1 Introduction

The 21st century will see substantial changes in economic and social development around the world, with accompanying transformations in the way that the world uses energy and its natural resources. The past hundred years witnessed revolutionary innovations in the technologies used to power homes and buildings, transport people and goods, and produce everyday goods and services. These innovations have been a significant source of the prosperity that the United States and many other countries currently enjoy. Continued innovations will be just as important in providing a prosperous future for countries around the world. At the same time, they will help enable and provide sound stewardship of the environment, including the Earth's climate system.

As a party to the United Nations Framework Convention on Climate Change (UNFCCC),[1] the United States shares with many other countries the UNFCCC's ultimate objective, that is, the "…stabilization of greenhouse gas[2] concentrations in Earth's atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system . . . within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner." Meeting this UNFCCC objective will require a long-term commitment and international cooperation.

> *I've asked my advisors to consider approaches to reduce greenhouse gas emissions, including those that tap the power of markets, help realize the promise of technology and ensure the widest-possible global participation….Our actions should be measured as we learn more from science and build on it. Our approach must be flexible to adjust to new information and take advantage of new technology. We must always act to ensure continued economic growth and prosperity for our citizens and for citizens throughout the world.*
>
> **President Bush (6/11/01)**

In addition, the actions that countries take to address climate change will be part of an array of social, economic and environmental objectives that countries will undertake to address sustainable development. Accordingly, the United States has placed special emphasis on the fundamental importance of technology investment as a means of achieving climate goals in ways that simultaneously support broader societal goals, and in particular that will meet the world's need for abundant, clean, secure, and affordable energy to provide a continuing engine for global economic advancement in this century.

Although the scientific understanding of climate change continues to evolve, the potential ramifications of increasing accumulations of carbon dioxide (CO_2) and other greenhouse gases (GHGs) in the Earth's

[1] The UNFCCC was adopted by 157 countries in 1992; as of May 24, 2004, 189 Parties, including the European Economic Community, had ratified the UNFCCC.

[2] Greenhouse gases (GHGs) are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds. This property causes the greenhouse effect. Water vapor, carbon dioxide (CO_2), nitrous oxide (N_2O) methane (CH_4), and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. Moreover, there are a number of entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine and bromine containing substances, dealt with under the Montreal Protocol. Besides CO_2, N_2O, and CH_4 the Kyoto Protocol deals with the greenhouse gases sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). Gases dealt with under the Montreal Protocol are excluded from the CCTP purview.

atmosphere have heightened attention on anthropogenic sources of GHG emissions and various means for their mitigation. Most long-term, prospective analyses of anthropogenic emissions of GHGs project significant increases over the next century, primarily from considerations of population growth and expansion of world's economic activity, accompanied by a continuation of existing patterns and trends in energy use (combustion of fossil fuels), land use, and industrial and agricultural production.

Climate change is a serious, long-term issue, requiring sustained action over many generations by both developed and developing countries. Solutions will likely require fundamental changes in the way the world produces and uses energy, as well as in many other GHG-emitting activities of industry, agriculture, land use, and land management. Developing innovative technologies and approaches that are cleaner and more efficient is the key to addressing our long-term climate challenge.

Under the leadership of President Bush, the United States has formulated and is implementing a comprehensive approach to climate change that anticipates and addresses this challenge. It is science-based, encourages innovation and scientific and technological breakthroughs, harnesses the power of markets, and encourages global participation. It includes elements for advancing climate change science and technology, and promoting international cooperation. It focuses on reducing emissions, while sustaining economic growth. Growth and the capital it will create are needed to finance investment in new technologies.

The technological elements of this approach, outlined in this *Strategic Plan*, build on America's strengths in innovation and technology. These longer-term elements are augmented by near-term policy measures, financial incentives, and voluntary and other Federal programs aimed at slowing the growth of U.S. GHG emissions and reducing GHG intensity.[3] These include the Climate VISION,[4] Climate Leaders,[5] Energy STAR,[6] and SmartWay Transport Partnership[7] programs, all of which work with industry to voluntarily reduce emissions. The Department of Agriculture's conservation programs provide incentives for actions that increase carbon sequestration[8] in trees and soils. Energy efficiency, alternative fuels, renewable and nuclear energy, methane capture and other GHG reduction programs and financial incentives are also underway.

The technological elements of this approach are buttressed by supporting international activities. These include bilateral agreements with 20 countries and the European Union; international partnerships to promote the advancement of renewable energy and energy efficiency, the hydrogen economy, carbon sequestration, nuclear power, methane recovery, and fusion energy (see Chapter 2). 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,[9] and embarked with other G8 countries on a far-reaching Plan of Action[10] to speed the development and deployment of clean energy technologies to

[3] Intensity means emissions per unit of economic output. See *White House Fact Sheet on Climate Change*, www.whitehouse.gov/news/releases/2003/09/20030930-11.html.
[4] See http://www.climatevision.gov
[5] See http://www.epa.gov/climateleaders
[6] See http://www.energystar.gov
[7] See http://www.epa.gov/smartway
[8] See http://www.usda.gov/news/releases/2003/06/fs-0194.htm
[9] See http://www.whitehouse.gov/news/releases/2005/07/20050727-9.html
[10] See http://www.whitehouse.gov/news/releases/2005/07/20050708-2.html

achieve the combined goals of addressing climate change, reducing harmful air pollution and improving energy security in the U.S. and throughout the world.

The Energy Policy Act of 2005, which the President signed into law in August 2005, provides for more rigorous standards and tax credits for more energy efficient appliances and vehicles. The Act also has provisions, such as those dealing with production tax credits and loan guarantees, designed to accelerate the market penetration and deployment of advanced energy technologies that will reduce GHG emissions in the future.

The U.S. approach to climate change, which is consistent with and supports the UNFCCC's ultimate objective, forms the long-term planning context for the CCTP. Significant progress toward meeting the climate change goals can be facilitated over the course of the 21st century by new and revolutionary technologies that can reduce, avoid, capture, or sequester GHG emissions, while also continuing to provide the energy-related and other services needed to sustain economic growth. The United States is committed to leading the development of these new technologies.

This *Plan* takes a century-long look at the nature of this challenge, across a range of planning uncertainties, and explores an array of opportunities for technological solutions. The *Plan* articulates a vision for new and advanced technology in addressing climate change concerns, defines a supporting planning and coordination mission for the multi-agency CCTP, and provides strategic direction to the Federal agencies in formulating a comprehensive portfolio of related technology research, development, demonstration, and deployment (R&D).[11] The *Plan* establishes six strategic goals and seven approaches to be pursued toward their attainment and identifies a series of next steps toward implementation.

1.1 U.S. Leadership and Presidential Commitment

On June 11, 2001, the President launched the National Climate Change Technology Initiative.[12] Backed by unprecedented levels of Federal investment in R&D in climate-change-related areas, this Presidential initiative signaled Federal leadership in climate change technology development and aimed to stimulate American innovation, strengthen associated research and education, and position the United States as a world leader in pursuit of advanced technologies that could, if successful, help meet this global challenge. The President said:

> *[W]e're creating the National Climate Change Technology Initiative to strengthen research at universities and national labs, to enhance partnerships in applied research, to develop improved technology for measuring and monitoring gross and net greenhouse gas emissions, and to fund demonstration projects for cutting-edge technologies.*

In February 2002, the President reorganized Federal oversight, management and administrative control of climate-change-related activities. He established a Cabinet-level Committee on Climate Change Science and Technology Integration (CCCSTI), thereby directly engaging the heads of all relevant departments

[11] Throughout this report, the use of the term "R&D" is meant generally to include research, development, demonstration, and deployment. However, where relevant, the report distinguishes research and development from demonstration and deployment, as the each activity has different rationales, different appropriate roles for the private sector, and different associated policy instruments.

[12] White House Rose Garden speech: www.whitehouse.gov/news/releases/2001/06/20010611-2.html.

and agencies in guiding and directing these activities. The President charged the CCCSTI to advance and coordinate climate change science and technology research.

In an earlier Cabinet-level climate change policy review, which gave rise to the CCCSTI, the President directed that innovative approaches for addressing climate change concerns be developed in accord with a number of basic principles: (1) be consistent with the long-term goal of stabilizing greenhouse gas concentrations in the atmosphere; (2) be measured, as more is learned from science, and build on it; (3) be flexible to adjust to new information and take advantage of new technology; (4) ensure continued economic growth and prosperity; (5) pursue market-based incentives and spur technological innovation; and (6) base efforts on global participation, including developing countries. These principles continue to apply to the development of innovative approaches under CCCSTI and its subordinate organizational elements.

Under the auspices of the CCCST, two multi-agency programs were established to coordinate Federal activities in climate change scientific research and advance the President's vision under his National Climate Change Technology Initiative. These are known, respectively, as the U.S. Climate Change Science Program, led by the U.S. Department of Commerce, and the U.S. Climate Change Technology Program, led by the U.S. Department of Energy (Figure 1-1).

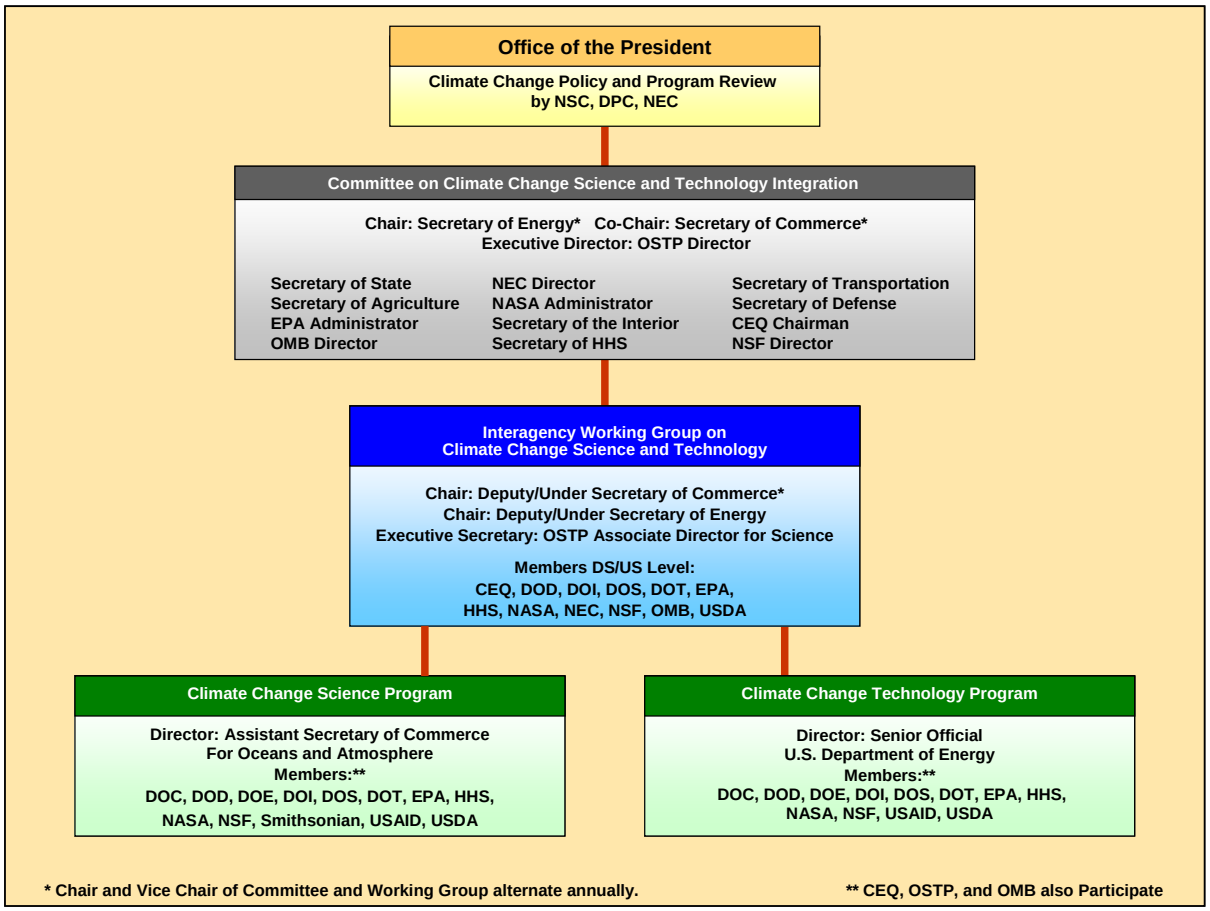

Figure 1-1. Cabinet-Level Committee on Climate Change Science and Technology Integration

1.2 U.S. Climate Change Science Program

The U.S. Climate Change Science Program (CCSP) is an interagency research planning and coordinating entity responsible for facilitating the development of a strategic approach to Federally supported research, integrated across the participating agencies. Collectively, the activities under CCSP constitute a comprehensive research program charged with investigating natural and human-induced changes in the Earth's global environmental system, monitoring important climate parameters, predicting global change, and providing a sound scientific basis for national and international decision-making. Its principal aim is to improve understanding of climate change and its potential consequences. Figure 1-1 shows that it operates under the direction of the Assistant Secretary of Commerce for Oceans and Atmosphere. It reports through the Interagency Working Group (IWG) on Climate Change Science and Technology, composed of agency deputies, to the CCCSTI.

Regarding climate change science, on May 11, 2001, the President asked the National Academies National Research Council (NRC) to examine the state of knowledge and understanding of climate change. The resulting NRC report concluded that "the changes observed over the last several decades are likely mostly due to human activities, but we cannot rule out that some significant part of these changes is also a reflection of natural variability." The report also noted that there are still major gaps in our ability to measure the impacts of GHGs on the climate system. Major advances in understanding and modeling of the climate system, including its response to natural and human-induced forcing; and modeling of the factors that influence atmospheric concentrations of GHGs and aerosols, as well as the feedbacks that govern climate sensitivity, are needed to predict future climate change with greater confidence.

In July 2003, CCSP released its strategic plan[13] for guiding climate research. The plan is organized around five goals: (1) improving our knowledge of climate history and variability; (2) improving our ability to quantify factors that affect climate; (3) reducing uncertainty in climate projections; (4) improving our understanding of the sensitivity and adaptability of ecosystems and human systems to climate change; and (5) exploring options to manage risks. Annually, the Federal Government spends about $2 billion on research related to advancing climate change science.[14]

A subsequent NRC review[15] of the CCSP strategic plan concluded that the Administration is on the right track, stating that the plan "articulates a guiding vision, is appropriately ambitious, and is broad in scope." The NRC's report also identified the need for a broad global observation system to support measurements of climate variables.

In June 2003, the United States hosted more than 30 nations at the inaugural Earth Observation Summit, which resulted in a commitment to establish an intergovernmental, comprehensive, coordinated, and sustained Earth observation system.[16] The data collected by the system will be used for multiple societal benefit areas, including better climate models, improved knowledge of the behavior of CO_2 and aerosols in the atmosphere, and the development of strategies for carbon sequestration.

[13] See: http://www.climatescience.gov/Library/stratplan2003/final/default.htm
[14] See Appendix A and http://www.usgcrp.gov/usgcrp/Library/ocp2004-5/default.htm.
[15] See: http://books.nap.edu/catalog/10139.html
[16] See: http://www.earthobservationsummit.gov

Since that initial meeting, two additional ministerial summits have been held, and the intergovernmental partnership has grown to nearly 60 nations. At the most recent meeting, Earth Observation Summit III in Brussels, a Ten Year Implementation Plan for the Global Earth Observation System of Systems (GEOSS) was adopted, and the intergovernmental Group on Earth Observations was established to begin implementation of the 2-, 6-, and 10-year targets identified in the plan. The U.S. contribution to GEOSS is the Integrated Earth Observation System (IEOS). In April 2005, the USG Committee on Environment and Natural Resources (CENR) released the *Strategic Plan for the U.S. Integrated Earth Observation System*[17] that addresses the policy, technical, fiscal, and societal benefit components of this integrated system, and established the U.S. Group on Earth Observation (USGEO).

1.3 U.S. Climate Change Technology Program

The U.S. Climate Change Technology Program (CCTP) is the technology counterpart to CCSP. It is a multi-agency planning and coordinating entity, led by the Department of Energy, aimed at accelerating the development of new and advanced technologies to address climate change. It works with participating agencies (Table 1-1), provides strategic direction for the CCTP-related elements of the

Table 1-1. Federal Agencies Participating in the U.S. Climate Change Technology Program and Examples of Related Activities

Agency	Selected Examples of Climate Change-Related Technology R&D Activities
DOC	Instrumentation, Standards, Ocean Sequestration, Decision Support Tools
DoD	Aircraft, Engines, Fuels, Trucks, Equipment, Power, Fuel Cells, Lasers, Energy Management, Basic Research
DOE	Energy Efficiency, Renewable Energy, Nuclear Fission and Fusion, Fossil Fuels and Power, Carbon Sequestration, Basic Energy Sciences, Hydrogen, Bio-Fuels, Electric Grid and Infrastructure
DOI	Land, Forest, and Prairie Management, Mining, Sequestration, Geothermal, Terrestrial Sequestration Technology Development
DOS*	International Science and Technology Cooperation, Oceans, Environment
DOT	Aviation, Highways, Rail, Freight, Maritime, Urban Mass Transit, Transportation Systems, Efficiency and Safety
EPA	Mitigation of CO_2 and Non-CO_2 GHG Emissions through Voluntary Partnership Programs, including Energy STAR, Climate Leaders, Green Power, Combined Heat and Power, State and Local Clean Energy, Methane and High-GWP Gases, and Transportation; GHG Emissions Inventory
HHS*	Environmental Sciences, Biotechnology, Genome Sequencing, Health Effects
NASA	Earth Observations, Measuring, Monitoring, Aviation Equipment, Operations and Infrastructure Efficiency
NSF	Geosciences, Oceans, Nanoscale Science and Engineering, Computational Sciences
USAID*	International Assistance, Technology Deployment, Land Use, Human Impacts
USDA	Carbon Fluxes in Soils, Forests and Other Vegetation, Carbon Sequestration, Nutrient Management, Cropping Systems, Forest and Forest Products Management, Livestock, and Waste Management, Biomass Energy and Bio-based Products Development
** CCTP-related funding for the indicated agencies is not included in the totals for CCTP in the budget tables of Appendix A. However, the agencies participate in CCTP R&D planning and coordination as members of CCTP's Working Groups. Agency titles for the acronyms above are shown in Appendix A.*	

[17] See: http://ostp.gov/html/EOCStrategic_Plan.pdf

overall Federal R&D portfolio, and facilitates the coordinated planning, programming, budgeting and implementation of the technology development and deployment aspects of U.S. climate change strategy, including advancing the President's vision for the National Climate Change Technology Initiative. The CCTP operates under the direction of a senior-level official at the Department of Energy and reports through the IWG to the cabinet-level CCCSTI.

1.3.1 The Role of Technology

Analyses documented in the literature (see Chapter 3) show that accelerated advances in technology have the potential, under certain assumptions, not only to facilitate progress toward meeting climate goals, but also to reduce significantly the cost of such progress over the course of the 21st century, compared to what would be the case without accelerated advances in technology.[18] Further, it is expected that the new technologies would create substantial opportunities for economic growth.

The CCTP aims to achieve a balanced and diversified portfolio of advanced technology R&D, focusing on energy-efficiency enhancements; low-GHG-emission energy supply technologies; carbon capture, storage, and sequestration methods; and technologies to reduce emissions of non-CO_2 gases. Conducting this R&D will help resolve technological uncertainties and improve the prospects that such technologies can be adapted to market realities, better positioning them for eventual deployment.

Together, CCSP and CCTP will help lay the foundation for future progress. Advances in climate change science under CCSP can be expected to improve understanding about climate change and its impacts. Uncertainties about causes and effects of climate change will be better understood and the potential benefits and risks of various courses of action will become better known. Similarly, advances in climate change technology under the CCTP can be expected to bring forth an expanded array of advanced technology options at lower cost that will both meet the needs of society and reduce GHG emissions. CCSP progress will provide the information needed to guide and pace future decisions about climate change mitigation. CCTP will provide the means for enabling and facilitating that progress.

Three publications issued by the CCTP provide more information about CCTP and related technologies in the CCTP R&D portfolio (see Appendix A). The *Vision and Framework for Strategy and Planning* provides strategic direction and guidance to the Federal agencies developing new and advanced global climate change technologies. The *Research and Current Activities Report* provides an overview of the science, technology, and policy initiatives that make up the Administration's climate change technology strategy. Readers interested in learning about more than 85 technologies in the R&D portfolio may consult the *Technology Options for the Near and Long Term Report*.[19]

1.4 Request for Public Comment

The United States, in partnership with others, has embarked on a near- and long-term global challenge, guided by science and facilitated by advanced technology, to address climate change concerns. The

[18] For example, see Battelle (2000) and IPCC (2000).

[19] All three documents are available at www.climatetechnology.gov. The internet-based version of the report on *Technology Options* is updated periodically.

CCTP *Strategic Plan*, presented here in proposed form, seeks public input (upon release) on its overall direction and completeness, recognizing that not all potentially important technologies can be pursued simultaneously.

The ability of CCTP to effectively address comments would be facilitated if commenters could use a standard commenting process, described at http://www.climatetechnology.gov. All comments will be catalogued and addressed. Alternatively, comments may be submitted by email to CCTP@hq.doe.gov, or in writing by mailing to:

Director
U.S. Climate Change Technology Program
1000 Independence Avenue, S.W.
U.S. Department of Energy
Washington, DC 20585

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