2 Vision, Mission, Goals, and Approaches

The Climate Change Technology Program (CCTP) is a multi-agency planning and coordination activity, led by the Department of Energy, which organizes and supports an associated portfolio of Federal R&D.[1] It was established under the Committee on Climate Change Science and Technology Integration in 2002 and subsequently authorized in the Energy Policy Act of 2005.

CCTP constitutes the "technology component" of a comprehensive U.S. approach to climate change that includes undertaking short-term actions to reduce greenhouse gas emissions intensity, advancing climate change science, and promoting international cooperation. CCTP's purpose is to accelerate the development, and reduce the cost of, new and advanced technologies, as well as promote the deployment of advanced technologies and best practices that could avoid, reduce, or capture and store greenhouse gas emissions. CCTP was established by President Bush to implement his National Climate Change Technology Initiative (NCCTI) and coordinate existing efforts. This initiative brings to bear America's strengths in innovation and technology to address climate change concerns.

CCTP has a number of publications that are available at http://www.climatetechnology.gov.

CCTP provides strategic direction and leadership through interagency coordination of R&D planning, programming, and budgeting. To support these functions, CCTP conducts analyses, technology assessments, and progress reviews. CCTP's interagency working groups have representatives from all participating agencies, and this *Plan* is an important product of this interagency effort.

The focus of this *Plan* is technology research, development, demonstration, and deployment, and it provides a broad roadmap to the future. It does not, however, provide detailed roadmaps for specific technologies. Such roadmaps are referenced in the appropriate sections throughout the document. Moreover, the *Plan* does not, nor is it intended to, provide a comprehensive mitigation strategy. It is not a policy document. It does not, for example, address technology incentives (e.g., tax credits) or regulation (e.g., energy efficiency standards), but it does set a course for evaluating such policies. Further, the *Plan* makes no judgments as to what constitutes a dangerous level of greenhouse gases in the atmosphere. For century-long planning, the technology portfolio must be designed to be robust in the face of a range of plausible concentration target scenarios. Finally, the *Plan* is not a budget document, but provides a framework to set budget priorities.

The *Plan* was prepared by an interagency team and includes the contributions of a broad range of government and non-government experts from many different disciplines. It is a "first-of-its-kind" document that provides a comprehensive, long-term look at the nature of the climate change challenge and defines clear and promising roles for advanced technologies.

This chapter outlines the vision, mission, strategic goals, core approaches, R&D prioritization process, and management of the program.

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1 Throughout this report the use of the term "R&D" is meant generally to include research, development, demonstration, and technology adoption programs. See also Footnote 14, Chapter 1.

2.1 Vision and Mission

CCTP seeks to attain, in partnership with others, a technological capability that could provide on a global scale abundant, clean, secure, and affordable energy and other services needed to power economic growth, while simultaneously achieving substantial reductions in emissions of GHGs (CCTP Vision). With leadership in R&D and progress in technology development, CCTP aims to inspire broad interest inside and outside of government and internationally, in an expanded global effort to develop and commercialize advanced technologies.

THE CCTP VISION

is to attain on a global scale, in partnership with others, a technological capability that can provide abundant, clean, secure, and affordable energy and other services needed to encourage and sustain economic growth, while simultaneously achieving substantial reductions in emissions of GHGs and mitigating the potential risks of climate change and increasing GHG concentrations.

THE CCTP MISSION

is to stimulate and strengthen the scientific and technological enterprise of the United States, through improved coordination and prioritization of multi-agency Federal climate change technology R&D programs and investments, and to provide global leadership, in partnership with others, aimed at accelerating development and facilitating adoption of technologies that can attain the CCTP vision.

CCTP will strive to stimulate and strengthen the scientific and technological enterprise of the United States, through improved coordination and prioritization of multi-agency Federal climate change technology R&D programs and investments. CCTP will provide support to decision-makers so that they can address issues, make informed decisions, weigh priorities on related science and technology matters, and provide strategic direction. It will do this through recommendations based on multi-agency planning, portfolio reviews, interagency coordination, technical assessments and other analyses. CCTP will also continue to work with and support the participating agencies in developing plans and carrying out activities needed to achieve the CCTP's vision and strategic goals (CCTP Mission).

2.2 Strategic Goals

The ultimate objective of the U.N. Framework Convention on Climate Change—stabilizing the GHG concentrations at a level that would prevent dangerous anthropogenic interference—provides an important (though not the only) planning context for CCTP's *Strategic Plan*. Two considerations that arise from this are relevant to long-term technology R&D planning and guidance. First, the level of GHGs in Earth's atmosphere implied by the UNFCCC is not known and is likely to remain a key planning uncertainty for some time.[2] Accordingly, CCTP's strategic goals are not based on any hypothesized level of stabilized GHG concentrations, but rather encompass a range of levels. Second, stabilizing the atmospheric GHG concentration at any level implies that global additions and withdrawals of GHGs to and from the atmosphere must achieve a net balance. This means that the growth in net GHG emissions would need to slow, eventually stop, and then reverse and approach levels that are low or near zero. The technological challenge is to develop new systems that could help achieve this goal affordably.

Set against this backdrop is the growing global appetite for energy to power economic growth and development. Energy-related GHG emissions account for over four fifths of total anthropogenic emissions, and the technologies employed to produce and use energy will have a direct bearing on future emissions. Different countries will approach climate objectives in different ways and in the context of other urgent needs. For most developing countries, the

2 Additional scientific research is required to determine the level of GHG concentrations that would prevent dangerous anthropogenic interference with the climate system. The CCSP's principal aim is to improve understanding of climate change and its potential impacts, which will inform CCTP.

overriding goal will continue to be economic development to reduce poverty and advance human well-being. Increased global energy use is needed to help lift out of poverty the nearly two billion people who lack even the most basic access to modern energy services. Addressing this "energy poverty" is one of the world's key development objectives, as lack of energy services is associated with high rates of disease and child mortality.

All countries can be expected to seek to ensure that energy sources are secure, affordable, and reliable, and to seek approaches that address other environmental concerns, in addition to climate change, such as air pollution and conservation. Opportunities for new and advanced technologies that can address multiple societal objectives, including GHG reduction, present themselves in a number of areas.

These opportunities form the basis for CCTP's six strategic goals as follows:

1. Reduce emissions from energy end use and infrastructure;
2. Reduce emissions from energy supply;
3. Capture and sequester carbon dioxide;
4. Reduce emissions of non-carbon dioxide greenhouse gases;
5. Improve capabilities to measure and monitor GHG emissions; and
6. Bolster basic science contributions to technology development.

To the extent that agency missions and other priorities allow, each participating CCTP agency will align the relevant components of its R&D portfolio in ways that are consistent with and supportive of one or more of these goals.

These six CCTP strategic goals focus primarily on mitigating GHG emissions to make progress toward stabilizing atmospheric GHG concentrations. They are not intended to encompass the broad array of technical challenges and opportunities that may arise from climate change. These may include such research areas as: mitigating vulnerabilities and adaptation of natural and human systems to climate change; addressing effects of acidification of the oceans; geoengineering to reduce radiative forcing through modification of the Earth's surface albedo or stratospheric sunlight scattering; and others. Such topics are important, but they are beyond the scope of this *Plan*.

A major and growing source of greenhouse gas emissions is closely tied to transportation.

Credit: iStockphoto

CCTP Goal 1
Reduce Emissions from Energy End Use and Infrastructure

Major sources of anthropogenic carbon dioxide (CO_2) emissions are closely tied to the use of energy in transportation, residential and commercial buildings, and industrial processes. Improving energy efficiency and reducing GHG-emissions intensity in these economic sectors through a variety of technical advances and process changes present large opportunities to decrease overall GHG emissions.

In addition, application of advanced technology to the electricity transmission and distribution (T&D) infrastructure (the "grid") can have dual effects on reducing GHG emissions. First, there is a direct contribution to energy and CO_2 reductions resulting from increased efficiency in the T&D system itself. Second, there can be an indirect contribution by enabling, through modernized systems, expanded use of low-emission electricity and distributed generating technologies (such as wind, cogeneration of heat and power, geothermal, and solar power), and by improved management of system-wide energy supply and demand. Emissions reduction from energy efficiency gains and reduced energy use could be among the most important contributors to strategies aimed at overall CO_2 emissions reduction.

Types of technological advancements and deployment activities applicable to this goal include, but are not limited to:

- **Efficiency, Infrastructure, and Equipment.** Development and increased use of highly efficient motor vehicles and transportation systems, buildings equipment and envelopes, industrial combustion and process technology, and components of the electricity grid can significantly reduce CO_2 emissions, avoid other kinds of environmental impacts, and reduce the life-cycle costs of delivering the desired products and services. Process technology includes non-energy sources of CO_2, such as the calcination of carbonates to produce cement and lime.
- **Transition Technologies.** So-called "transition" technologies, such as high-efficiency natural gas-fired power plants, are not completely free of GHG emissions, but are capable of achieving significant reductions of GHG emissions in the near and mid terms by significantly improving or displacing higher GHG-emitting technologies in use today. Ideally, transition technologies would also be compatible with more advanced GHG-free technologies that would follow in the future.
- **Enabling Technologies.** Enabling technologies contribute indirectly to the reduction of GHG emissions by making possible the development and use of other important technologies. The example of a modernized electricity grid, mentioned above, is seen as an essential step for enabling the deployment of more advanced end-use technologies and distributed energy resources that can reduce GHG emissions. An intelligent electricity grid integrated with smart end-use equipment would further raise system performance. Another example is storage technologies for electricity or other energy carriers.
- **Alternatives to Industrial Processes, Feedstocks, and Materials.** Manufacturing, mining, agriculture, construction, services, and other commercial and industrial activities will require feedstocks and other material inputs to production.[3] In addition to the energy efficiency improvements discussed above, opportunities for lowering CO_2 and other GHG emissions from industrial and commercial activities include: replacing current feedstocks with those produced through processes (or complete resource cycles) that have low or net-zero GHG emissions (e.g., bio-based feedstocks); reducing the average energy intensity of material inputs; and developing alternatives to current industrial processes and products.
- **Improved Land Use and Management Practices.** Improved land use and management practices can reduce emissions of CO_2 in agriculture through energy-efficient and conservation practices. Additionally, long-term local and regional planning can help integrate and optimize residential, business, and transportation systems.

CCTP Goal 2
Reduce Emissions from Energy Supply

Current global energy supplies are dominated by fossil fuels—coal, petroleum products, and natural gas—that emit CO_2 when burned. A transition to a low-carbon future would likely require the availability of multiple energy supply technology options characterized by low or net-zero CO_2 emissions. Many such energy supply technologies are available today or are under development. When combined with improved energy carriers (e.g., electricity, hydrogen), they offer prospects for both reducing

Earth's city lights suggest where the world's energy use is concentrated. Advanced technologies in various forms of energy supply, including electricity generation, could significantly reduce or avoid future greenhouse gas emissions.

Credit: Craig Mayhew and Robert Simmons, NASA GSFC

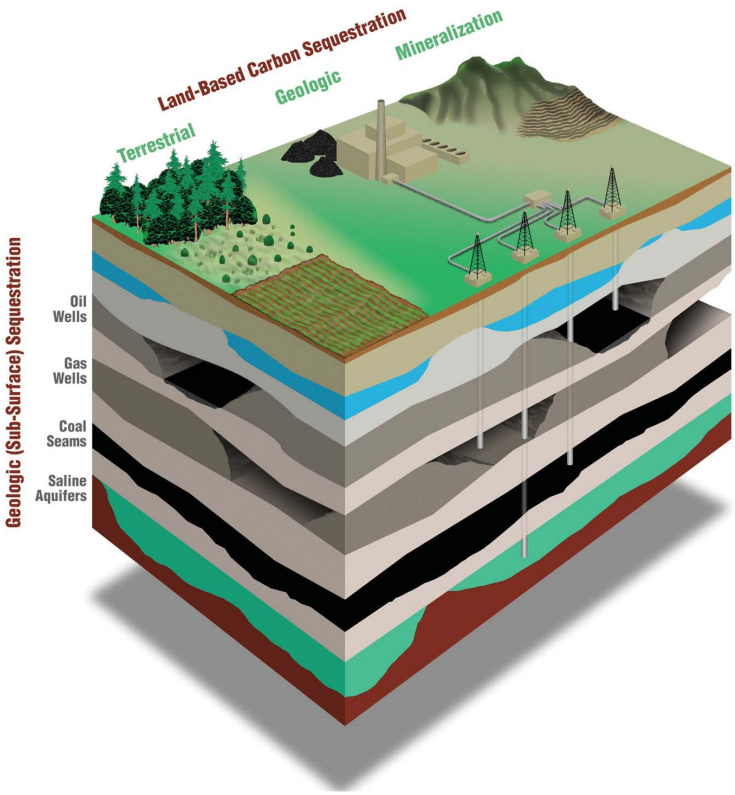
3 Producing feedstocks and materials can and does result in net emissions of GHGs.

GHG emissions and improving overall economic efficiency. Examples include the following:

- **Electricity**. Electricity will remain an important energy carrier in the global economy in the future. While substantial improvements in efficiency can reduce the growth of electricity consumption, the prospects of increased electrification and growing demand, especially in the developing regions of the world, still imply significant increases in electricity supply. Reducing GHG emissions from electricity supply could be achieved through further improvements in the efficiency of fossil-based electricity generation technologies, deployment of renewable technologies, increased use of fossil-fuel-based power systems in conjunction with CO_2 capture and sequestration (see Goal 3), increased use of nuclear energy, and the development of fusion energy or other novel power sources.
- **Hydrogen, Bio-Based, and Low-Carbon Fuels.** The world economy will have a continuing need for portable, storable energy carriers for heat, power, and transportation. A promising energy carrier is hydrogen, which can be produced in a variety of ways, including carbon-free or low-carbon methods using nuclear, wind, hydroelectric, solar energy, biomass, or fossil fuels combined with carbon capture and sequestration. Hydrogen and other carriers, such as methanol, ethanol, and other biofuels, could serve both as a means for energy storage and as energy carriers in transportation and other applications, if such carriers were to be produced by carbon-free or low-carbon methods.

CCTP Goal 3
Capture and Sequester Carbon Dioxide

Fossil fuels will likely remain a mainstay of global energy production well into the 21st century. Transforming fossil-fuel-based combustion systems into low-carbon or carbon-free energy processes would enable the continued use of the world's plentiful coal and other fossil energy resources. Such a transformation would require further development and application of technologies to capture CO_2 and store it using safe and acceptable means, removing it from the atmosphere for the long term. In addition,



Capture, storage and other forms of CO_2 sequestration could significantly reduce emissions to the atmosphere and slow the growth of greenhouse gas concentrations.

Credit: NETL

large amounts of CO_2 could be removed from the atmosphere and sequestered on land or in oceans through improved land, forest, and agricultural management practices, changes in products and materials, and other means. Focus areas include:

- **Carbon Capture and Storage.** Advanced techniques are under development that could capture CO_2 from such sources as coal-burning power plants, oil refineries, hydrogen production facilities, and various high-emitting industrial processes. Carbon capture would be linked to geologic storage — long-term storage in geologic formations, such as depleted oil and gas reservoirs, deep coal seams, saline aquifers, other deep injection reservoirs, and chemical or other forms of storage.
- **CO_2 Sequestration.** Land-based, biologically-assisted means for removing CO_2 from the atmosphere and sequestering it in trees, soils, or other organic materials have proven to be relatively low-cost means for long-term carbon storage. Enhancing the ocean's biological CO_2

sink could also play a role. An understanding of the efficacy and environmental effects of the preceding approaches is needed.

CCTP Goal 4
Reduce Emissions of Non-CO_2 GHGs

GHGs other than carbon dioxide, including methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6) and others, are more potent per unit weight as radiant energy absorbers than CO_2.[4] In addition, the atmospheric concentration of troposphere ozone (O_3), another GHG, is increasing due to human activities. The Intergovernmental Panel on Climate Change (IPCC) estimated that the cumulative effects of such gases since pre-industrial times account for about 40 percent of the anthropogenic radiative forcing[5] from GHGs. Reducing emissions of these other GHGs is an important climate change goal and key component of a comprehensive climate change technology strategy. Many categories of technologies are relevant to the attainment of this CCTP goal. Highlights include:

Emissions of gases other than CO_2, such methane from landfills, coal mining operations and natural gas pipelines, add to greenhouse concentrations in the atmosphere. Their capture and return to marketable uses can reduce their contributions to global warming.

Credit: EPA

- **Methane Collection and Utilization.** Improvements in methods and technologies to collect methane and detect leaks from various sources, such as landfills, coal mines, natural gas pipelines, and oil and gas exploration operations, can prevent this GHG from escaping to the atmosphere. These methods are often cost-effective, because the collected methane is a fuel that can be used directly or sold at natural gas market prices.
- **Reducing N_2O and Methane Emissions from Agriculture.** Improved agricultural management practices and technologies, including altering application practices in the use of fertilizers for crop production, dealing with livestock waste, and improved management practices in rice production, are key components of the strategy to reduce other GHGs.
- **Reducing Use of High Global-Warming-Potential (GWP) Gases.** Hydrofluorocarbons and perfluorocarbons have substituted for ozone-depleting chlorofluorocarbons in a number of industries, including refrigeration, air conditioning, foam blowing, solvent cleaning, fire suppression, and aerosol propellants. These and other high-GWP synthetic gases are generally used in applications where they are important to complex manufacturing processes or provide safety and system reliability, such as in semiconductor manufacturing, electric power transmission and distribution, and magnesium production and casting. Because they have high GWPs, methods to reduce leakage and use of these chemicals can contribute to UNFCCC goal attainment and include the development of lower-GWP alternatives to achieve the same purposes.
- **Black Carbon Aerosols.** Programs aimed at reducing airborne particulate matter have led to significant advances in fuel combustion and emission control technologies in both transportation and power generation sectors. Further advances can continue to reduce future black carbon aerosol emissions. Reduced emissions of black carbon, soot, and other chemical aerosols can have multiple benefits. Apart from improving public health and air quality, they can reduce radiative forcing in the atmosphere.

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4 These calculations are made on the basis of instantaneous radiative forcing, not time-integrated radiative forcing (i.e., not accounting for different atmospheric lifetimes).

5 Radiative forcing is a measure of the overall energy balance in the Earth's atmosphere. It is zero when all energy flows in and out of the atmosphere are in balance, or equal. If there is a change in forcing, either positive or negative, the change is usually expressed in terms of watts per square meter (W/m^2), averaged over the surface of the Earth. When it is positive, there is a net "force" toward warming, even if the warming itself may be slowed or delayed by other factors, such as the heat-absorbing capacity of the oceans or the energy absorption needed for the melting of natural ice sheets.

CCTP Goal 5
Improve Capabilities to Measure and Monitor GHG Emissions

Improved technologies for measuring, estimating, and monitoring GHG emissions and the flows of GHGs across various media and boundaries will help characterize emission levels and mark progress in reducing emissions. With enhanced means for GHG measuring and monitoring, future strategies to reduce, avoid, capture, or sequester CO_2 and other GHG emissions can be better supported, enabled, and evaluated. Key areas of technology R&D related to this goal may be grouped into four areas:

- **Anthropogenic Emissions.** Measurement and monitoring technologies can enhance and provide direct and indirect emissions measurements for various types of emissions sources using data transmission and archiving, along with inventory-based reporting systems and local-scale atmospheric measurements or indicators.
- **Carbon Capture, Storage, and Sequestration.** Advances in measurement and monitoring technologies for geologic storage can assess the integrity of subsurface reservoirs, transportation and pipeline systems, and potential leakage from geologic storage. Measurement and monitoring systems for terrestrial sequestration are also needed to integrate carbon sequestration measurements of different components of the landscape (e.g., soils versus vegetation) across a range of spatial scales.
- **Non-CO_2 GHGs.** Monitoring the emissions of methane, nitrous oxide, black carbon aerosols, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride is important because of their high global warming potential (GWP) and, for some, their long atmospheric lifetimes. Advanced technologies can make an important contribution to direct and indirect measurement and monitoring approaches for both point and diffuse sources of these emissions.
- **Integrated Measuring and Monitoring System Architecture.** An effective measurement and monitoring capability is one that can collect, analyze, and integrate data across spatial and temporal scales, and at many different levels of resolution. This may require technologies such as sensors and continuous emission monitors, protocols for data gathering and analysis, development of emissions accounting methods, and coordination of related basic science and research in collaboration with the Climate Change Science Program and the U.S. Integrated Earth Observation System.[6]

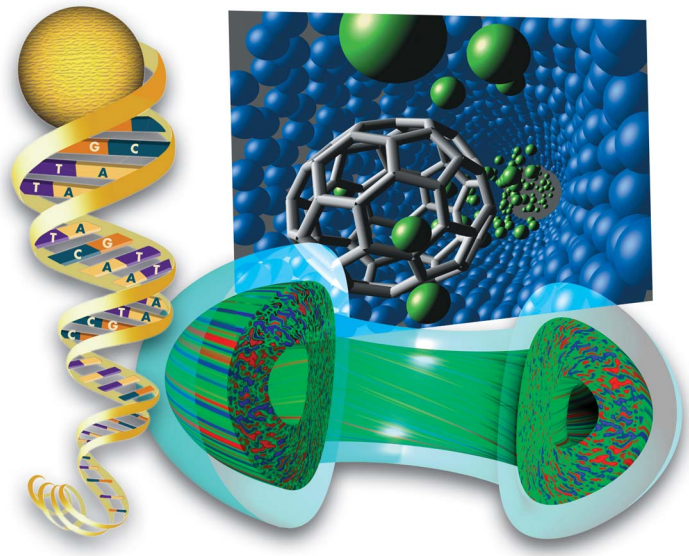
Integrated systems of instruments for measuring and monitoring greenhouse gas emissions and inventories can help to inform strategies for climate change technology development and associated emissions mitigating options.

Credit: NASA

CCTP Goal 4
Bolster Basic Science Contributions to Technology Development

Advances arising from basic scientific research are fundamental to future progress in applied technology research and development. The dual challenges—addressing global climate change and providing the energy supply needed to meet future demand and sustain economic growth—will likely require discoveries and innovations well beyond what today's science and technology can offer. Science must not just inform decisions, but provide the underlying knowledge foundation upon which new technologies can be built. The CCTP framework aims to

6 http://ostp.gov/html/EOCStrategic_Plan.pdf.



Fundamental discoveries from basic research can help overcome technical barriers to progress in applied climate change technology research programs and illuminate entirely new pathways to innovative solutions.

Courtesy: DOE, Office of Science

strengthen the basic research enterprise so that it will be better prepared to find solutions and create new opportunities, including fostering new ideas and approaches that may be outside current R&D thrusts. CCTP will focus on several ways to meet this goal:

- **Fundamental Research.** Fundamental research provides the underlying foundation of scientific knowledge necessary for carrying out applied activities of research and problem solving. It is the systematic study of properties and natural behavior that can lead to greater knowledge and understanding of the fundamental aspects of phenomena and observable facts, but without prior specification toward applications, processes, or products. It includes scientific study and experimentation in the physical, biological, and environmental sciences, as well as interdisciplinary areas, such as computational sciences. Fundamental research is the source of much of underlying knowledge that will enable future progress in CCTP.
- **Strategic Research.** Strategic research is basic research that is inspired by technical challenges in the applied research and development programs. This is research that could lead to fundamental discoveries (e.g., new properties, phenomena, or materials) or scientific understanding that could be applied to solving specific problems or technical barriers impeding progress in advancing technologies in energy supply and end use; carbon capture, storage, and sequestration; other GHGs; and monitoring and measurement.
- **Exploratory Research.** Innovative concepts are often too risky or multi-disciplinary for one program mission to support. Sometimes they do not fit neatly within the constructs of other mission-specific program goals. Therefore, not all of the research on innovative concepts for climate-related technology is, or should be, aligned directly to one of the existing Federal R&D mission-related programs. The climate change challenge calls for new breakthroughs in technology that could dramatically change the way energy is produced, transformed, and used in the global economy. Basic, exploratory research of innovative and novel concepts, not elsewhere covered, is one way to uncover such "breakthrough technology" and strengthen and broaden the R&D portfolio.
- **Integrated Planning.** Effective integration of fundamental research, strategic research, exploratory research, and applied technology development presents challenges to, and opportunities for, both the basic research and applied research communities. These challenges and opportunities can be effectively addressed through innovative and integrative planning processes that place emphasis on communication, cooperation and collaboration among the many associated communities, and on workforce development, to meet the long-term challenges. CCTP seeks to encourage broadened application of successful models and best practices in this area.

2.3 Core Approaches

Consistent with the principles established by the President, CCTP will employ seven core approaches to stimulate participation by others and ensure progress towards attaining 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.

Chapter 10 outlines next steps for CCTP for each of these core approaches.

APPROACH 1:
Strengthen Climate Change Technology R&D

The Federal Government is engaged in a wide range of research and technology development and deployment activities that directly or indirectly contributes to meeting the President's climate change goals, investing about $3 billion in Fiscal Year 2006 in related technology R&D, including demonstration and deployment activities (Appendix A). Strengthening these activities, however, does not necessarily mean spending more money—it can also mean spending available resources more wisely by appropriately prioritizing activities and reallocating resources, or by leveraging them with the work of others.

To strengthen the current state of the U.S. climate change technology R&D, the CCTP has made, and will continue to make, recommendations to the Cabinet-level Committee on Climate Change Science and Integration (CCCSTI) to sharpen the focus of, and provide support for, climate change technology R&D in a manner consistent with the mix and level of R&D investment required by the nature of the technical challenge.

APPROACH 2:
Strengthen Basic Research Contributions

A base of supporting fundamental research is essential to the applied research and development for technology development. The CCTP approach includes strengthening basic research in Federal research facilities and academia by focusing efforts on key areas needed to develop insights or breakthroughs relevant to climate-related technology R&D. A strong and creative science program is necessary to support and enable technical progress in CCTP's portfolio of applied research and development programs, explore novel approaches to new challenges, and bolster the underlying knowledge base for new discoveries.

Fundamental discoveries can reveal new properties and phenomena that can be applied to development of new energy technologies and other important systems. These can include breakthroughs in our understanding of biological functions, properties and phenomena of nano-materials and structures,

CCTP is charged with reviewing the Federal portfolio of related R&D and making recommendations to strengthen it. For recent results of a series of technical workshops that provided input to this process, see http://www.climatetechnology.gov.

Courtesy: Energetics, Inc., 2006

computing architectures and methods, plasma science, environmental sciences, and other emerging areas of scientific discovery.

APPROACH 3:
Enhance Opportunities for Partnerships

Federal research is but one element of the overall strategy for development and adoption of advanced climate change technologies. Engagement in this process by private entities, including business, industry, agriculture, construction, and other sectors of the U.S. economy, as well as by non-Federal governmental entities, such as the States and non-governmental organizations, is essential to make R&D investments wisely and to expedite innovative and cost-effective approaches for reducing GHG emissions.

Public-private partnerships can facilitate the transfer of technologies from Federal and national laboratories into commercial application. Partnering can also advise and improve the productivity of Federal research and can promote the adoption of new technologies and best management practices. Private partners also benefit because those who are engaged in Federal R&D gain rights to intellectual property and gain access to world-class scientists, engineers, and laboratory facilities. This can help motivate further investment in the commercialization of technology.

Today, partnering is a common mode of operation in most Federal R&D programs, but it can be improved. Opportunities exist for private participation in virtually every aspect of Federal R&D. With respect to climate change technology R&D, the CCTP seeks to expand these opportunities in R&D planning, program execution, and technology demonstrations, leading ultimately to more efficient and timely commercial deployment.

Another important aspect of this approach is non-research and development partnerships. Such partnerships arise when there are mutual benefits and aligned interests between governmental and non-governmental entities in promoting progress toward CCTP strategic goals. Examples include the Climate VISION,[7] Climate Leaders,[8] ENERGY STAR®,[9] and SmartWay Transport Partnership[10] programs, all of which encourage industry to undertake activities that can lead to reduced GHG emissions.

APPROACH 4: Increase International Cooperation

Given the global nature of climate change concerns, and in recognition of the contributions being made abroad, the CCTP seeks to engage other nations—government to government—in large-scale cooperative technology research initiatives. Such cooperation can prove beneficial to the success of U.S. technology development initiatives, through leveraging of resources, partitioning of research activities addressing large-scale and multi-faceted complex problems, and sharing of results and knowledge created. Indeed, in certain areas of climate change technology research and development, such as advanced wind turbine design and nuclear fission and fusion energy research, U.S. technical expertise can be augmented by many advanced technical capabilities that reside outside the United States. The U.S. Government has initiated or joined several multilateral cooperative agreements, such as the International Partnership for the Hydrogen Economy, Carbon Sequestration Leadership Forum, Generation IV International Forum, international Methane-to-Markets Partnership, and the ITER project to develop fusion as a commercially viable power source.

Since June 2001, the United States has launched bilateral partnerships with Australia, Brazil, Canada, China, Central America, Germany, the EU, India, Italy, Japan, Mexico, New Zealand, Republic of Korea, the Russian Federation, and South Africa on issues such as climate change science, energy and sequestration technologies, and climate change policy approaches. The countries covered by these bilateral partnerships account for about three quarters of global GHG emissions. In addition, the U.S. is a leader in the 59-member country Global Earth Observations System of Systems.

In related developments in July 2005, President Bush and the G-8 Leaders agreed on a far-reaching Plan of Action to speed the development and deployment of clean energy technologies to achieve the combined goals of addressing climate change, reducing harmful air pollution, and improving energy security in the United States and throughout the world. The G-8 will work globally to advance climate change policies that spur and sustain economic growth, and improve the environment.

Also in July 2005, the United States joined with Australia, China, India, Japan, and South Korea to accelerate clean development under a new Asia-Pacific Partnership on Clean Development and Climate. These countries together account for roughly half of the world's population, economic growth, energy use, and GHG emissions. The focus of this Partnership is on voluntary practical measures taken by these six countries in the Asia-Pacific region to create new investment opportunities, build local capacity, and remove barriers to the introduction of clean, more efficient technologies. APP countries will work in partnership to meet nationally-designed strategies for improving energy security, reducing air pollution, and addressing the long-term challenge of climate change.

CCTP seeks to expand on these and other international opportunities to stimulate international participation in the development of new and advanced climate change technologies, foster capacity building in developing countries, encourage cooperative planning and joint ventures, and enable more rapid development, transfer and deployment of advanced climate change technology.

7 See http://www.climatevision.gov

8 See http://www.epa.gov/climateleaders

9 See http://www.energystar.gov

10 See http://www.epa.gov/smartway

APPROACH 5:
Support Cutting-Edge Technology Demonstrations

While the government role is targeted primarily toward long-term, high-risk research and development activities, demonstrations of cutting-edge climate change technologies also constitute an important aspect of the goal to advance climate change technologies. Demonstrations help advance a cutting-edge technology from the laboratory to the commercial market. After a concept has been proven in principle, pilot or full-scale demonstrations are needed to identify real-world performance issues. Subsequently, demonstrations can prove the viability of the technology for deployment.

Technology demonstrations afford unique opportunities to reduce investment risks. They clarify the parameters affecting a technology's cost and operational performance. They identify areas needing further improvement or cost reduction. Federal leadership through technology demonstrations can strongly influence decisions of private-sector investors and other non-government parties.

Because technology demonstrations can be costly, which can reduce funds available for related research, it is often advantageous for demonstrations to be cost-shared with industry to the extent practical. Demonstrations are most beneficial when the technology is ready for demonstration and when the results are shared with the public. Open and competitive processes will help to ensure fairness of opportunity among all interested parties.

APPROACH 6:
Ensure a Viable Technology Workforce of the Future

The development and deployment, on a global scale, of new and advanced climate change technologies will require a skilled workforce and an abundance of intellectual talent, well versed in associated concepts and disciplines of science and engineering.

Workforce development and education are an added benefit of Federal research funding, since portions of research grants often support graduate and undergraduate research stipends.

CCTP-funded research provides an opportunity to promote education and experience for students in science, math, and engineering education and to attract talented individuals to focus their careers on this global endeavor.[11] Such efforts could be coordinated with other countries, and particularly in emerging economies of the developing world, where much of 21st century emissions are expected to occur.

APPROACH 7:
Provide Supporting Technology Policy

While some advanced climate change technologies may be sufficiently attractive to penetrate the marketplace on a large scale without supporting policy or incentives, others may not. For example, technologies that capture or sequester CO_2 or others that afford certain climate change-related advantages are expected to remain more expensive than competing technologies, even considering further technical progress. Widespread adoption of these technologies would likely require support from appropriate government policies, potentially including market-based incentives.

As Federal efforts to advance technology go forward, broadened participation by the private sector in these efforts is important both to the acceleration of innovation and to the adoption of technologies. Extending such participation beyond R&D partnering and demonstrations (Approaches 3 and 5 above) can be encouraged by appropriate and supporting technology policy. This is evidenced today, in part, by a number of market-based incentives already in place, by others proposed by the Administration[12], and by still others soon to be implemented in accord with the provisions of Title XIII of the Energy Policy Act of 2005.[13]

Finally, Title XVI of the Energy Policy Act of 2005 sets the stage for future development of policies that would facilitate new technology adoption. This Title requires that the Administration identify barriers to

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11 The CCTP approach is linked with the American Competitiveness Initiative (ACI), which aims to build the technologically skilled workforce of the future. ACI will double the Federal commitment to the most critical research programs emphasizing the physical sciences, modernize and make permanent the research and development tax credit, reform the job training system, and strengthen math and science education. See http://www.whitehouse.gov/stateoftheunion/2006/aci/.

12 *Federal Climate Change Expenditures Report to Congress*, March 2005. http://www.whitehouse.gov/omb/legislative/fy06_climate_change_rpt.pdf

13 Financial incentives in Title XIII for technologies related to climate change goals are scored at more than $11 billion over 10 years.

14 See text of EPACT Title XVI at http://www.climatetechnology.gov.

the commercialization and deployment of GHG-intensity-reducing technologies, and develop recommendations for the removal of these barriers to facilitate the deployment of these technologies and practices.[14] This effort will be led by the Secretary of Energy.

2.4 Prioritization Process

An important role of the CCTP is to provide strategic direction for, and to strengthen, the Federal portfolio of investments in climate change technology R&D. The CCTP continues to prioritize the portfolio of Federally-funded climate change technology R&D consistent with the President's NCCTI. The CCTP has identified within its portfolio a subset of NCCTI priority activities for Fiscal Year 2006 and Fiscal Year 2007 (listed in Appendix B), defined as discrete research and development activities that address technological challenges, which, if successful, could advance technologies with the potential to dramatically reduce, avoid, or sequester GHG emissions.

Prioritization of Federal technology R&D activities related to climate change is a dynamic process that has evolved over time in response to emerging knowledge. This evolution is expected to continue.

Through coordinated interagency planning, the CCTP priorities will be reviewed periodically in conjunction with the Federal budget process, and recommendations will be made through the Interagency Working Group (IWG) to the CCCSTI.

This CCTP *Strategic Plan* provides a government-wide basis for guiding the formulation of the comprehensive Federal climate change technology R&D portfolio, identifying high priority investments, gaps, and emerging opportunities, and organizing future CCTP-related research. The CCTP planning activities are informed by results of studies, inputs from many and diverse sources, technical workshops, assessments of technology potentials, analyses regarding long-term energy and emissions outlooks, and modeling by a number of groups of a range of technology scenarios over the next 100 years (see Chapter 3). Additionally, these planning activities are guided by several important portfolio planning principles and investment criteria.[15]

Portfolio Planning Principles

The CCTP adheres to three broad principles. The first principle, given the many attendant uncertainties about the future, is that the whole of the individual R&D investments should constitute a balanced and diversified portfolio. Considerations include the realizations that: (1) no single technology will likely meet the challenge alone; (2) investing in R&D in advanced technologies involves risk since the results of these investments are not known in advance (some may fail, and others may not prove as successful as hoped); and (3) a diverse array of technology options can hedge against risk and provide flexibility in the future, which may be needed to respond to new information that could change strategy. The CCTP portfolio also strives to balance short- and long-term technology objectives.

A balanced and diversified portfolio must hedge risks, for example, by investing in projects that will pay off under different states of the future world. For this purpose, it is helpful to understand the major sources of uncertainty, such as the level of future GHG emissions, energy prices, technology costs and performance, and other factors. CCTP's tools in this regard are partially addressed in Chapter 3, but further work in terms of portfolio analysis and expected benefits and costs will be required.

The second principle is to ensure that factors affecting market acceptance are addressed. To enable widespread deployment of advanced technologies, each technology must be integrated within a larger technical system and infrastructure, not just as a component. Market acceptance of technologies is influenced by myriad social and economic factors. The CCTP's portfolio planning process must be informed by, and benefit from, private sector and other non-Federal inputs, examine the lessons of historical analogues for technology acceptance, and apply them as a means to anticipate issues and inform R&D planning.

Third and perhaps most importantly, the anticipated timing regarding the commercial readiness of the advanced technology options is an important CCTP planning consideration. Energy infrastructure has a long lifetime, and change in the capital stock occurs slowly. Once new technologies are available, their adoption takes time. Some technologies with low or near-net-zero GHG emissions may need to be available and moving into the marketplace decades before their maximum market penetration is achieved.

15 These criteria are consistent with the Better R&D Investment Criteria outlined in The President's Management Agenda. See http://www.whitehouse.gov/OMB/budget/fy2002/mgmt.pdf

Portfolio Planning and Investment Criteria

Within the planning framework of vision, mission, goals, approaches, and portfolio investment principles, the CCTP's prioritization process applies four criteria (see Box 2-1). CCTP will evaluate the merits of competing investments based on maximum expected benefits versus costs (Criterion #1), subject to consideration of the distinct roles of the public and private sectors in R&D (Criterion #2).[16] In addition, because of the risk of spreading resources across too many areas, CCTP focuses on technologies with the potential for large-scale application (Criterion #3). Nevertheless, technologies expected to have limited

BOX 2-1

CCTP PORTFOLIO PLANNING AND INVESTMENT CRITERIA

1. **Maximizing Expected Return on Investment.** R&D investments that have the prospect to generate maximum expected benefits per dollar of investment receive priority in investment planning. Benefits are defined with respect to expected contributions to the attainment of CCTP goals, particularly GHG reductions, but also include other considerations, such as cost-effectiveness, improved productivity, and reduction of other pollutants. Climate change benefits are long-term public goods. Discount rates must be appropriate to the context, particularly when applied to very long-term impacts. This criterion includes considerations of development and deployment risks, and the hedging of risks across multiple projects. Projects with high risk, but low emissions-reduction potential should be removed from the CCTP R&D portfolio.

2. **Acknowledging the Proper and Distinct Roles for the Public and Private Sectors.** The CCTP portfolio recognizes that some R&D is the proper purview of the private sector; other R&D may be best performed jointly through public-private partnerships; and still other R&D may be best performed by the Federal sector alone. In cases where public support of R&D is warranted, technology development and adoption require cooperation and engagement with the private sector. History demonstrates that early involvement in technology R&D by the business community increases the probability of commercialization. A key consideration in the investment process is the means for engaging the talents of the private sector using innovative and effective approaches.

3. **Focusing on Technology with Large-Scale Potential.** The scope, scale, and magnitude of the climate change challenge suggest that relatively small, incremental improvements in existing technologies will not enable full achievement of CCTP goals. Every technology option has limits of various kinds. Such limits need to be identified, explored, and understood early in the planning process. Technology options should be adaptable on a global scale and have a clear path to commercialization. High-priority investments, including exploratory research, will focus on technology options that could, if successful, result in large mitigation contributions, accumulated over the span of the 21st century. For technologies on the lower end of this criterion, benefits should be deliverable earlier in the century and/or be particularly compelling from a marginal benefit/cost perspective.

4. **Sequencing R&D Investments in a Logical, Developmental Order.** Investments must be logically sequenced over time. Supporting a robust and diversified portfolio does not mean that all technology options must be supported simultaneously, or that all must proceed at an accelerated pace. Logical sequencing of R&D investments takes into account (i) the expected times when different technologies may need to be made available and cost-effective, (ii) the need for early resolution of critical uncertainties, and (iii) the need to demonstrate early success or feasibility of technologies upon which other technology advancements may be based.

[16] In a market economy, commercially-orientated R&D is primarily a private sector matter. Government support of basic and applied R&D is warranted when the social benefits of such R&D outweigh the benefits that can be captured by innovating businesses and their customers, leading to inadequate investment in such R&D by the private sector.

BOX 2-2

CCTP WORKING GROUPS

Energy End Use – Led by DOE
- Hydrogen End Use
- Transportation
- Buildings
- Industry
- Electric Grid and Infrastructure

Energy Supply – Led by DOE
- Hydrogen Production
- Renewable and Low-Carbon Fuels
- Renewable Power
- Nuclear Fission Power
- Fusion Energy
- Low Emissions Fossil-Based Power

CO_2 Sequestration – Led by USDA
- Carbon Capture
- Geologic Storage
- Terrestrial Sequestration
- Ocean Storage
- Products and Materials

Other (Non-CO_2) Gases – Led by EPA
- Energy & Waste – Methane
- Agricultural Methane and Other Gases
- High Global-Warming-Potential Gases
- Nitrous Oxide
- Ozone Precursors and Black Carbon

Measuring and Monitoring – Led by NASA
- Application Areas
- Integrated Systems

Basic Research – Led by DOE
- Fundamental Research
- Strategic Research
- Exploratory Research
- Integrative R&D Planning

impact on overall GHG emissions may still be given priority if they can deliver reductions earlier in the century and/or are particularly cost-compelling. Finally, the timing of investments is an important consideration in the decision process. The CCTP planning process gives weight to the logical sequencing of research (Criterion #4), where the value in knowing whether a technological advance is successful can have a cascading effect on the sequencing of later investments.

Application of Criteria

The CCTP's review, planning, and prioritization process will rely on ongoing reviews of strategies for technology development, buttressed by analysis, and of the overall R&D portfolio's adequacy to make progress toward attaining each CCTP strategic goal. There will be an emphasis on identifying gaps and key opportunities for new initiatives that will be accompanied by periodic realignments. The process is not easily reduced to quantitative analysis due, in part, to the large number of variables and uncertainties associated with the nature of the climate change technology challenge and, in part, to the CCTP's century-long planning horizon. Nevertheless, the prioritization criteria discussed above will be applied by the participating agencies to the maximum extent practicable and augmented by inputs from various sources.

The first step in the prioritization process is to establish a baseline, or inventory, of the existing portfolio of R&D activities across the participating agencies. The criteria used to compile this portfolio baseline, which closely track CCTP strategic goals, are listed in Appendix A. The resulting multi-agency baseline inventory accounted for more than $3 billion in R&D activities in Fiscal Year 2006. This inventory will be periodically updated.

The second step in the process is to use the insights gained from the scenario modeling[17] and other analyses to identify the more important elements of a diversified strategy and to assess the potential contributions of each activity within the CCTP portfolio. This assessment may affirm some elements of the portfolio, challenge others, and identify gaps and promising opportunities. Once a full set of candidate investments is identified, the prioritization criteria can be applied to each proposed investment activity. This step will require continuing

[17] See Chapter 3 for a discussion of the scenario analyses.

development of analytical tools and methods, including assessments of various technologies and their limitations.

The results of this process for Fiscal Year 2007, as evidenced in the Administration's budget request, are shown in Appendix A. Within this overall CCTP portfolio, NCCTI priorities are identified in Appendix B. Finally, key initiatives that advance multiple policy goals, while also addressing major thrusts of CCTP strategic goals, are highlighted throughout the *Plan* in their respective technology areas.[18] A current list of the key initiatives, with links to current programmatic information, may be found at the CCTP website.[19]

The current CCTP portfolio reflects a "snapshot" in time of an ongoing review and realignment that takes into account new and changing emphasis among competing national priorities. In the years ahead, CCTP's portfolio and planning emphasis is expected to evolve as more studies and analyses are conducted, technology assessments are completed, additional gaps and opportunities are identified, and new developments and scientific knowledge emerge.

2.5 Management

The CCTP is a multi-agency R&D planning and coordination activity. It accomplishes its work by engaging and assisting the Federal R&D agencies in their respective efforts to plan, prioritize, and coordinate research activities to meet CCTP goals. CCTP also works with the Administration to formulate overall budget guidance and recommend adjustments, where appropriate, to the Federal R&D portfolio to align it more with CCTP goals. CCTP also has a role in coordinating non-R&D-related activities, monitoring progress, and accounting for related investments. As discussed below, the CCTP's management functions include executive direction, interagency planning and integration, agency implementation, external interactions, and program support.

Executive Direction

The CCTP exercises executive direction through the CCCSTI, and its associated IWG on Climate Change Science and Technology. The IWG is comprised of agency deputies who can adopt and implement plans and actions coordinated by the Group. The IWG also provides guidance on strategy and reviews and approves CCTP strategic planning documents.

A CCTP Steering Group, comprised of senior-level representatives from each participating Federal agency, provides a venue for agencies to raise and resolve issues regarding CCTP and its functions as a facilitating and coordinating body. It also assists the CCTP Director in accessing needed information and resources within each agency. The Steering Group assists in developing agency budget crosscuts and proposals, conveying information and actions back to the agencies, and supporting the CCTP mission. In addition, it ensures that consistent guidance and direction is given to the CCTP Working Groups, and it helps formulate recommendations and advice to the CCCSTI through the IWG.

Interagency Planning and Integration

Six multi-agency CCTP Working Groups (WGs), aligned with the six CCTP strategic goals (Box 2-2), are primarily responsible for carrying out the missions and staff functions of CCTP in a coordinated manner. The WGs are assisted by subgroups, as appropriate, and by technical staff drawn from participating agencies, affiliated laboratories and facilities, and other available consulting staff. The WGs are expected to:

- Serve as the principal means for interagency deliberation and development of CCTP plans and priorities and for the formulation of guidance for supporting analyses in their respective areas;
- Provide a forum for exchange of inputs and information relevant to planning processes, including workshops and other meetings;
- Engage, cooperate with, and coordinate inputs from relevant agencies;
- Identify ongoing R&D activities and gaps, needs, and opportunities for the near and long term;
- Support relevant interaction with CCSP science studies and analyses;
- Formulate advice and recommendations to present to the IWG and CCCSTI; and
- Assist in preparing periodic reports to Cabinet members and the President.

[18] See also CCTP *Vision and Framework for Strategy and Planning* (2005).

[19] See CCTP: http://www.climatetechnology.gov.

Agency Implementation

CCTP relies on participating Federal agencies and their respective R&D portfolios to contribute to achieving CCTP goals. At the same time, the CCTP recognizes that agencies must balance these priorities with other mission requirements. The Program depends on these agencies to place appropriate priority on implementing CCTP programs. Each participating agency has representation in the groups that facilitate the setting of CCTP priorities and follow through on attaining these priorities. Agency heads and deputies serve on the CCCSTI and IWG, and top agency officials make up the CCTP Steering Group. Agency executives and senior-level managers also serve as chairs and members of the CCTP Working Groups. Once CCTP plans, programs, and priorities are set and approved, the agencies are expected to contribute to their execution and completion.

External Interactions

The CCTP taps expert opinion and technical input from various external parties through advisory groups, program peer review, conferences, international partnerships, and other activities. In addition, CCTP staff convenes technical workshops and meetings with experts both inside and outside the Federal Government. CCTP activities are of interest to a number of external parties, including State and local governments, regional planning organizations, academic institutions, national laboratories, and non-governmental organizations. They are of interest, as well, to foreign governments and international organizations, such as the Organization for Economic Cooperation and Development, the International Energy Agency, various global and regional compacts, and the IPCC. CCTP needs to communicate its activities to such entities and provide coordinated support, through the relevant agency programs, for enhanced external and international cooperation by engaging with and supporting activities of mutual interest.

Program Support

CCTP staff will provide technical and administrative support and day-to-day coordination of program integration, strategic planning, product development, communication, and representation. CCTP staff will: (1) provide support for the Working Groups and the Steering Group; (2) foster integration of activities to support CCTP goals; (3) conduct and support strategic planning activities that facilitate the prioritization of R&D activities and decision-making on the composition of the CCTP R&D portfolio, including conducting analytical exercises that support planning (such as technology assessments and scenario analysis); (4) develop improved methods, tools, and decision-making processes for climate technology planning and management, R&D planning, and assessment; (5) develop products that communicate CCTP's plans as well as the progress of the Program toward meeting its goals; (6) coordinate interagency budget planning and reporting; (7) assist and support the Administration in representing U.S. interests in the proceedings of the United Nations' IPCC Fourth Assessment Report; and (8) coordinate agency support of international cooperative agreements.

2.6 Strategic Plan Outline

The chapters that follow provide a century-long planning context, goal-oriented strategies for technology development, and a summary of conclusions and next steps. Chapter 3 provides a synthesis assessment on energy-economic modeling and forecasting of future global GHG emissions, based on a number of representative works in the literature. Chapter 3 also includes a number of insights regarding opportunities for advanced technologies drawn from scenarios analyses. Chapters 4 through 9 focus in some depth on each of CCTP's six strategic goals. Each chapter outlines elements of a technology development strategy, highlights ongoing work, and suggests promising areas for future research. Chapter 10 provides a summary of conclusions regarding CCTP and its strategic goals and identifies a series of next steps within the context of each of CCTP's seven approaches.