5. SYNTHESIS AND MOVING FORWARD

5.1 SYNTHESIS

In this report to Secretary of Energy Peña, the directors of 11 DOE national laboratories conclude that

1. Advances in science and technology are necessary to reduce GHG emissions from the United States while sustaining economic growth and providing collateral benefits to the nation.
2. Success will require the pursuit of multiple technology pathways, providing choices and flexibility for reducing GHG emissions.

One cost-effective strategy for reducing long-term GHG emissions while continuing economic growth is to develop and deploy a portfolio of new and improved technologies (as described in Chapter 2). Successful development of these technologies would require advances in many fields of basic science (as described in Chapter 3) along with strong public–private strategic alliances (as described in Chapter 4). Rapid and widespread deployment may also require the development and implementation of supportive programs and policies. The features of such programs and policies are not specified in this report.

5.1.1 The RD&D Path to Carbon Stabilization

Chapter 2 described the broad menu of technology pathways that could significantly reduce U.S. carbon emissions over the next three decades. If a vigorous, accelerated RD&D program were pursued, these pathways would enable the transformation of our nation's energy system. Given the breadth of technology options, this transformation could take place in an orderly fashion. Industry and consumers would be able to recover their investments in the nation's current energy infrastructure, while new energy and carbon sequestration technologies were gradually absorbed, as they became profitable, through the normal process of capital stock turnover.

By offering a technology-based, evolutionary—not revolutionary—path to a sustainable energy future, this report outlines the possibility of a transition that could be profitable to a wide array of potential constituents.

Over a 30-year planning horizon, implementing a climate change technology strategy could quickly expand the portfolio of options available for reducing U.S. GHG emissions. The three decades of this planning horizon appear to be distinct in terms of the dominant climate change technology opportunities.

- In the first decade, significant advances in energy efficiency technologies would reduce carbon emissions substantially by reducing the energy intensity (E/GDP) of the U.S. economy. Based on the five-laboratory study, the increased use of these technologies could offer energy-savings benefits that exceed their implementation costs (Interlaboratory Working Group 1997). Clean energy technologies would continue to gain market share, and carbon sequestration technologies could begin to emerge.
- Along with continued improvements in energy efficiency, research-based advances in clean energy technologies would begin to reduce the carbon intensity (C/E) of the U.S. energy economy significantly during the second decade. A wide range of renewable, fossil, and nuclear technologies could be introduced and widely deployed in this period. These clean energy options could begin to overshadow the impact of increased end-use efficiencies by the year 2030.
- Complementing ongoing advances in clean energy and efficiency technologies well into the third decade, carbon sequestration technologies would add a third important dimension to the package of solutions. We assume that these would not be widely available until the 2020 to 2030 time frame; however, successful introduction earlier could result in significantly greater reductions in carbon emissions. Success in this technology area could enable the nation to continue its extensive use of fossil fuels without changing the climate.

This technological progression can be seen in Table 5.1, which summarizes the carbon reduction estimates of each of the nine technology areas described in Chapter 2. Estimates of carbon-saving potential are difficult because of the many factors that can affect the performance and market penetration of a new technology. Consistent with these uncertainties, the values shown in Table 5.1 are provided in five ranges from low to high.

These estimates of carbon reduction potential were made relative to the *Annual Energy Outlook 1998* reference (business-as-usual) case (EIA 1997). They assume an accelerated federal RD&D program and a continuation of current federal programs and policies. The estimates do not presume the creation of any new incentives. The carbon reduction estimates were made individually for each technology area; competition between technologies and other effects of one technology on the success of another were not fully considered.

Because of the uncertainties associated with the carbon impacts of each pathway and the complexities associated with aggregation across pathways, our estimate of the combined potential effects of all of the pathways has a wide range. In total, it is estimated that an accelerated RD&D effort could provide advanced technologies with the potential to reduce U.S. carbon emissions by 400

Table 5.1. Potential reduction of U.S. carbon dioxide emissions from nine technology areas
(in MtC)*

	2010	2020	2030
Energy efficiency			
Buildings	L/M	M/H	H
Industry	L/M	M/H	H
Transportation	M	H	H
Agriculture and forestry	L	L	L/M
Clean energy			
Fossil resource development	L	M/H	H
Fossil power generation	L	M	H
Nuclear energy[a]	L	M	H
Renewables	L/M	H	H
Carbon sequestration	NA	NA	NA

*Assumes successful technology development and subsequent marketplace adoption without significant policy changes. Greater impacts could be expected with the addition of vigorous new policies and deployment programs, particularly in early years when the market penetration of existing and near-term technologies could be accelerated.

L = 0–25 MtC, L/M = 25–50 MtC, M = 50–75 MtC, M/H = 75–100 MtC, and H = 100+ MtC. Shaded areas show significant additions to the technology routes to reducing greenhouse gases. NA = Not applicable because the carbon reductions require policy changes.

[a]The 2020 and 2030 estimates for nuclear energy (M and H, respectively) are relative to an adjusted reference case forecast, which takes into account the large capacity of nuclear power scheduled for retirement after 2010. By extending the operation of one-third to one-half of these plants, significant carbon emissions can be avoided.

to 800 MtC/year in the year 2030. This represents a significant portion of the carbon emission reductions that may be targeted by the United States for 2030.

Table 5.1 and the discussions of each pathway in Chapter 2 also indicate that no single area or pathway can deliver sufficient GHG emission reductions; success will require pursuit of multiple technology pathways. The lower range of the estimated impact (400 MtC per year) could result from major technological advances and market success in several of the pathways. Achieving the upper range (800 MtC per year) would require technological breakthroughs and market success in a wider spectrum of pathways. This higher, more optimistic range is viewed as unlikely without also strengthening the policies and deployment programs that exist today. We did not attempt to quantify the potential reductions from a combination of accelerated RD&D and more vigorous deployment programs, policies, and financial incentives. However, it is believed that such a combination could drive U.S. carbon emissions down much further than the 400 to 800 MtC range described in this report.

This report's estimates of carbon reduction potential are quite modest compared with the estimates produced by many other studies. The smaller overall impacts estimated by this report are due primarily to our focus on the potential of accelerated RD&D within the context of today's policies and programs. Additional reductions would result from the implementation of new policies and deployment programs, particularly in early years when the market penetration of existing and near-term technologies could be accelerated.

The 1991 report by the Office of Technology Assessment titled *Changing by Degrees* (OTA 1991) analyzed the potential for energy efficiency to reduce carbon emissions by the year 2015, starting with the base year of 1987. Its “moderate” scenario results in a 15% rise in carbon emissions, from 1300 MtC/year of carbon in 1987 to 1500 MtC/year of carbon in 2015 (compared with a business-as-usual forecast of 1900 MtC/year). Its “tough” scenario results in a 20% to 35% reduction in emissions relative to 1987 levels, or emissions levels of 850 to 1000 MtC/ year of carbon in 2015.

Scenarios of U.S. Carbon Reductions by the Interlaboratory Working Group (1997) modeled three scenarios of carbon emissions in the year 2010 based on an array of assumptions about increased RD&D efforts, supporting policies, and deployment programs (see Chapter 1 for further details). The results were carbon reduction estimates of 120, 230, and 390 MtC in the year 2010. The most aggressive scenario reduces carbon emissions in 2010 to their levels in 1990 and reduces energy consumption in 2010 to 1997 levels.

Energy Innovations (1997) provides a third point of comparison. It estimates the levels of carbon emissions that are possible in 2010 and 2030 as the result of vigorous RD&D, deployment, and policies. It estimates that by 2010, carbon emissions could drop to a level that is 10% below emissions in 1990. By 2030, it suggests, carbon emissions could possibly be reduced to 728 MtC per year, which is almost half of the 1990 benchmark and well below the estimates provided in this report.

A fourth study by the National Academy of Sciences (NAS), *Policy Implications of Greenhouse Warming* (1992), identified a set of energy conservation technologies that would have either a positive economic return or a cost of less than $2.50 per tonne of carbon. Altogether, NAS concluded that these technologies offer the potential to reduce carbon emissions by 463 million tonnes, with more than half of the reductions arising from cost-effective investments in building energy efficiency. The NAS study characterized the current technological potential available at the time; thus it did not take into account stock turnover rates and other factors that prevent the instantaneous, full market penetration of technologies. Nor did it describe the role of RD&D in expanding future technology opportunities.

5.1.2 Factors Influencing GHG Reduction Potential

Many factors influence the ability of technology development efforts to reduce future U.S. GHG emissions. These include the magnitude of available R&D resources, technological risk, market size, stock turnover rates, and public acceptance issues. While this study has not attempted to analyze the effects of all of these various factors, it has compiled a considerable amount of information on them in its review of nearly 50 technology pathways. That information can be found in Appendix B, which includes a two-page description of each pathway that explains many of the factors.

Table 5.2 summarizes some of this information for technology areas grouped as energy efficiency, transportation fuels, electricity, and carbon sequestration. The table expands on the information in Table 5.1 in two ways. First, it includes information for those specific sectors and technologies that at this time appear to represent the largest potential carbon emission reductions over the 30-year planning period. For example, in the transportation sector, light-duty vehicles represent 58% of the CO_2 emissions in the transportation sector. Therefore, one entry in Table 5.2 summarizes information for the two technology pathways that address light-duty vehicles: (1) advanced conventional technologies for light-duty vehicles and (2) hybrid, battery-electric, and fuel cell vehicles.

Second, Table 5.2 provides information on several of the key factors that will influence future carbon emission reductions. This includes a column listing some of the significant issues or opportunities that will impede or enable the realization of potential carbon reductions. These issues and opportunities are selected from a more comprehensive accounting in Appendix B.

Altogether, Table 5.2 provides the reader with an indication of the most important results of this study in the form of the sectors and technologies that can play the largest role, as well as the factors and considerations that will determine their future contributions to GHG emission reductions.

The key factors that are used in Table 5.2 are defined as follows:

- Total market size: current total market in terms of carbon emissions (MtC/year) that is relevant to the technology
- Turnover rate: rate of retirement of the current stock of energy equipment or systems displaceable by this technology, with

  "Fast" corresponding to less than 10 years average lifetime
  "Moderate" corresponding to 11 to 20 years average lifetime
  "Slow" corresponding to greater than 20 years average lifetime

- Estimates of carbon emissions reductions: best estimate of the carbon emissions reductions (in MtC/year) that are likely to be achieved given this accelerated RD&D effort and continuing government deployment programs and policies. The estimates are based on the overall market size, the stock turnover rate, some consideration of the expected competitive position of the technology, and so on. For energy efficiency and clean energy technologies, the estimates assume no new fiscal incentives such as a carbon charge. See Sect. 2.1.2 for a more complete description of the study's assumptions. The entries are defined as follows:

  "High" corresponding to >100 MtC/year
  "Medium" corresponding to 50 to 100 MtC/year
  "Low" corresponding to 0 to 50 MtC/year

- Technological risk: subjective estimate of the risk that the technology will not be developed to the point that it can compete in its market as expected with

  "High" reflecting research that is still at the basic sciences level or involves complex systems integration
  "Moderate" reflecting research that is currently at both the basic research and technology prototype level
  "Low" reflecting development activities for technologies at the prototype or more advanced stage

- Significant issues or opportunities: illustrative major factors particularly noteworthy for this technology

Table 5.2. Potential reduction of U.S. carbon dioxide emissions from selected sectors and technology pathways*

Sector/area[a]	Technologies	Market size (MtC in 1995)[b]	Turnover rate	Estimated carbon emission reductions[c] 2010	2020	2030	Technical risk	Significant issues and opportunities
Efficiency—Buildings (1)		489	Mod	L/M	M/H	H	Lo	• minimal private sector R&D
	Building Equipment and Appliances (1.1)	489	Mod to Fast	L/M	L/M	L/M	Lo	• slow adoption of innovations • CFC ban accelerates chiller turnover
Efficiency—Industry (2)		463	Mod	L/M	M/H	H	Med	• short payback periods required
	Industrial Energy Conversion (2.1)	463	Mod	L	L/M	L/M	Med	• pollution prevention often saves energy
Efficiency—Transportation (3)		457	Mod	M	H	H	Med	• cost of lightweight materials
	Light-Duty Vehicles (includes trucks through class 6) (3.1 and 3.3)	265	Mod	L/M	M/H	H	Med to High	• consumer preference for power and size over high mpg
Transportation fuels (5.2 and 8.7)		457	Fast	L	L/M	L/M	Med	• distribution infrastructure barriers
	Biomass Fuels (8.7)	457	Fast	L	L/M	L/M	Med	• limited stocks at competitive prices
Electricity—Fossil (6)		494	Slow	L	M	H	Med	• large domestic coal resources
	Accelerated Development of High-Efficiency Power Generation (6.1)	494	Mod	L	L/M	M/H	Lo	
Electricity—Nuclear[d] (7)		494	Slow	L	M	H	Med	• public acceptance • nuclear waste storage
	Lifetime Extension and Generation Optimization (7.1)	113	Mod	L	L/M	M/H	Lo	• competition with natural gas

Table 5.2. (continued)

Sector/area [a]	Technologies	Market size (MtC in 1995) [b]	Turnover rate	Estimated carbon emission reductions [c] 2010	2020	2030	Technical risk	Significant issues and opportunities
Electricity—Renewables (8)		494	Slow	L/M	H	H	Med	• competition with natural gas • large domestic resources
	Biomass Electric (8.1)	494	Mod	L	L	L/M	Lo	• biomass resource limitations at competitive prices
	Wind and Photovoltaics (8.2, 8.4)	247	Slow	L	L/M	M	Med	• price penalty for intermittent power
Carbon Sequestration (9)		>6200	NA	NA	NA	NA	High	• small potential impact without regulations, incentives, or growth in markets for CO_2 • extends fossil fuel use
	Enhanced Carbon Cycle (4.3, 9.1, 9.4)	>6200	NA	NA	NA	NA	High	• ecological risk
	Capture and Sequestration (9.2, 9.3, 9.4, 9.5, 9.6)	1400	NA	NA	NA	NA	High	• stability of clathrates and and hydrates • diffusivity of CO_2 in the ocean • permanency

NA=not applicable because the carbon reductions require policy changes. The carbon sequestration pathways could enable the nation to continue its extensive use of fossil fuels without changing the climate.

*Assumes successful technology development and subsequent marketplace adoption without significant policy changes. Greater impacts could be expected with the addition of vigorous new policies and deployment programs, particularly in early years when the market penetration of existing and near-term technologies could be accelerated.

[a] Technology pathways identified in ( ) are cross-referenced to Table 2.1

[b] The technologies and sectors shown in this table overlap in terms of the carbon reductions they can deliver. For instance, decarbonization of the electricity sector through the introduction of clean energy technologies will reduce the potential carbon reductions from end-use sector efficiency technologies. As a result, it is not valid to simply add either the market size or the carbon reduction estimates.

[c] L=0–25 MtC, L/M=25–50 MtC, M=50–75 MtC, M/H=75–100, and H=100+ MtC. These estimates assume an enhanced federal RD&D program aimed at developing GHG reduction technologies. They do not presume the creation of any new financial incentives for reducing carbon emissions. The technologies covered in this table could deliver even greater GHG reductions if incentives, such as a carbon emissions trading program, or more vigorous deployment programs and policies, were implemented.

[d] Estimated carbon emission reductions are relative to the reference case in the *Annual Energy Outlook 1997* (EIA 1996), extended to 2020 and 2030 by extrapolating current carbon emission growth rates. The exceptions are the 2020 and 2030 estimates for nuclear energy (M and H, respectively). These are relative to an adjusted reference case forecast, which takes into account the large capacity of nuclear power scheduled for retirement after 2010.

The estimates of potential GHG reductions shown in Table 5.2 are consistent with the conclusions that were offered in conjunction with Table 5.1; that is, substantial reductions are available by 2030, and many technology areas can be contributing to these savings at that point.

Table 5.2 also shows that technology areas face different challenges, opportunities, and issues. Many of the technology issues can be addressed by the technology RD&D outlined in this report.

Technical risks are low to moderate in each of the energy efficiency areas and especially in the buildings sector. Counterbalancing this advantage in terms of delivering carbon impacts is the low level of private-sector R&D, the slow pace of adoption of innovations by builders, and the moderate rate of stock turnover in the buildings sector. The transportation and industrial sectors face generally moderate levels of technical risk. In transportation, economic risk is increased by consumer preferences for power and size over efficiency; and in industry, economic risk results from high discount rates that impede investments in efficient equipment.

Many of the clean energy options for generating electricity are threatened by the uncertainty of utility industry restructuring and competition with inexpensive natural gas combined-cycle technology. Nuclear power also has the additional institutional risks of a long-term waste repository solution and concerns over proliferation.

Carbon sequestration technologies face high technical risks because of the exploratory stage of their development. In addition, environmental and economic issues need to be resolved. However, these technologies hold the potential to extend the continued use of fossil fuel.

In most cases, risk can be reduced by technology and basic research programs that include analysis of economic and social consequences. Modeling tools and analyses are needed to complement the technology RD&D process to assess the potential acceptance of developmental technologies, identify likely concerns, and develop mechanisms to address those concerns. Such efforts to understand the social and economic risks are critical.

5.1.3 The Time-Line of Technology Products

Consistent with the notion of an orderly technology evolution, the products of a vigorous RD&D program to develop GHG reduction technologies could be adopted and implemented in time frames that mirror the typical pace of capital stock turnover. As a result, improvements in energy efficiency, clean energy, or carbon sequestration technologies would typically be available long before their impact on carbon emissions could be discerned. Thus, it is useful to forecast when different incremental improvements and breakthrough technologies will be available as cost-effective alternatives, recognizing that many years will typically be required before they are mature technologies.

Figures 5.1 and 5.2 present time lines of selected technology products. They illustrate the steady stream of important accomplishments that the vigorous RD&D program could produce. (Many more technology products are identified in Appendix B.) The technology products shown in these figures are consistent with the trend in carbon savings from energy efficiency gains in the first decade, to significant contributions by a variety of clean energy technologies in the second decade, followed by the emergence of carbon sequestration technologies in the third decade.

A second trend illustrated in these figures is the transition from the development of individual components to the emergence of novel, integrated systems. Over the next two decades, many components will be designed and engineered that can be woven into existing technology and capital infrastructures to improve their performance while reducing carbon emissions. Ultimately, these components will overhaul many of the systems that exist today. Such orderly sequencing of component development, with the ultimate goal of creating entirely new systems, can minimize the costs of capital displacement and economic disequilibrium. Two examples are provided below.

- The gasoline/electric hybrid vehicle (envisioned for development before 2005) is a precursor to the hydrogen fuel cell vehicle, which could be available by 2015. Following breakthroughs in hydrogen production, such as the manufacture of hydrogen from the solar conversion of water (perhaps by 2020), we envision a transformed transportation system by 2025 with a mature hydrogen supply infrastructure fueling multiple modes of transportation
- By 2010, we envision that biofuels could be cost-competitive with transportation fuels and that they could be distributed by the existing infrastructure of filling stations (worth hundreds of billions of dollars) with only modest modifications. By 2015, RD&D could enable the widespread production of chemicals from biomass feedstocks. Ultimately, 2030 could see a broad-based biomass industry with new crops, feedstocks, and distribution systems producing food, transportation fuels, chemicals, materials, and electricity, and possibly an entirely new distribution system at the wholesale and retail levels

The two examples illustrate the need for pursuing multiple technology pathways in critical areas (e.g., for alternative transportation fuels), because the success of any single pathway cannot be guaranteed. In addition, no single pathway appears able to deliver the amount of GHG reductions that may be needed.

Figures 5.1 and 5.2 portray a possible time line for the commercial introduction of new technology. The technologies themselves will endure much longer than the 30-year horizon indicates. They will become the legacy of the technology strategy that eventually is followed. With many of these technologies is an infrastructure and a whole economic system. Just as the introduction of the mass-produced Model-T Ford and the interstate highway system transformed transportation, these technologies will have comparable enduring effects.

Of course, RD&D programs by their very nature cannot guarantee that anticipated outcomes will result. Many technical and market risks prevent laudable efforts from producing successful technologies. However, there will also be important technological successes not foreseen at this time. If we invest in a portfolio of RD&D activities, historic data indicate that the winners will more than compensate for the cost of the failures (Brown 1997).

Fig. 5.1. Illustrative time-line of anticipated technology products: 2000–2010.

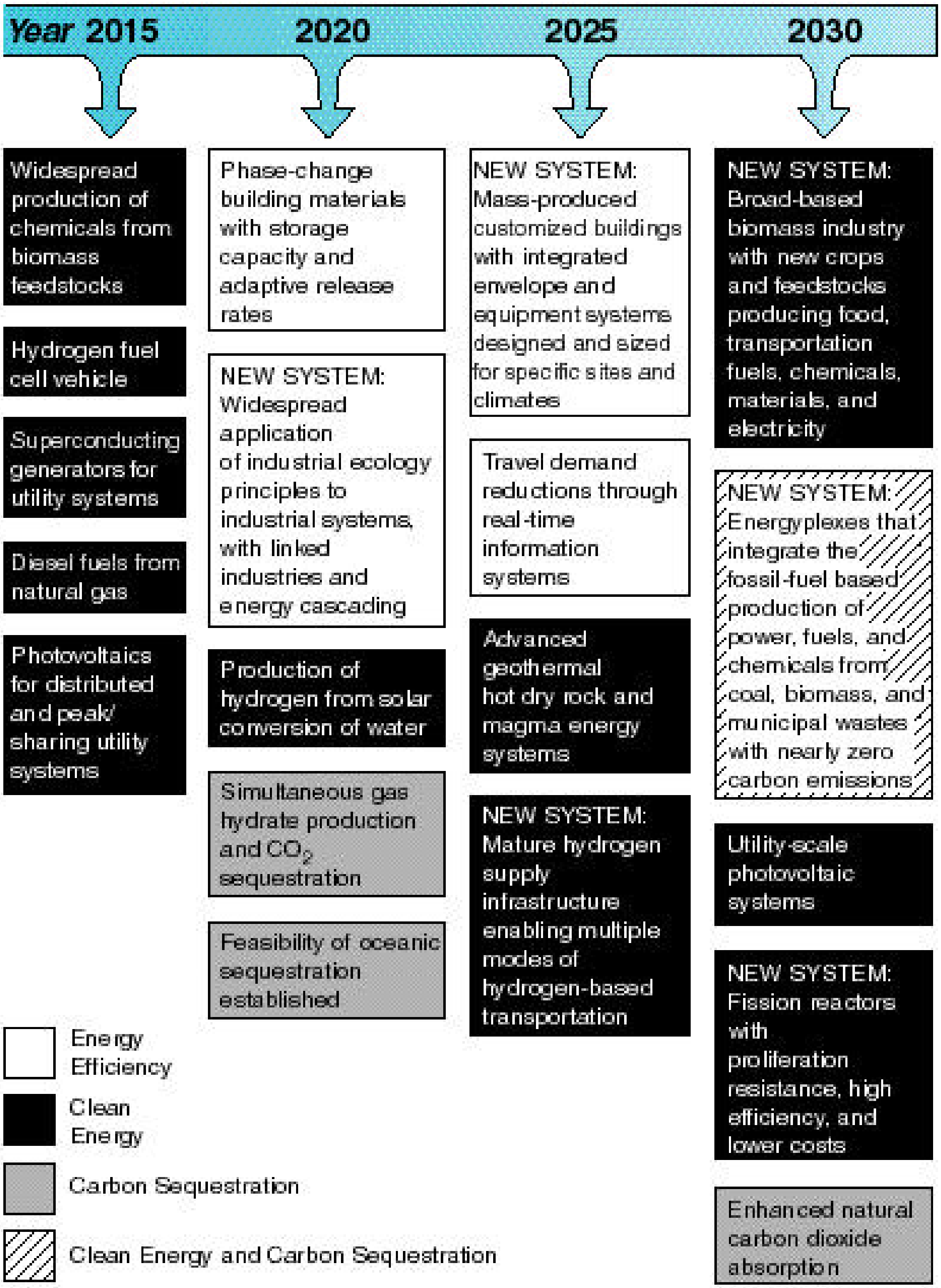

Fig. 5.2. Illustrative time-line of anticipated technology products: 2015–2030.

5.1.4 Performance Goals

Another way of viewing the products of the proposed technology pathways is by specifying performance goals they could achieve. These goals do not rely on particular technology developments; rather, they specify performance criteria that could be met by many alternative technologies. Recommended goals are presented, along with some of the technologies that could contribute to meeting them.

Energy Efficiency

- Use electricity more efficiently through the deployment of advanced technologies (e.g., intelligent building control systems, cost-effective refrigerators that use half as much electricity as today's models, and fuel cells for heat and power in commercial buildings).
- Reduce the use of gas and oil for space and water heating through building efficiency measures (e.g., super insulation, gas-fired heat pumps that provide highly efficient space heating and cooling, and building envelopes that capture and store solar energy for later use).
- Improve industrial resource recovery and use (e.g., develop an IGCC power technology, which can convert coal, biomass, and municipal wastes into power and products) and industrial processes to save energy (e.g., advanced catalysis and separations technologies).
- Increase transportation efficiency through new technologies (e.g., a hybrid electric vehicle that is three times more fuel efficient than today's standard model).

Clean Energy

- Change the energy mix to increase the use of sources with higher generating efficiencies and lower emissions—natural gas, safer and more efficient nuclear power plants, renewable energy (e.g., solar and wind power; electricity and fuels from agricultural biomass), and hydrogen (to produce electricity through fuel cells).
- Develop "energyplexes" that would use carbon efficiently without emitting GHGs for the integrated production of power, heat, fuels, and chemicals from coal, biomass, or municipal wastes.
- Distribute electricity more efficiently to reduce emissions (e.g., distributed generation using superconducting transformers, cables, and wires).
- Switch transportation to energy sources with lower emissions (e.g., trucks that run on biodiesel fuel; ethanol from cellulosic feedstocks).
- Remove carbon from fuels before combustion.

Carbon Sequestration

- Sequester CO_2 in large-capacity geological formations in deep oceans.
- Efficiently remove CO_2 from combustion emissions before they reach the atmosphere.
- Increase the rate at which oceans, forests, and soils naturally absorb atmospheric CO_2.
- Develop carbon storage technologies sufficient for geologic times.

5.1.5 Basic and Applied Research Are Needed

Meeting the goals described above also depends upon incremental improvements and breakthroughs in the basic sciences. These basic research needs include

- basic research to understand the global carbon cycle (i.e., computational modeling and

measurements to understand the ocean–atmosphere–terrestrial biosphere interactions) and judge the benefits and risks of sequestration options
- basic research supporting GHG reduction technologies (i.e., materials, chemical sciences, biotechnology, environmental and ecological sciences, geosciences, nuclear sciences, and computational sciences)

To support multiple technology pathways, enabling technologies also must be improved, especially those that enhance the utilization of energy carriers and systems. Relevant enabling technologies include

- hydrogen production/storage/distribution
- fuel cells
- electrical transmission, distribution, and components
- sensors and controls
- energy storage systems

5.1.6 Collateral Benefits and Costs

In addition to the benefits of GHG avoidance, the technology pathways described in this report could have significant secondary effects, as such pathways have in the past. For example, in the buildings area, there is a remarkable record of success in federally supported RD&D leading to products in the marketplace that have generated energy savings far exceeding their costs of development. In addition to reducing energy costs, the pathways would lead to improved environmental quality and public health, reduced U.S. dependence on imported oil, and increased exports of U.S. technologies to help other nations reduce GHG emissions, all of which will sustain economic growth.

The environmental and public health benefits of new and improved GHG reduction technologies could be very large. Clean energy options for generating electricity offer the prospect of significantly reducing air pollution. The development of efficient low-carbon transportation fuels would reduce pollutant emissions and abate ground-level ozone. Pollution prevention and waste minimization are important hallmarks of improved industrial process efficiencies. These collateral benefits would lead directly to major improvements in public health (Romm and Ervin 1996).

These environmental and public health benefits would not be limited to the United States. Better technology options would help to control the GHG emissions of other countries for many decades to come. They could also position the United States as the provider of choice for these new energy and environmental systems, with major economic growth consequences. The global energy market is estimated at $1 trillion, and the market for environmental technologies is estimated to be $400 billion. Renewable resources are widespread around the world, are highly attractive to developing countries, and represent a huge potential market for U.S. companies. An important collateral benefit of continued pursuit of nuclear power is the economic benefit of serving as an international supplier. The increased use of nuclear energy is foreseen around the developing world, especially in the Pacific Rim countries. The international market for ATSs and fuel cells is also likely to grow rapidly. Thus, implementation of a technology strategy would help to grow the U.S. economy by creating an energy technology export business.

The reductions in petroleum use that would result from the technology pathways would cut U.S. oil import dependence and could lower oil prices to consumers (Interlaboratory Working Group 1997, p. 5.47). It is estimated that efficiency improvements and alternative fuels in the transportation sector could result in reductions of one billion barrels per year by 2010.

Some of the pathways might also spawn significant collateral costs. For instance, increased nuclear waste might result in negative environmental repercussions, large-scale biomass production might cause soil and water contamination, and ocean fertilization might precipitate ecosystem damage. Regions that flourish in today's energy economy might be negatively impacted by shifts in the resource and labor requirements of new energy systems. The workplace requirements associated with advanced energy technologies might strain the nation's capacity to train and educate its labor force. History has shown that such challenges often can be managed. Further, if multiple pathways are pursued, those judged unacceptable can be set aside in favor of those that are preferred.

5.1.7 Research, Development, and Demonstration Resources

This report describes the carbon emission reductions that could result from an accelerated RD&D program. It does not consider collateral benefits from initiating complementary deployment programs or policies aimed at stimulating markets for GHG reduction technologies. It is believed that an integrated approach (i.e., science and technology in combination with deployment programs and supporting policies) is the most cost-effective one.

To achieve the annual emission reductions of 400 to 800 MtC by 2030 described in this report, absent any additional deployment or policy thrusts, federal RD&D budget increments would be necessary in three areas:

- The annual federal RD&D budget for the development of advanced energy technologies would need to grow to produce a sufficient number of the technological solutions.
- Additional resources are needed to initiate research into carbon sequestration technologies, which would also require supporting research on carbon cycle modeling, monitoring, and ecosystems.
- Supplemental RD&D support is needed to strengthen the basic research areas that are the wellspring of future technological breakthroughs.

The projects listed in Appendix B represent a catalog of promising technologies without prioritization. We believe that effective progress toward greenhouse gas emission reductions can be made with an additional RD&D investment of approximately $1B/year once priorities are established. Any budget decisions should be based on more detailed planning and analysis than was possible during development of this report. Initiation of that analysis and planning, which is a primary recommendation for moving forward, is discussed further in Sect. 5.2.

Actual budgets should be ramped up over several years in a way consistent with sound program development. Also, resource requirements for the outyears obviously would be affected by developments between now and then. Finally, it is anticipated that additional private-sector research effort would be leveraged by this federal increment.

5.2 MOVING FORWARD

This report identifies in general terms a set of future technologies that appear to hold great promise for reducing U.S. GHG emissions. By summarizing the status and potential of a broad range of technologies relevant to reducing GHG emissions, this report provides one key element, namely, the "technology basis," for developing a climate change technology strategy. However, full definition of such a strategy requires several additional steps, including

- an assessment of alternative programs and policies to promote deployment
- analysis of the costs and benefits of alternative technology and policy options to develop priorities
- development of technology goals and performance metrics for measuring progress
- identification of key players for pursuing these promising technology pathways
- estimation of budget requirements and appropriate allocation for each technology pathway
- mechanisms for ensuring strong ties between technology development activities and supporting basic sciences
- delineation of public- and private-sector responsibilities
- linkages to related ongoing activities in the United States and abroad
- a plan for managing the technology RD&D programs to be pursued over the years and decades ahead

The strong recommendation of this report is that the United States should develop and pursue a detailed and comprehensive climate change technology strategy.

Further, the planning process should begin immediately, and implementation of the strategy should occur quickly.

As the federal agency with the most involvement in the full range of technologies described in this report, the U.S. DOE should initiate and lead the planning required for implementation of this strategy. However, that planning effort must include significant participation from industry and business, the university community, Congress, and other federal agencies, as well as DOE and the national laboratories. Indeed, this planning should be a collaborative effort, just as is recommended for implementation of the technology RD&D programs.

While not all of the details of this planning and strategy implementation can be defined here, two clear needs should be explicitly addressed. The first is establishing a collaborative national planning effort to provide leadership and guidance to meet the RD&D challenges of a climate change technology strategy. The second is initiating an analysis activity to provide the information necessary for making sound decisions on the issues indicated. Both of these steps should be taken immediately.

Several other issues deserve immediate attention. One of these is the connection between developing promising technology pathways and designing policies to promote their deployment. There are many tradeoffs among how fast one pushes development, how much emphasis is placed on deployment of technologies that are ready to contribute to reduced emissions, and the timetable for achieving different reduced emission levels.

Another issue requiring study is the relationship between the implementation of promising technology pathways and the phenomenon of climate change, as well as the need for a better understanding of the phenomenon itself. This report strongly endorses the need to continue to improve our understanding of GHG emission levels, atmospheric concentrations of GHGs, climate change, and their impacts on our biosphere. A science-based understanding of the carbon cycle is essential as a framework for guiding our technology investments and ensuring their cost-effectiveness.

A third issue is consideration of the organizational structure of the technology RD&D programs. The recommendation to use strategic alliances recognizes the need to move away from the technology partnerships of the past. While there is no single organizational structure for creating strategic alliances, the traditional roles of users, industry, federal agencies, universities, states, national laboratories, and not-for-profit organizations may require redefinition as strategic alliances are formed to develop and deploy climate change technologies. Flexibility and adaptability in the structure of these partnerships is critical to the most effective pursuit of technology development programs to reduce GHG emissions.

A fourth issue is that of relating and coupling this domestic technology strategy with related international GHG emission reduction efforts. International collaboration can provide important domestic savings and global benefits.

Finally, it is important to understand the consequences of not developing and pursuing a technology strategy. Perhaps one of the greatest risks is underestimating the magnitude of the impact we are attempting to achieve. Energy is central to development and modern civilization. We are talking about transforming a national and global infrastructure that currently includes all of the things that support combustion as a means of energy generation. This is not a trivial matter. The generation of CO_2 is embedded deeply in the social infrastructure of this nation and is being embedded in the developing world right now.

The availability of advanced technologies on a timely basis to address future GHG emission reduction commitments requires initiation of the RD&D now and a commitment to following through on all the pathways that continue to show promise. Technologies not pursued are likely to result in lost opportunities to apply them to mitigating climate change, as well as a loss of their collateral benefits.

5.3 CONCLUSION

This report concludes that a national investment in a technology RD&D program over the next three decades would provide a portfolio of technologies that could significantly reduce GHG emissions well into the twenty-second century. Many technology opportunities exist that could accomplish this goal without harming the nation’s economy. A strategic plan that includes deployment policies to complement technology R&D will be necessary for success. Hence, development of a climate change technology strategy is the recommended next step. Based on the conclusions of this report, the strategy should specify an approach that pursues multiple technology pathways, that emphasizes public–private strategic alliances, and that is designed in close coordination with supportive government policies and deployment programs.

By delivering a portfolio of highly promising technologies, a climate change technology strategy could produce savings and revenues that far exceed the cost of an accelerated research program. The bottom line: with the help of technology and appropriate government programs and policies, we can slow GHG emissions and grow the economy. DOE's national laboratories stand ready to champion this enterprise.

5.4 REFERENCES

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