10 Conclusions and Next Steps

Under Presidential leadership, and in partnership with others, the United States is now embarked on an ambitious undertaking to develop new and advanced climate change technologies. These technologies have the potential to facilitate a global shift toward significantly lower greenhouse gas (GHG) emissions, and do so at substantially lower cost, while continuing to provide the energy-related and other services needed to spur and sustain economic growth.

The United States recognizes that making meaningful progress in such an undertaking will require a long-term commitment and international cooperation. By providing Federal leadership, through strategic direction and sustained commitment to a significant and well-guided portfolio of Federal R&D investments, CCTP seeks to strengthen the U.S. research enterprise; stimulate U.S. innovation and technology development on a broad scale, inside and outside the Federal Government; and inspire others at home and abroad to join in this effort. In this way, the United States intends to contribute to the building of a global technological capability that can achieve meaningful progress toward attainment of the world's shared commitment to the UNFCCC's ultimate objective.

Working under the auspices of the Cabinet-level Committee on Climate Change Science and Technology Integration (CCCSTI) and its Interagency Working Group on Climate Change Science and Technology (IWG), the U.S. Climate Change Technology Program (CCTP) seeks to provide strategic direction and effect coordinated implementation of the technological component of U.S. approach to climate change. CCTP, led by DOE, functions as a multi-agency planning and coordination entity, whose leadership and ongoing activities are both guided and carried out by representatives of its participating R&D agencies. CCTP's principal aim is to accelerate the advancement of technologies believed to be important to attaining its strategic goals.

CCTP's strategic goals parallel the opportunities for advanced technologies to contribute to the attainment of CCTP's mission and vision (Chapter 2). These opportunities were identified, in part, by the synthesis assessment of a number of long-term studies and analyses (Chapter 3). To the extent that agency missions and other priorities may allow, each participating CCTP agency will be guided by applicable elements of this *Strategic Plan* and align the relevant components of its R&D portfolio in ways that are consistent with and supportive of one or more of following CCTP strategic goals:

- Reduce emissions from energy end-use and infrastructure
- Reduce emissions from energy supply
- Capture, store, and sequester carbon dioxide (CO_2)
- Reduce emissions of non-CO_2 greenhouse gases
- Improve capabilities to measure and monitor GHG emissions
- Bolster basic science contributions to technology development

Consistent with principles established by the President, CCTP and its participating R&D agencies will pursue seven approaches to ensure progress toward attainment of CCTP's strategic goals: (1) strengthen climate change technology R&D; (2) strengthen basic research contributions; (3) enhance opportunities for partnerships; (4) increase international cooperation; (5) support cutting-edge technology demonstrations; (6) ensure a viable technology workforce of the future, and (7) provide supporting technology policy. To one extent or another, all approaches may be applied to each strategic goal.

Much work lies ahead. The next steps outlined at the end of this chapter indicate where CCTP's work will focus in the coming years. Much work is also underway. Core R&D programs related to climate change are being examined and strengthened. In certain research areas, the R&D portfolio has been realigned. Proposals for future technology R&D investments are now being evaluated, in part, on their ability to contribute to CCTP strategic goals. In some research areas, climate change strategic goals have provided compelling motivations for new or realigned program rationales, thus strengthening the overall CCTP R&D portfolio.

10.1 Portfolio Priorities and Current Emphasis

Emerging from this ongoing planning, coordination, and prioritization process is a CCTP R&D portfolio of activities that is reasonably well aligned with CCTP's strategic goals, but where additional refinements are expected. The CCTP portfolio is at an early stage of development, will undergo further scrutiny and evaluation, and is expected to continue to evolve as CCTP and its participating R&D agencies become more informed by analyses and technology assessments, search for key gaps and opportunities, and plan for the future.

Chapters 4 through 9 of this *Strategic Plan* examine the potential role for advanced technology to address each of CCTP's six strategic goals. These chapters articulate strategies for technology development, highlight ongoing R&D activities aligned with these strategies, and identify promising directions for future research, particularly in basic research areas. Representative technologies arising from these strategies are shown graphically by CCTP strategic goal in Figure 10-1 and summarized in the sections that follow.

10.1.1 Energy End-Use

The Federal government makes a substantial investment in the development of advanced energy efficiency technologies. Owing to the readiness of many of energy-efficient technologies in the near term, this area of the CCTP research and technology development portfolio is augmented by significant expenditures on technology deployment activities.

The existing CCTP portfolio related to energy end-use reduction is diverse, supporting an array of potentially productive avenues for reduced emissions in all sectors of the economy. Some of the research efforts are directed at lowering energy consumption and emissions in residential and commercial buildings, and in industrial facilities and processes. In addition, one of the more significant thrusts is toward new transportation technologies. Analyses suggest that the transportation sector, apart from electricity generation, may have the highest growth in global CO_2 emissions over the next 25 years. The CCTP portfolio emphasizes the introduction and expanded use of low-carbon fuels and other energy carriers, such as hydrogen, as well as research initiatives directed toward advanced light and heavy vehicles, organized primarily under the FreedomCAR program and the 21st Century Truck Partnership, involving the Departments of Transportation, Energy, and Defense (DOT, DOE, and DoD). These programs include research on fuel cell vehicles that use hydrogen (in cooperation with the Hydrogen Fuels Initiative).

Another important component of this strategic area is modernizing the electricity transmission grid and its associated infrastructure, particularly because such modernization can enable the use of technology for many new and advanced supply and end-use technologies. Significant efficiency gains are possible from

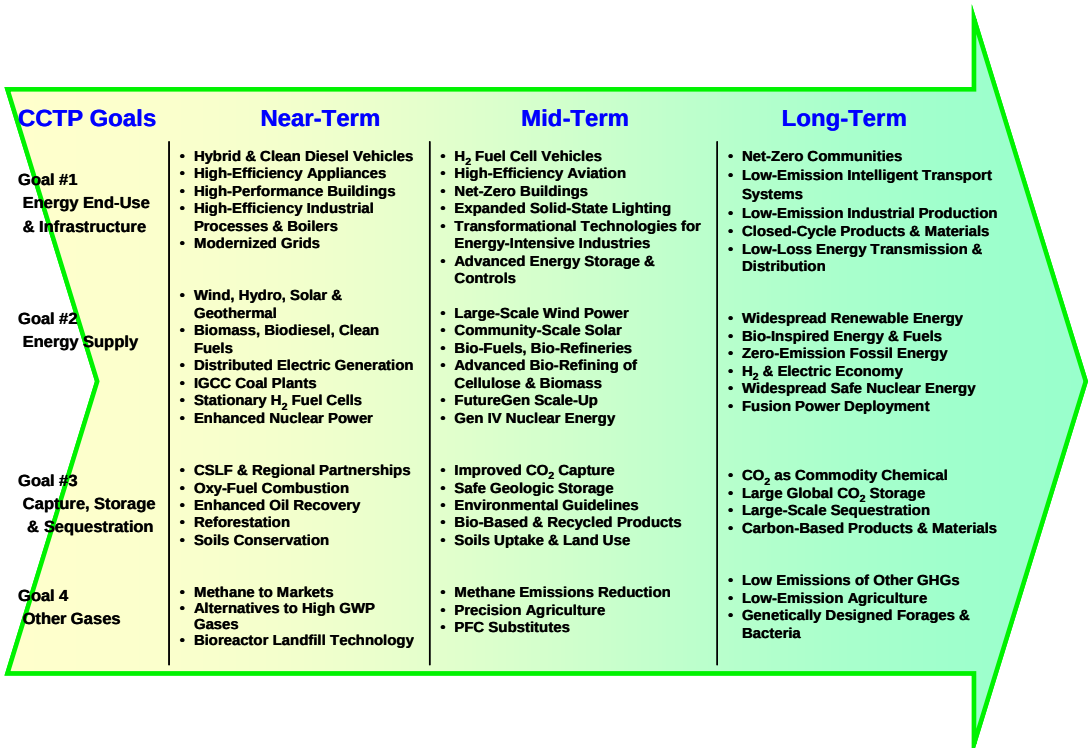

Figure 10-1. Roadmap for Climate Change Technology Development and Deployment for the 21st Century

(Note: Technologies shown are representations of larger suites. See Chapters 4 through 9 for more comprehensive information on technology strategies, development plans and timelines. With some overlap, "near-term" envisions significant technology adoption by 10 to 20 years from present, "mid-term" in a following period of 20-40 years, and "long-term" in a following period of 40-60 years. See also List of Acronyms and Abbreviations.)

the adoption of advanced technology and practices—such as distributed generation technologies; energy storage; sensors, controls, and communications; and power electronics, which can be applied in both developed and emerging economies. High-temperature superconductivity has the potential to revolutionize electric transmission systems. Technologies are needed that would make it possible to store energy for many hours at attractive costs to effectively make use of intermittent renewable energy technologies, thus permitting very large contributions from renewable energy to electricity supplies in the long term. More detail on these initiatives can be found in Chapter 4.

10.1.2 Energy Supply

Despite large and relatively cost-effective contributions expected in the CCTP technology strategy from energy-efficiency gains, energy supply technologies with low or net-zero GHG emissions are likely to be required under a range of advanced technology planning assumptions. Recent changes in the CCTP portfolio show increasing emphasis on low-emissions, fossil-based power and fuels; hydrogen; renewable energy and fuels; nuclear fission; and fusion energy. Details can be found in Chapter 5.

Selected highlights of key initiatives include (1) FutureGEN, aimed at demonstrating the viability of near-zero-emissions, high-efficiency, coal-based electricity generation plants with CO_2 capture and storage that

have the ability to co-produce low-cost hydrogen; (2) the Hydrogen Fuel Initiative, which complements the FreedomCAR initiative and focuses on research to produce, store, and deliver hydrogen; (3) the International Partnership for the Hydrogen Economy (IPHE), which now involves 15 countries; (4) increasing emphasis on wind energy, biomass, and photovoltaics; (5) the next-generation nuclear fission energy systems (Generation IV) that offer advances in proliferation resistance, physical protection, safety, waste reduction, and economic efficiency; (6) the Nuclear Power 2010 program, designed to pave the way for an industry decision by the latter half of this decade to order at least one new nuclear power plant for deployment in the 2010-2015 timeframe; (7) the Advanced Fuel Cycle Initiative (AFCI), focused on developing advanced nuclear fuel cycle technologies; and (8) the international magnetic fusion experiment (ITER), which involves the United States, Europe, Japan, China, Russia, and the Republic of Korea.

10.1.3 Carbon Capture and Sequestration

Capture, storage, and sequestration of CO_2 may play a potentially transforming role in addressing climate concerns. In areas related to CO_2 capture, geologic storage, and oceanic sequestration, many questions regarding the technical, economic, and environmental acceptability will need to be explored and resolved. Early resolution of such issues is important, as the outcomes will have implications for investments in R&D on other technologies. Details on the research related to carbon capture, geologic storage, terrestrial sequestration, and ocean sequestration are presented in Chapter 6.

Important research activities include (1) the international Carbon Sequestration Leadership Forum (CSLF), which coordinates data gathering, R&D, and joint projects to advance the development and deployment of carbon sequestration technologies worldwide; (2) the Regional Carbon Sequestration Partnerships, which include seven regional partnerships of state agencies, universities, and private companies that form the core of a nationwide network designed to determine the best approaches for capturing and storing CO_2 for the long term; and (3) R&D programs in advanced forest and crop management systems, which are important to understanding and implementing cost-effective methods to enhance terrestrial sequestration. In addition, FutureGen (mentioned above) has elements relevant to this goal.

10.1.4 Other Greenhouse Gases

The CCTP analyses suggest that there are a number of potentially fruitful areas for technologies to mitigate growth in emissions of non-CO_2 GHGs and that such emissions-reduction contributions can be significant. The strategy for addressing non-CO_2 GHGs has two main elements. First, it focuses on the key emission sources of these GHGs and identifies specific mitigation options and research needs by gas, sector, and source. Given the diversity of emission sources, a generalized technology approach is not practical. Second, the strategy emphasizes both the expedited development and deployment of near-term and close-to-market technologies, and expanded R&D into longer-term opportunities that could lead to large-scale emission reductions, considering tradeoffs among mitigation options for carbon dioxide and other gases. By stressing both near- and long-term options, the strategy offers maximum climate protection in the early part of the 21st century and a roadmap to achieve dramatic gains in later years.

Research aimed at reducing emissions of these GHGs focuses on (1) methane emissions from energy and waste, (2) methane and nitrous oxide emissions from agriculture, (3) emissions of gases with high global

warming potential, (4) nitrous oxide emissions from combustion and industrial sources, and (5) emissions of tropospheric ozone precursors and black carbon. Details are provided in Chapter 7.

10.1.5 Measurement and Monitoring

A wide assortment of GHG sensors, measurement platforms, monitoring and inventorying systems, models, and inference methods will likely be needed to meet the basic GHG emissions measurement requirements of the future. Measurement systems must be developed that can establish baselines and measure carbon storage and GHG fluxes at various scales, from individual projects to large geographic areas. Improved measurement and monitoring technologies and capabilities can also inform the state of climate science and help to identify and guide future opportunities for technology development.

Under the Applied Terrestrial Sequestration Partnership, the Department of Agriculture (USDA), DOE and the National Energy Technology Laboratory (NETL) are working to improve measuring and monitoring of GHG emissions and changes in soil carbon. For example, Laser Induced Breakdown Spectroscopy (LIBS), supported by USDA, DOE, and the National Aeronautics and Space Administration (NASA), is a breakthrough carbon measurement technology with the ability to quickly and cost-effectively measure carbon in soils. It will be key to the monitoring of terrestrial sequestration projects.

Another important project is Agriflux, a USDA-led network of 30 sites for measuring the effects of environmental conditions and agricultural management decisions on carbon exchange between the land and the atmosphere. Studies will identify crop management practices to optimize crop yield, crop quality, and carbon sequestration under carbon dioxide concentrations and other environmental conditions expected in the 21st century. A third example is AmeriFlux, a research network of 75 sites, used in collecting, synthesizing, and disseminating long-term measurements of CO_2, water, and energy exchange for a variety of terrestrial landscapes across the United States. Details are provided in Chapter 8.

The CCTP is encouraging integrative system design, with near- and long-term advances in technology. In the near term, it is possible to (1) incorporate transportation measurement and monitoring sensors into the onboard diagnostic and control systems of production vehicles; (2) prepare geologic sequestration measurement and monitoring technologies for deployment with planned demonstration projects; (3) exploit observations and measurements from current and planned Earth observing systems to measure atmospheric concentrations and profiles of GHGs from planned satellites; (4) undertake designs and deploy the foundation components for a national, multi-tiered monitoring system with optimized measuring, monitoring, and verification systems; (5) deploy sounding instruments, biological, and chemical markers (either isotopic or fluorescence), and ocean sensors on a global basis to monitor changes in ocean chemistry; (6) maintain *in situ* observing systems to characterize local-scale dynamics of the carbon cycle under changing climatic conditions; and (7) maintain *in situ* observing systems to monitor the effectiveness and stability of CO_2 sequestration activities. The Integrated Earth Observing System (IEOS) is an important part of these technology advances.

In the long term, with sustained future investments, it may be possible to (1) model emissions based on a dynamic combination of human activity patterns, emission sources, energy sources, and chemical processes; (2) develop process-based models that reproduce the atmospheric physical and chemical processes (including transport and transformation pathways) that lead to the observed vertical profiles of GHG concentrations due to surface emissions; (3) determine to what degree natural exchanges with the surface affect the net national emissions of GHGs; (4) develop a combination of space-borne, airborne

(including satellite, aircraft, and unmanned aerial vehicles), and surface-based scanning and remote sensing technologies to produce three-dimensional, real-time mapping of atmospheric GHG concentrations; (5) develop specific technologies for sensing of global methane "surface" emissions with resolution of 10 km; (6) develop remote sensing methods to determine spatially resolved vertical GHG profiles rather than column averaged profiles; and (7) develop space-borne and airborne monitoring for soil moisture at resolutions suitable for measurement and monitoring activities.

10.1.6 Basic Science Support to Climate-Related Technology Development

A diverse range of energy sources, GHG emissions reduction strategies, and carbon sequestration technologies will be required to meet the climate change challenge, and similarly a broad range of basic science research is needed to enable these diverse technologies. Science is on the threshold of a variety of discoveries in biology, nanoscience, computational modeling and simulation, physical processes, and environmental sciences that offer opportunities, many yet unimagined, for innovations in both technologies and instrumentation. In addition, the rapidly developing global infrastructure for computing, communications, and information is expected to accelerate the scientific process and reduce the time and cost of bringing new discoveries to the marketplace. Such new discoveries may hold the ultimate key to GHG emissions reduction.

Workforce development and education are also integral components of any sustained and successful scientific and technological undertaking of this scope and magnitude. Basic research conducted in conjunction with CCTP goals can provide unique opportunities to strengthen and revitalize Federal investments in science, math, and engineering education, with an additional emphasis on climate change technology development. This would attract new talent to associated careers and ensure the growth of a future workforce knowledgeable and skilled in the needed technical areas.

In this area of the CCTP portfolio, three strategic thrusts are being pursued. One is to conduct basic research, that is, strategic research, in areas inspired by the technical challenges in the applied R&D programs associated with the CCTP strategic goals, described in Chapters 4 through 8. The second is to carry out, subject to the availability of funds, an exploratory research program on innovative concepts and enabling technologies, which have great potential for breakthroughs in new or unknown areas important to the climate change challenge. The third thrust is to improve and more widely implement an integrative R&D planning process that will better identify and facilitate agency pursuit of the basic science research needed by the applied climate change technology R&D programs. Recent examples of planning processes that have attempted to bolster this linkage between basic and applied R&D include workshops on carbon sequestration and hydrogen research needs.

10.2 Next Steps

The CCTP's next steps focus on two broad thrusts. First, the CCTP will continue to provide support to the Administration's leadership on climate change, namely, the Cabinet-level CCCSTI and its IWG. Support is likely to include activities such as multi-agency planning, portfolio reviews, interagency coordination, technical and other analyses, and formulation of recommendations. The CCTP will strive to provide support that will enable CCCSTI and the IWG to address issues, make informed decisions, and weigh policies and priorities on related science and technology matters to the President and the agencies.

Second, the CCTP will continue to work with and support the participating agencies in developing plans and carrying out activities needed to advance the attainment of the CCTP's vision, mission, and strategic goals. For each CCTP strategic goal, to the extent suitable for each goal, agency plans and activities will be guided by the seven core approaches.

Specific activities that follow these seven approaches are outlined below, although not all activities will be pursued at once.

Strengthen Climate Change Technology R&D

- Continue to review, realign, reprioritize, and expand, where appropriate, Federal support for climate change technology research, development, demonstration, and deployment.

- Periodically assess the adequacy of the multi-agency portfolio with respect to its ability achieve or make technical progress toward CCTP strategic goal attainment, identify gaps and opportunities, and make recommendations.

- In key technology areas, perform long-term assessments of technology potentials, including market considerations and potentially limiting factors.

- Develop improved methods, tools, and decision making processes for climate technology planning and management, and R&D planning and assessment, including tools that allow portfolio planning that addresses risk in a way that hedges that risk.

Strengthen Basic Research Contributions

- Establish or improve within each of the participating Federal R&D agencies a process for the integration with, and application of, basic research to help overcome barriers impeding technical progress on climate change technology development.

- Develop means for expanding participation in climate change technology R&D, including relevant basic research, at universities and other non-Federal research institutions.

Enhance Opportunities for Partnerships

- Review status and encourage further formation of public-private partnerships as a common mode of conducting R&D portfolio planning, program execution, and related technology demonstration, transfer, and commercialization activities.

Increase International Cooperation

- Expand international participation in key climate change technology activities; build on the many cooperative international initiatives already underway.

- Assist the Department of State and CCSP in the coordination of U.S. input and support of the IPCC's Fourth Assessment Report, Working Group III on Mitigation; the IPCC Special Report on Carbon Capture and Storage; and other relevant Special Reports, as means of stimulating international efforts to develop advanced technologies.

- Support continued efforts to negotiate and execute bilateral agreements that encourage international cooperation on climate change science and technology research. Pursue opportunities for outreach and communication to build relationships and encourage other country initiatives.

- Pursue additional means to enhance the effective use of existing international organizations, such as OECD, IEA, IPCC, Group of 8 (G8[1]), GEOSS, and others, to shape and encourage expanded R&D on climate change technology development worldwide. Witness the recent G8 Communiqué of Gleneagles, Scotland, and the assisting role envisioned for IEA.

- Develop globally integrated approaches, such as the recently established Asia-Pacific Partnership for Clean Development[2], to foster capacity building in developing countries, encourage cooperative planning and joint ventures and, enable the development, transfer and deployment of advanced climate change technology.

Support Cutting-Edge Technology Demonstrations

- As part of the agencies' regular planning and budgeting processes, consider additional cutting-edge technology demonstrations relevant to CCTP strategic goals.

Ensure a Viable Technology Workforce of the Future

- Explore the establishment of graduate fellowships for promising candidates who seek a career in climate-change-related technology research and development.

- Explore possibilities of expanding internships related to climate change technology development in Federal agencies, national and other laboratories, and other Federally Funded Research and Development Centers (FFRDCs).

- Explore possibilities for establishing CCTP-sponsored educational curricula in K-12 programs related to climate change and advanced technology options.

Provide Supporting Technology Policy

- Evaluate various technology policy options for stimulating private sector investment in CCTP-related research, development, and experimentation activities.

- Evaluate various technology policy options for stimulating private investment in advanced technology related to climate change or other GHG-related investments, and/or for accelerating the experimentation with and adoption of advanced technology to reduce GHGs.

- Evaluate various technology policy options for stimulating land-use and land management practices that promote carbon sequestration and GHG emission reductions.

[1] The countries are, in alphabetical order, Canada, France, Germany, Italy, Japan, Russia, United Kingdom, and United States. The G8 meetings often include the European Commission.

[2] The Asia Pacific Partnership for Clean Development was announced in July 2005. Six countries are participating, namely: Australia, China, India, Japan, South Korea and the United States.

In carrying out these activities, CCTP will be advised by the CCTP Steering Group, assisted by its multi-agency CCTP Working Groups, informed by inputs from varied sources, and supported by CCTP staff and resources. Results will be conveyed to the CCCSTI via the Interagency Working Group. The CCTP also plans to issue reports on its current activities, future plans, and research progress.

10.3 Closing

This CCTP *Strategic Plan* completes an important step toward implementing the President's initiative in this area. The *Plan* provides a vision for the role of advanced technology in addressing climate change, defines a supporting mission for the multi-agency CCTP, establishes strategic direction for the Federal R&D portfolio within a framework of guiding principles, outlines the approaches to be employed in pursuing attainment of CCTP's six strategic goals, and identifies a series of next steps by which to effect progress on implementation.

As evidenced by the programs highlighted in Chapters 4 through 9, a number of important activities are underway in the Federal R&D portfolio, motivated by climate change considerations. However, much work remains to be done, both in following through on current commitments and in identifying and pursuing additional opportunities. With sustained vision and commitment, augmented by enhanced activity and cooperation from others, this technological undertaking will succeed, securing a bright energy and economic future for our Nation and ensuring a healthy planet for future generations.

10.4 References

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