4. TECHNOLOGY INNOVATION APPROACHES

4.1 INTRODUCTION

Previous chapters of this report identified a set of technology pathways that we believe offer the United States affordable options to reduce GHG emissions to sustainable levels. We have emphasized that R&D, both fundamental and applied, needs to be continued and/or initiated to advance the technologies identified within the pathways, thereby moving them closer to the goal of deployment in the marketplace. This section discusses three technology innovation approaches and presents several factors for consideration in deciding which approach to use to develop a particular technology. While each of the approaches provides a viable option, we believe that in most cases public–private strategic alliances are the best approach for developing and deploying these technologies.

4.2 APPROACHES

In this section, we evaluate the pros and cons of three approaches for advancing the RD&D of GHG reduction technologies. These approaches can be characterized as

- government led and financed
- industry led and financed
- public–private strategic alliances

Although we recommend public–private strategic alliances as the best approach for developing and deploying most of the technologies discussed in the technology pathways section, in some cases one of the other approaches may be more appropriate.

When selecting an approach to pursue the RD&D of a technology, we recommend the following factors be considered:

- national strategic value of the technology
- target market of the technology
- return on private-sector investment

A technology has *strategic value to the nation* when it provides a significant benefit to national security, economic well-being, environmental quality, and/or public health. National defense is the casebook example of high strategic value to the nation. Historically, the strategic value criterion has also been a justification for government support of technologies in the areas of space, health, energy, and agriculture.

The *target market* factor refers to the expected end-user or consumer of the technology. In some cases, a technology is developed for a specific target market or end-user (e.g., the federal government), and the technology has little application beyond that market. For example, technologies to process uranium have had little application beyond the nuclear industry. In other cases, a technology, such as the transistor, has applications in multiple markets and industries. Technologies that are applicable to a variety of markets and industry are sometimes referred to as "generic technologies" (Bloch 1991).

The third criterion refers to whether the private sector believes it can attain a large enough *return on its RD&D investment* within a reasonable time frame and at acceptable levels of risk to warrant supporting the innovation process. The complexity and the length of time needed to develop and deploy a technology are key variables considered by private industry when it is deciding whether to invest in a technology, because both factors can increase the risk of not receiving the expected return on investment. Of the three factors presented, expected return on investment is the key factor companies consider when deciding whether to invest in the development of a technology. Although this factor is of primary importance to the private sector, it is not necessarily mutually exclusive from the national strategic value criterion. In many cases, companies have led and financed the development of technologies that have underpinned the formation of industries with a high strategic value to the nation (e.g., computer software, drug, and automobile industries).

The following sections discuss the characteristics and relationship among the three approaches to technology innovation in an effort to provide selection criteria for determining the optimum approach to achieving the RD&D goals for individual technologies (Table 4.1).

4.2.1 Government Led and Financed Approach

The government typically leads and finances projects throughout the RD&D process when a technological innovation has a high strategic value to the nation, the public sector is the intended end-user of the technology, and the expected return on investment is too low to warrant the private sector's bearing the RD&D costs (Table 4.1). Examples of projects led and financed primarily by the federal government include the Manhattan Project, which

Table 4.1. Approaches to technological innovation

	National strategic value	Target market	Return on private sector investment
Government led and financed	High	Public sector	Low
Industry led and financed	Low-medium	Specific market	High
Public–private alliance	Medium-high	Multiple markets	Low-medium

developed the atomic bomb in World War II, and the Apollo Project, which put a man on the moon in 1969. Government led and financed projects have been very successful in meeting their goals when the conditions warrant government leadership and it has been able to focus the best resources of the nation on solving a problem with clearly defined technological goals and large public benefits and support.

The government led and financed approach could be applied to reducing GHGs, but it contains some inherent barriers to full effectiveness. In contrast to the examples given earlier, the government is not the primary target market for GHG reduction technologies, and there is no single technological solution to stabilizing atmospheric concentrations of CO_2. Therefore, significant GHG reductions will be achieved only if a number of technologies penetrate a broad spectrum of commercial target markets. In addition, some of the GHG technologies will have economic benefits in reduced fuel use, higher productivity, and reduced waste generation. Therefore, we expect the private-sector return on investment in the innovation process to be at a sufficiently high level for some of the technologies to warrant private-sector RD&D cost sharing.

4.2.2 Industry Led and Financed Approach

The private sector typically leads and finances projects throughout the RD&D process when a technological innovation has a high potential return on investment from specific commercial markets, regardless of its national strategic value. Historically, technological innovation leading to products for the commercial market has been primarily the responsibility of the private sector. Numerous examples exist of technology innovation led and financed primarily by industry, including plastics, pharmaceuticals, scientific instrumentation, information systems, and robotics. These technologies were driven by the demands of consumers in target markets, not by the federal government. Market-driven technology development is critical to continued economic growth because it enables companies, through the deployment of technological innovations, to profit by meeting the demands of consumers.

The strong relationship between technological development and quality of life in America in the twentieth century is a testament to the value of the industry led and financed approach to innovation. However, for this to be the primary approach for developing and deploying GHG reduction technologies, carbon mitigation would have to be highly valued in the marketplace to enable private companies to profit from their RD&D investments. Some technologies that result in GHG reduction may attract sufficient private-sector investment because they offer additional benefits that consumers are willing to pay for to amortize the RD&D costs and to provide adequate profits. However, short of policies that create a large economic incentive for reducing carbon emissions, industry is not likely to lead and finance RD&D on a broad spectrum of GHG reduction technologies.

4.2.3 Public–Private Strategic Alliances

Public–private alliances are typically established to share the costs of RD&D and deployment of technologies that have a strategic value to the nation and have value for multiple markets and industries, but do not promise sufficient return on investment to motivate the private sector to bear all the RD&D costs. Many of the technology pathways for reducing GHGs have these characteristics, making public–private strategic alliances the optimum approach for promoting their development and deployment.

The Clinton administration has been a strong advocate of forming partnerships to advance science and technology in America and has "forg[ed] a closer working partnership among industry, federal and state governments, workers and universities" (Clinton and Gore 1993, p.1). During the past decade, the process by which federally funded technology makes its way to the private sector for commercial use has improved substantially. In addition, the federal government is now working hand-in-hand with industry, combining resources to achieve common technology objectives (OSTP 1997).

Numerous examples of public–private alliances exist, such as SEMATECH, PNGV, IOF, the International Energy Agency Greenhouse Gas R&D Programme, the Clean Coal Technology program, the Advanced Light Water Reactor program, and PVMaT. In the case of PNGV, technologies to increase the fuel efficiency of automobiles have a *high strategic value to the nation* because they reduce our consumption of oil, thereby increasing our economic and national security, and mitigate GHG emissions, thereby reducing global warming and improving the quality of the air we breathe. In addition to being deployed in the automobile industry, many of the technologies being developed by the PNGV consortia are likely to be deployed in *multiple markets*. For example, one of the goals of PNGV is to increase fuel economy threefold. In order to meet this goal the vehicle weight must be reduced 40%; therefore, a significant portion of the steel and cast iron components in these vehicles must be replaced with aluminum and polymer composites. These new lightweight, high-strength materials will be deployed in other transportation markets (e.g., aircraft and rail), as well as multiple segments of our infrastructure (e.g., bridges, buildings, energy). Finally, although the technologies being developed by PNGV have a high strategic value, the *market return* on fuel efficiency investments is currently very small because the cost of gasoline in the United States has been decreasing at an average annual percentage rate of 1.8% (in constant dollars) since 1978.

The combination of high strategic value, multiple target markets, and expected low return on investment makes public–private strategic alliances the optimal approach for developing and deploying GHG reduction technologies. This approach will allow sharing of costs and pooling of resources, thereby motivating private companies to invest in the technology even though the return on investment is likely to be low in the short term, and encouraging government agencies to support the RD&D process even though the public sector may not be the targeted end-user of the technology.

The interactive nature of the innovation process is another reason to use public–private alliances to develop and deploy GHG reduction technologies. It is now widely recognized (Kline 1991; OTA 1995; Branscomb et al. 1997; *R&D Magazine* 1997) that most complex technological innovations advance through a nonlinear, interactive innovation process (Fig. 4.1), in which there is synergy between scientific research, technology development, and deployment activities. The interactive process is a more effective model for developing and deploying technology than the linear model that depicts the innovation process as starting with basic scientific research and then advancing sequentially through the technology development and deployment phases (Fig. 4.2). This linear approach can take longer and can result in potential innovations being delayed or never making it to the marketplace. The interactive process has several advantages in that it provides the following:

- a continuous feedback loop for development and use of new scientific capabilities and facilities that can expedite the innovation cycle
- effective dialog between the research and user communities on innovation needs
- an effective basis for focusing research in the highest priority areas and evaluating progress along the technology pathways

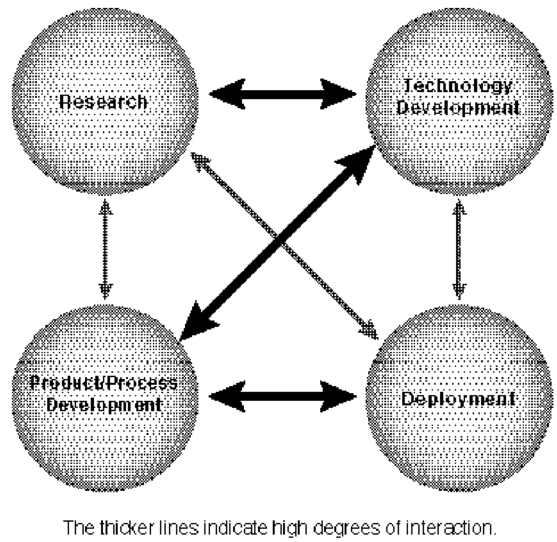

Fig. 4.1. Interactive model of innovation.

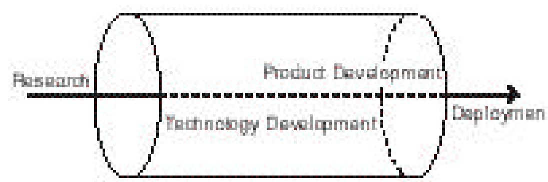

Fig. 4.2. Linear model of innovation.

4.3 STRATEGIC ALLIANCE ROLES

One of the major benefits of strategic alliances is that they help maximize the efficiency of the innovation process by bringing together an interdisciplinary team of scientists, engineers, and analysts (e.g., market, social, and financial) from industry, government laboratories, universities, and nongovernment organizations who can ensure that the scientific, technical, and commercial challenges that arise throughout the innovation process are successfully resolved. We recognize that there will be many stakeholders in a climate change technology strategy and that over the course of time, some of the technology pathways will dramatically restructure the nation's energy, buildings, industrial, and transportation sectors. International customers and suppliers will be concerned about their costs and their markets. The financial community, insurance industry, and standards organizations all have a stake in the process; the list is long. Their input will be important for formulating effective public–private alliances, monitoring progress toward GHG reductions, and sustaining interest in the climate change technology strategy over the decades that will be required to implement it.

In many respects, the whole is greater than the sum of its parts in strategic alliances, for while private companies, universities, federal laboratories, government organizations, and nongovernment organizations each have unique capabilities, a synergy results when their resources are applied strategically toward a common goal, such as developing technologies to reduce GHG emissions. For example,

- Private companies and industrial consortia, such as the Electric Power

Research Institute and the Gas Research Institute, play a key role in the innovation process by identifying requirements for technologies that help ensure their commercial viability, by performing R&D in collaboration with federal laboratories and universities, and eventually by demonstrating and deploying the technologies.
- Government laboratories and nongovernment research organizations provide scientific staff who have conducted and managed research for more than 50 years. These laboratories have conducted much of the research that provides the scientific underpinning for many technological breakthroughs. This scientific resource can provide new approaches to reducing emissions in the future. The national laboratories also provide unique facilities for use by researchers from industry and academia, as well as by their own researchers, in the development of these technologies.
- Universities provide a wealth of scientific talent to undertake the scientific research required to understand the role of GHGs in global climate change and to understand the basic mechanisms of biological and chemical processes that might be used to reduce GHG emissions. The linking of science and technology in the interactive process of innovation makes the scientific resources of universities and laboratories critical throughout the innovation process. In addition to providing scientific resources, universities are the training ground for future scientists and engineers needed for a sustained national effort to minimize the effect of GHGs on climate change.

Along with private companies, federal laboratories, and universities, it is important that government agencies, international organizations, and other nongovernmental organizations that are stakeholders in global climate change have a role in strategic alliances.

- Government agencies at the federal, state, and local levels contribute financial resources that are critical for advances in scientific research and basic technologies, as well as legislative mechanisms that can play an important role in removing barriers to the deployment of climate change technologies. In addition, government institutions can help educate the American public about climate change and can provide a forum for stakeholders to express their views on this subject.
- Climate change is a global issue, and international collaborative RD&D efforts will be needed. Japan has recently announced a national program to support international R&D on technologies to mitigate global climate change and pollution. Other efforts involving the U.S. federal government and U.S. companies are under way (e.g., the International Energy Agency Greenhouse Gas R&D Programme).
- Nongovernment organizations, including end-users, environmental organizations, financial institutions, and other interest groups, possess expertise that can be valuable to scientists, engineers, and market analysts as they work to better understand climate change and market issues.

4.4 CONCLUSION

Three specific approaches for implementing RD&D and deployment activities on GHG technologies are considered: (1) government led and financed, (2) industry led and financed, and (3) public–private strategic alliances. In selecting an implementation approach, we encourage the consideration of three factors: strategic value to the nation, target market, and expected return on private-sector investment. A systematic assessment of the relationship between the technology being developed and the three implementation approaches will allow selection of the optimum approach.

For most of the GHG emission reduction technologies discussed in this report, we believe that the public–private strategic alliance approach is the best choice. Although many of these technologies will be able to compete cost-effectively in the marketplace in the future, industry may not be willing to lead and finance the innovation process for many of these technologies because of the high risk associated with developing technologies that will not be deployed for decades and because the market currently does not place a high value on carbon mitigation. Additional factors favoring public–private strategic alliances include the *interactive nature* of the innovation process and the need to develop and deploy a variety of technologies in a number of target markets to reduce GHG emissions significantly. A public–private alliance will enhance the efficiency of the innovation process by bringing together stakeholders who can meet the scientific, technical, and commercial challenges involved in developing and deploying the required technologies. In this context, institutional efforts, such as collaborative RD&D enterprises, that help bring together industries, government laboratories, universities, government agencies, and nongovernment organizations to focus on common technological issues will be of great value in fostering the development of public–private alliances.

While public–private strategic alliances are only one part of the nation's climate change technology strategy, we feel they are a vital element if we hope to efficiently and effectively develop and deploy the GHG reduction technologies discussed in this report.

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