompted DOE-ITP to pursue three important strategies: 1) focus on efficiency improvements in the most energy-intensive industries, 2) use public-private partnerships to leverage technical and financial resources, and 3) focus on grand technical challenges associated with achieving next-generation manufacturing platforms (USDOE 2003).

Public-private partnerships align private technology objectives with government missions. They bring together the strengths of business and government to solve increasingly complex and difficult problems and help reduce risk and stimulate private investment. This is accomplished through: 1) collaborative planning that reduces uncertainty associated with technology options, and 2) sharing R&D costs to lower the effective hurdle rate for private investors. These approaches are the foundation of DOE's *Industries of the Future* strategy, which seeks to reduce the energy-intensity in materials processing industries. The strategy takes advantage of the inherent relationship between efficiency and production costs, using market drivers to help focus scarce resources where they can effect the greatest efficiency improvements. Collective planning, through industry-led visions and technology roadmaps, helps industry focus their R&D priorities on major technical challenges in precompetitive areas. This often helps companies to reduce the uncertainty associated with high-risk technology projects by confirming R&D priorities with other technology experts.

R&D investment risk is further reduced when companies collaborate with customers, other manufacturers, suppliers, and DOE-ITP in cost-shared R&D projects directed at precompetitive manufacturing and enabling technology. Even when technologies appear commercially promising, collaborative research may be needed because the technical scope and financial requirements are beyond the capabilities of individual firms. Research teams that bring together complementary expertise to tackle challenging problems have been the most successful in reducing both the technical and financial risk. According to an R&D manager from the glass industry, *"Collaborative research is the key to addressing the challenges of the glass industry. Glass manufacturing requires significant capital outlays for equipment and facilities; no one company, or even the industry by itself, is capable of footing the bill for research on this scale"* (Henry 2000).

The reluctance of companies to invest in innovative manufacturing concepts has prompted DOE-ITP to restructure its R&D portfolio. Innovative, next-generation technologies often involve one or more core technical challenges that, if solved, could produce dramatic improvements in energy efficiency, environmental performance, and product yield. These "*Grand Challenges*" typically require high-risk, high-return R&D such as an entirely new processing route that requires much less energy than current processes. DOE-ITP identifies high-value opportunities by calculating the minimum energy requirements of specific manufacturing processes. It then targets opportunities that can best capitalize on the difference between actual and practical minimum energy requirements. Through this approach, DOE-ITP targets the most pressing technical challenges that would unlikely proceed without government support. It addresses specific market failures and barriers that inhibit investment. These include the high cost of process R&D, the requirement for multiple and complex technical capabilities, and the inherent uncertainty and risk associated with game-changing process technology.

Conclusions

Market failures that lead to suboptimal private R&D investment are nothing new; governments have acknowledged them for many years and have experimented with a variety of economic and policy remedies. However, the growing technical content of our economy, coupled with the broad restructuring of global markets, has changed the nature and severity of market failures. The healthy growth in overall R&D expenditures by U.S. industry over the past two decades belies the underinvestment in R&D that is occurring within the energy-intensive industries. Increased competition, low margins in commodity-based products, large R&D and capital requirements for new production platforms, and the multiple scientific and technical resources required make it increasingly difficult for companies to make the required R&D investments that can lead to large increases in energy efficiency, environmental performance, and productivity.

To address these problems, DOE's Industrial Technologies Program has developed strategies that stimulate private R&D investment in innovative energy-efficient manufacturing without subsidizing R&D that would have occurred anyway. It pursues public-private partnerships to plan and implement R&D projects that target the most promising energy efficiency opportunities in the most energy-intensive industries. It encourages the development of next-generation production technology by focusing on solutions to *Grand Challenges*, which represent the core technical barriers that inhibit technology advancement. These strategies enable DOE-ITP to maximize public investment and address specific market failures that discourage private investment in energy-efficiency R&D. The program helps reduce industry's uncertainty and risk of investing in precompetitive R&D and stimulates investment in technologies that can provide large public benefits.

References

Dooley 1999. *Energy R&D in the United States.* PNNL-12188. Richland, WA: Pacific Northwest National Laboratory.

EIA 2001. *1998 Manufacturing Energy Consumption Survey.* (MECS), Available online: http://www.eia.doe.gov/emeu/mecs/contents.html. Washington, DC: Energy Information Administration.

EIA 2002. *Annual Energy Review 2001*. Available online: http://www.eia.doe.gov/emeu/aer/contents.html. Washington, DC: Energy Information Administration.

Garland, R. and J. Eisenhauer 1996. "What is the Federal Government's Role in Sponsoring Energy R&D?" In *Proceedings of the 31st Intersociety Energy Conversion Engineering Conference (IECEC 96)*, 96483: 1572-1576. New York, N.Y.: Institute of Electrical and Electronics Engineers

Henry, V. 2000. "America's First Industry on Threshold of New Era of Development." *Sandia Technology* 2 (3): 20-21.

Jaffe, A. 1996. *Economic Analysis of Research Spillovers Implications for the Advanced Technology Program.* Available online: http://www.atp.nist.gov/eao/grc708.htm. Gaithersburg, MD: National Institute of Standards and Technology.

Mann, Darrell 1999. *Using S-Curves and Trends of Evolution in R&D Strategy Planning.* Available online: http://www.triz-journal.com/archives/1999/07/g/. Bath, U.K.: University of Bath.

Margolis, R. and D. Kammen 1999. "Underivestment: The Energy Technology and R&D Policy Challenge." *Science* 285: 690-692.

NSF 2003. *National Patterns of Research and Development Resources 2002 Data Update*. Available online: http://www.nsf.gov/sbe/srs/nprdr/start.htm. Arlington, VA: National Science Foundation.

NSF 2002. *Research and Development in Industry: 2000.* Available online: http://www.nsf.gov/sbe/srs/srs02403/start.htm. Arlington, VA: National Science Foundation.

Raymond, D. 2003. "Mitigating Investment Risk in the Development and Deployment of New Technologies." Paper presented at the International Finance Forum for the Pulp, Paper And Allied Industries, Atlanta, GA, 18-19 February, 2003.

Tassey, G. 1997. *The Economics of R&D Policy*. Westport, CT: Quorum Books.

USDOC 2002. *U.S. Corporate R&D Investment, 1994 - 2000 Final Estimates.* Available online: http://www.ta.doc.gov/reports/CorpR&D_Inv/CorpR&D_Lists_1994-2000.htm. Washington, DC: U.S Department of Commerce, Technology Administration.

USDOE 2003. *Industrial Technologies Program Strategic Plan (Draft).* Washington, DC: Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy