Introduction

The 21st century will see substantial changes in economic and social development around the world, with accompanying transformations in the way the world uses energy and its natural resources. The 20th century witnessed revolutionary innovations in technologies used to produce goods and services, power homes and buildings, and transport people and goods. These innovations have contributed significantly to the prosperity that the United States and many other countries currently enjoy. Continued innovations will be just as important in making possible a prosperous future for countries around the world as they are for enabling sound stewardship of the environment, including the Earth's climate system (Figure 1-1).

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 objective will require a sustained, long-term commitment by all nations over many generations.

Figure 1-1. Courtesy: NASA, Hasler Laboratory for Atmospheres Goddard Space Flight Center, Credit: Nelson Stockli

> 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)**

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 GHGs in the Earth's atmosphere. Moreover, there are a number of entirely human-made GHGs 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 GHGs sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs). Gases dealt with under the Montreal Protocol are excluded from the Climate Change Technology Program (CCTP) purview.

Although 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 atmosphere have heightened attention on anthropogenic sources of GHG emissions and various means to mitigate them. Most long-term, prospective analyses project significant increases of anthropogenic GHG emissions over the next century, stemming primarily from global population growth, economic expansion, and a continuation of existing patterns and trends in energy use (combustion of fossil fuels), land use, and industrial and agricultural production. Energy is the biggest source of emissions. Over 80 percent of current anthropogenic GHG emissions are energy related, and although projections vary considerably, a tripling of global energy demand by 2100 is not unimaginable. The International Energy Agency (2004) estimates that 1.6 billion people lack access to electricity. Governments around the world are working to ensure that their people have access to energy to power economic development.

A realistic climate change policy, therefore, must embrace these and other legitimate concerns. Indeed, the most effective way to meet this challenge is not to focus solely on GHG emissions, but on a broader agenda that promotes economic growth, provides energy security, reduces pollution, and mitigates GHG emissions. It is within this context that U.S climate change policy has been developed. Accordingly, the United States places special emphasis on the fundamental importance of science and technology as a means of achieving climate goals in ways that support these other societal goals. More than $25 billion has been so invested since 2001. Ultimately, meeting these complementary goals may entail fundamental changes in the way the world produces and consumes energy, operates industrial enterprises, grows food and fiber, and manages and uses its land.

The United States has established and implemented a robust and flexible climate change policy that harnesses the power of markets and technological innovation, uses the best available science, maintains economic growth, and encourages global participation. Major elements of this approach include implementing policies and measures to slow the growth in GHG emissions, advancing climate change science, accelerating technology development, and promoting international collaboration.

For the near term, the President has set a national goal to reduce the GHG emissions intensity of the U.S. economy by 18 percent between 2002 and 2012.[3] To this end, the Administration has developed an array of policy measures, including financial incentives, voluntary programs, and other Federal efforts. 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 Energy encourages entity-wide emissions reductions through its Voluntary Reporting of Greenhouse Gases program, which was authorized under section 1605 of the Energy Policy Act of 1992. 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 Energy Policy Act of 2005, which the President signed into law in August 2005, also promotes clean energy technologies. The Act authorizes approximately $11 billion (net) in tax credits over 10 years for a broad range of clean technologies, including those associated with energy efficiency and conservation, renewable energy, clean vehicles and alternative fuels, clean coal, nuclear power, and other technologies, all of which can potentially contribute to reducing GHG emissions. It also: authorizes loan guarantee programs that may help to accelerate the commercialization of advanced energy technologies with potential to reduce GHG emissions in the future; mandates the use of renewable fuels (such as ethanol and biodiesel) in gasoline, increasing their use from 4.0 billion gallons in 2006 to 7.5 billion gallons in 2012; authorizes standby support coverage for certain regulatory delays for up to six new nuclear plants; and authorizes the setting of efficiency standards for more than a dozen additional energy-using products.

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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.

Internationally, the Administration believes that well-designed multilateral collaborations focused on achieving practical results can accelerate development and commercialization of new technologies, and the United States has brought together key nations to jointly tackle some tough energy challenges. These multilateral collaborations in hydrogen, carbon sequestration, nuclear power, methane recovery and use, and fusion energy mirror the main strategic thrusts of our domestic technology research programs. They address a number of complementary energy concerns, such as energy security, climate change, and environmental stewardship. These programs are discussed in greater detail in Chapter 2.

The technology-focused approach that puts climate change in the context of broader development goals is gaining adherents in many parts of the world. In July 2005, the Group of Eight Leaders meeting at Gleneagles, Scotland agreed to a Plan of Action on Climate Change, Clean Energy, and Sustainable Development[9] that is based on over fifty specific, practical activities, mostly focused on technology development and deployment. Later that same month, the United States, Australia, China, India, Japan, and South Korea announced they were joining together to accelerate clean development under the new Asia-Pacific Partnership on Clean Development and Climate (APP).[10] The focus of APP will be on helping each country meet nationally-designed strategies for improving energy security, reducing harmful pollution, promoting economic development, and addressing the long-term challenge of climate change.

This integrated approach, which supports the UNFCCC objective, forms the long-term planning environment in which this *Plan* was developed. 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 U.S. strategy for developing these technologies, both in the near and long term, is outlined in this *Plan*, which builds on America's strengths in innovation and technology.[11] The United States is committed to leading the development of these new technologies.

The *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.[12] The *Plan* articulates a vision for new and advanced technology in addressing climate change concerns, defines a supporting planning and coordination mission, and provides strategic direction to the Federal agencies in formulating a comprehensive portfolio of related technology research, development, demonstration, and deployment (R&D).[13] 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

Soon after assuming office, the President initiated a cabinet-level climate change policy review and directed that innovative approaches for addressing climate change concerns be developed in accordance with a number of basic principles. Specifically, the approaches should: (1) be consistent with the long-term goal of stabilizing GHG concentrations in the atmosphere; (2) be measured as we learn more 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) be based on global participation, including developing countries.

In June 2001, the Administration released an interim report of the Cabinet-level climate change working group, and President Bush unveiled, among other initiatives, the National Climate Change Technology Initiative (NCCTI).[14] Backed by significant levels of Federal investment in climate change R&D and

9 See http://www.whitehouse.gov/news/releases/2005/07/20050708-2.html.

10 See http://www.whitehouse.gov/news/releases/2005/07/20050727-9.html.

11 See technology roadmaps as described in Chapters 4, 5, 6, 7, 8, and 10.

12 To achieve GHG stabilization, emission reductions must continue beyond the 100-year CCTP planning horizon.

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

Cabinet-Level Committee on Climate Change Science and Technology Integration

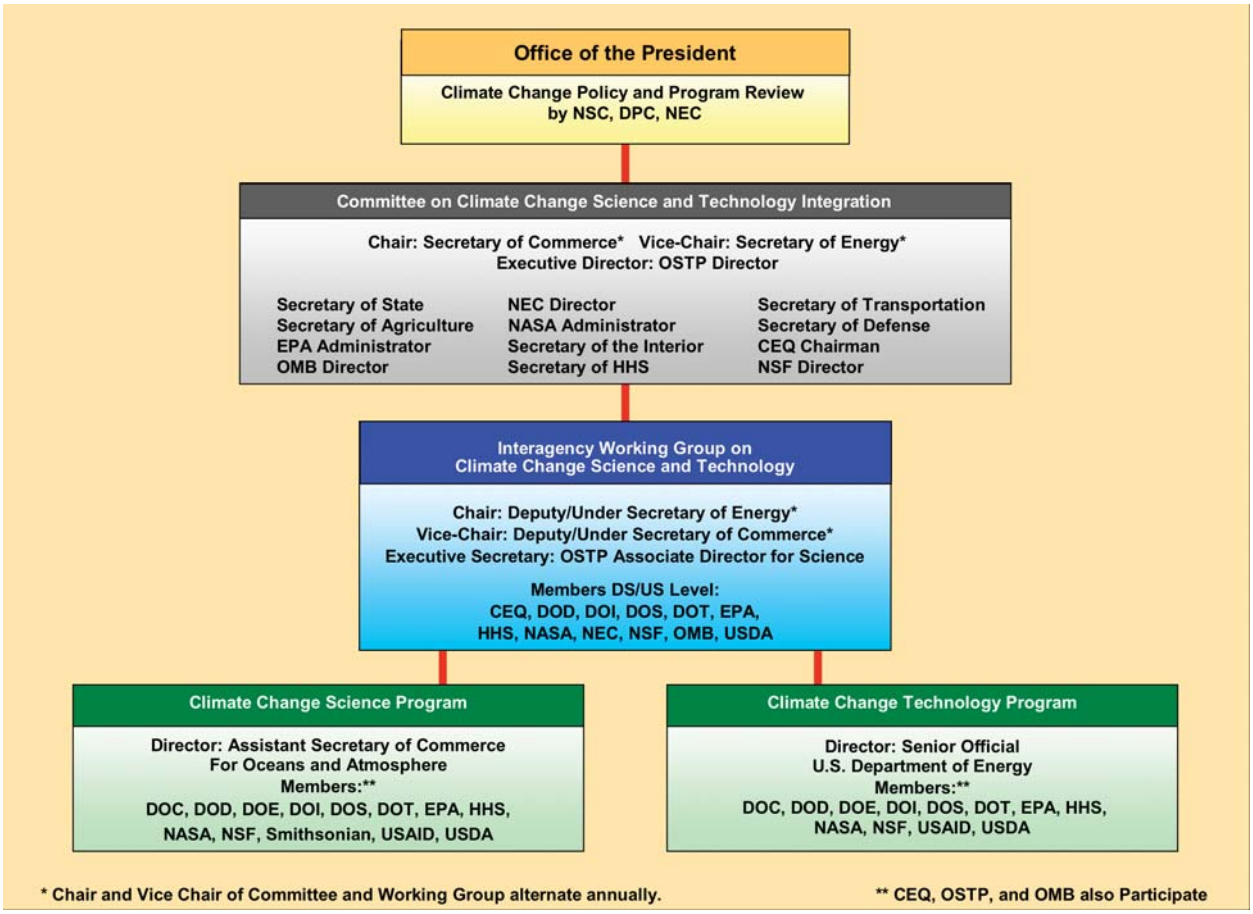


Figure 1-2. Cabinet-Level Committee on Climate Change Science and Technology Integration

related areas, this Presidential initiative signaled a U.S. intent to maintain the United States' position as a world leader in the 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) and charged it with coordinating and advancing, in an integrated fashion, climate change science and technology research. This action directly engaged the heads of all relevant departments and agencies in guiding and directing these activities. Directly under the CCCSTI is an Interagency Working Group (IWG) on Climate Change Science and Technology composed of agency deputies.

Under the auspices of the CCCSTI, two multi-agency programs were established to coordinate Federal activities in climate change scientific research and advance the President's vision under his Climate Change Research Initiative and National Climate Change Technology Initiative. These are known, respectively, as the U.S. Climate Change Science Program (CCSP), led by the Department of Commerce, and the U.S. Climate Change Technology Program (CCTP), led by the Department of Energy (Figure 1-2).

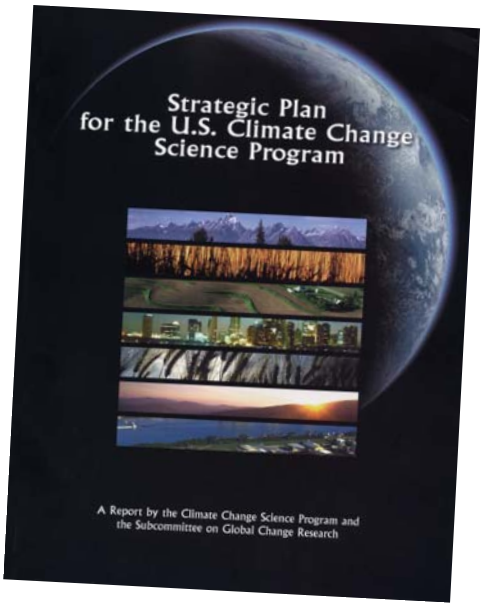
[14] White House Rose Garden speech: www.whitehouse.gov/news/releases/2001/06/20010611-2.html.

1.2 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. CCSP operates under the direction of the Assistant Secretary of Commerce for Oceans and Atmosphere and reports through the IWG to the CCCSTI (Figure 1-2).

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 most likely 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[15] for guiding climate research. The plan is organized around five goals: (1) improving the knowledge of climate history and variability; (2) improving the ability to quantify factors that affect climate; (3) reducing uncertainty in climate projections; (4) improving the understanding of the sensitivity and adaptability of ecosystems and human systems to climate change; and (5) exploring options to manage risks. In Fiscal Year 2005, the Federal Government spent about $2 billion on research related to advancing climate change science.[16]



A subsequent NRC review[17] 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.[18] 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.

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

15 See http://www.climatescience.gov/Library/stratplan2003/final/default.htm.

16 See Appendix A and http://www.usgcrp.gov/usgcrp/Library/ocp2004-5/default.htm.

17 See http://books.nap.edu/catalog/10139.html.

18 See http://www.earthobservationsummit.gov.

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*[19] 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

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 overall Federal R&D portfolio, and facilitates the coordinated

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, 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

** Agency titles for the acronyms above are shown in the list of Abbreviations and Acronyms*

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

[19] See http://iwgeo.ssc.nasa.gov.

planning, programming, budgeting, and implementation of the technology development and deployment aspects of U.S. climate change strategy, including advancing the President's NCCTI. The CCTP operates under the direction of a senior-level official at the Department of Energy and reports through the IWG to the CCCSTI.

The Potential Role of Technology

Analyses documented in the literature (see Chapter 3) show that accelerated advances in technology have the potential to facilitate progress towards meeting climate change goals and, under certain assumptions, to significantly reduce the cost of such progress over the course of the 21st century, compared to what otherwise would be the case without accelerated advances in technology.[20] Further, it is expected that the new technologies would create substantial opportunities for economic growth.

CCTP aims to achieve a balanced and diversified portfolio, including a broad range of deployment activities 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 reduce technology risk and improve the prospects that such advanced technologies can be adapted to market realities, better positioning them for eventual commercialization.

Together, CCSP and CCTP will help lay the foundation for future progress. Advances in climate change science under CCSP can be expected to improve the knowledge of climate change and its potential impacts. As a result, uncertainties about the causes and effects of climate change and increasing concentrations of GHGs will be better understood, as will the potential benefits and risks of various courses of action.

Similarly, advances in climate change technology under the CCTP can be expected to bring forth an expanded array of advanced technology options, at reasonable costs, that can meet a range of societal needs, including reducing GHG emissions. The pace and scope of needed technology change will be driven partially by future trends in GHG emissions that are uncertain. The complex relationships among population growth; economic development; energy demand, mix, and intensity; resource availability; technology; and other variables make it difficult to predict with confidence future GHG emissions on a 100-year time scale. Progress in the CCSP will provide much of 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. And the CCTP report, *Technology Options for the Near and Long Term*, provides details on the 85 technologies in the R&D portfolio.[21] (Figure 2-1)

1.4 Continuing Process

The United States, in partnership with others, is now embarked on a near- and long-term global challenge, guided by science and facilitated by advanced technology, to address concerns about climate change and increasing concentrations of GHGs. This CCTP *Strategic Plan* is a first step toward guiding Federal investments in R&D to accelerate technologies that will address these concerns. It is hoped that this *Plan* will form the basis for continuing dialogue with the public and interested partners. The *Plan* will be updated periodically, as needed. As noted earlier, the *Plan* is but one component of a comprehensive approach to climate change, which includes policy measures, financial incentives, and voluntary and other Federal programs aimed at slowing the growth of U.S. GHG emissions and reducing GHG intensity. To the extent that technology development needs to be complemented by additional and supporting policies and measures to spur adoption, CCTP intends to evaluate a number of options along these lines (see "Next Steps" in Chapter 10).

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

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

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