

National Aeronautics and Space Administration (NASA)
NASA Earth Science Research for Energy Management

**Part 1: Overview of Energy Issues and an Assessment of the Potential for
Application of NASA Earth Science Research**

by

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EXECUTIVE SUMMARY

Effective management of energy resources is critical for the U.S. economy, the environment, and, more broadly, for sustainable development and alleviating poverty worldwide. The scope of energy management is broad, ranging from energy production and end use to emissions monitoring and mitigation and long-term planning. Given the extensive NASA Earth science research on energy and related weather and climate-related parameters, and rapidly advancing energy technologies and applications, there is great potential for increased application of NASA Earth science research to selected energy management issues and decision support tools. The NASA Energy Management Program Element is already involved in a number of projects applying NASA Earth science research to energy management issues, with a focus on solar and wind renewable energy and developing interests in energy modeling, short-term load forecasting, energy efficient building design, and biomass production.

The NASA Energy Management Program Element seeks to expand application of NASA Earth science research to other energy management areas and to more closely align with Administration initiatives. This paper represents Part 1 of a two-phase project where we define a broad range of energy management issues and assess the potential applicability of NASA research for decision support in those areas. We begin with an overview of energy management issues aligned with Administration initiatives—specifically, the Global Earth Observation System of Systems (GEOSS), United States Group of Earth Observations (USGEO), Climate Change Science Program (CCSP), Climate Change Technology Program (CCTP), and U.S. Ocean Action Plan—and alignment with NASA goals and objectives. The main section of the paper assesses the potential for new or increased application of NASA Earth science data and models to decision support tools aligned with Administration initiatives through partnerships with energy sector organizations (government, private, and non-governmental organizations involved in energy production, use, planning, management, or impacts assessment).

Table ES-1 summarizes the potential for applying NASA Earth science research to energy management issues. Based on the current state of remote sensing technology and the specific information needs and decision support tools of energy sector organizations, the most promising new applications of NASA Earth science research in the energy management sector are to the areas of forecasting (short-term and long-term, including impacts of climate change on the energy sector) and renewable energy resources (primarily biomass and hydropower). Additional potential opportunities are in the areas of electricity transmission and oil and gas pipelines, distributed generation, waste and water emissions monitoring and mitigation, and impacts of sea-level rise on energy infrastructure. Part 2 of this project is to prepare an in-

depth evaluation and recommendations on the most promising applications of NASA Earth science research to energy management decision support tools.

Table ES-1. Summary of Potential Application of NASA Earth Science to Energy Management

	Energy Management	NASA Earth Science Research Application		Alignment with Administration Initiatives		See Page
		Potential	Status	GEOSS & USGEO	CCSP & CCTP	
Energy Production and Distribution	Renewable energy ¹	High	Established / Limited ²	✓	✓	19
	Traditional energy exploration, processing, and generation ¹	Low	Limited		✓	22
	Developing energy sources: hydrogen and methane hydrate deposits	Low	Limited		✓	24
	Electricity transmission, oil and gas pipelines, and solid fuel transport	Medium	Limited	✓		26
Energy Integration, Use, Short-Term Forecasting, & Operations	Distributed energy generation and grid integration	Medium	Limited	✓	✓	28
	Energy efficiency	Medium/High	Moderate	✓	✓	29
	Urban heat island	Medium	Moderate			31
	Supply and load forecasting	High	Limited	✓		33
	Event response	Low	Limited ³	✓		35
Emissions Monitoring and Mitigation	Atmospheric emissions	Low	Established ⁴	✓	✓	38
	Waste and water	Medium	Limited	✓		39
	Carbon sequestration	Medium	Established ⁵	✓	✓	41
Long-Term Planning and Threats	Long-term energy modeling and forecasting	High	Limited	✓	✓	43
	Impact of sea-level rise on energy infrastructure	Medium	Limited	✓	✓	46
	Impacts of climate change on energy sector	High	Limited	✓	✓	48

¹ Area also aligns with the U.S. Ocean Action Plan Administration Initiative. ² NASA wind and solar programs are well established; programs on biomass, geothermal, and hydropower are limited. ³ Area primarily covered by NOAA. ⁴ Applications established in NASA Air Quality Applications Program. ⁵ Applications established in the NASA Carbon Management Program Element.

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1.0 INTRODUCTION

Effective management of energy resources is critical for the U.S. economy and environment and, more broadly, for sustainable development and alleviating poverty worldwide.¹ Affordable, reliable, and secure energy supplies for the global community will help address challenges in human health, economic growth and expansion, and preservation of the environment, among other areas. The scope of energy management is broad, including exploration, production, processing, and transportation of fossil fuel and nuclear energy resources, harvesting of renewable energy resources, and generation and distribution of electricity and fuel. Energy management also includes energy use and efficiency, models and forecasting required for effective planning, operation, and regulation of energy resources, assessment of emissions, relationship with climate change, and carbon sequestration.

Recognizing the importance of energy management, NASA's Energy Management Program Element focuses on providing information for improved decisions and assessments for energy production and efficiency.² NASA is strongly interested in application of its Earth science research, partially as a result of a 2002 mandated program review³ that encouraged NASA to increase the usefulness and availability of its Earth observation datasets. While this review concluded that satellite sensor data collections had increased over the previous 10 years, the review noted that the data are not all easily accessible, and the lack of documentation and description of tools inhibits their use by "experts in the fields to which the data are being applied."⁴ Given the extensive NASA Earth science research on energy and on related weather and climate parameters, and rapidly advancing energy technologies and applications, there is great potential for increased application of NASA Earth science research to selected energy management issues and decision support tools.

1.1 NASA Resources and Energy Management

The geophysical parameters being measured by NASA Earth observation sources, and the associated models and analysis systems, are increasing and maturing rapidly. NASA Earth science

¹ International Energy Agency, The Developing World and the Electricity Challenge, Workshop Summary, <http://www.worldenergyoutlook.org/poverty/ElectandDevSum.pdf>. Accessed July 26, 2005.

² NASA Science Mission Directorate, Earth-Sun System Applied Sciences Program, Energy Management Program Element, FY 2005-2009 Plan, v1.1, March 16, 2005.

³ National Research Council, Space Studies Board, Board on Earth Sciences and Resources, Assessment of the Usefulness and Availability of NASA's Earth and Space Science Mission Data, 2002.

⁴ Ibid.

resources provide unique, objective data that have the additional advantage of yielding global, homogeneous, and repetitive coverage. In terms of energy management, NASA Earth science resources can have a role in identifying energy resources; providing historical, near-real time, and forecasted information for planning and operations; monitoring and assessing environmental impacts; minimizing impacts on energy infrastructure from events; and assessing carbon sequestration opportunities. The demand for more detailed weather and sector-specific information such as solar radiation information is increasing as energy technologies become more advanced. With the globalization of energy technologies, especially in developing countries, climatological information is needed to fill gaps and provide globally consistent information for energy project development and operation.⁵

The Energy Management Program Element leverages NASA observations and predictions related to atmospheric composition, carbon cycle and ecosystems, climate change and variability, water and energy cycles, weather, sun-solar systems research, and Earth surface and interior. The Energy Management Program Element is involved in a number of energy management projects such as production of the Surface meteorology and Solar Energy (SSE) data set for solar and wind industries, support for the National Energy Modeling System (NEMS), and data input for short- and long-term load forecasting, among others. Active partnerships have been established with government and non-government organizations both domestically and internationally, including the U.S. Department of Energy (DOE)'s National Renewable Energy Lab, Pacific Northwest National Laboratory, and Energy Information Administration (EIA); Canadian Meteorological Service; Center for Renewable Energy and Sustainable Technology; International Energy Agency; and Electric Power Research Institute (EPRI). Other partnerships under development are with U.S. Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration (NOAA), and U.S. Department of Agriculture (USDA). Each of these groups has decision support tools for energy resource management or policymaking.

The current emphasis of NASA Energy Management Program Element initiatives appears to be renewable energy, with particular emphasis on solar energy. NASA has also been developing partnerships focused on energy modeling, short-term load forecasting, energy efficient building design, and biomass production.

⁵ Stackhouse, Jr., Paul W., Charles H. Whitlock, Roberta C. DiPasquale, Donald E. Brown II and William S. Chandler, Meeting Energy-Sector Needs with NASA Climate Datasets, Earth Observation Magazine, Vol. 11, No. 8, August 2002.

1.2 Report Purpose and Organization

The purpose of this Part 1 report is to investigate potential new energy management application areas that could be developed through expanded partnerships between NASA and energy sector organizations (government, private, and non-governmental organizations involved in energy production, use, planning, management, or impacts assessment). NASA is also interested in better aligning its Energy Management Program activities with objectives of the Global Earth Observation System of Systems (GEOSS), United States Group of Earth Observations (USGEO), Climate Change Science Program (CCSP), Climate Change Technology Program (CCTP), and U.S. Ocean Action Plan, as well as better alignment with NASA goals and objectives. Thus, this report presents a broad overview of the energy management issues with respect to these selected Administration initiatives and assesses the potential for application of NASA Earth science data and models to related decision support tools. Part 2 will be a more in-depth analysis of energy management areas with the highest potential to benefit from the application of NASA resources.

The following section is an overview of the history, partners, goals and objectives, and energy management issues of GEOSS, USGEO, CCSP, CCTP, and U.S. Ocean Action Plan. This section is followed by a description of transition from research to operations, in alignment with NASA's goals and objectives. The balance of the report is organized according to energy management topics based on the range of issues addressed in NASA's Energy Program Element Plan and the CCTP goals, including the issues aligned with Administration initiatives.⁶ The four major topics are:

- Energy Production and Distribution (Chapter 2)
- Energy Integration, Use, Short-Term Forecasting, and Operations (Chapter 3)
- Emissions Monitoring and Mitigation (Chapter 4)
- Long-Term Planning and Threats (Chapter 5).

Subtopics under each category were chosen to cover the range of key energy management issues with some emphasis on areas of potential application of NASA resources. For each subtopic, the report briefly describes the sector, potentially relevant NASA resources, current status and relevant issues, example projects with NASA involvement, alignment with Administration initiatives, and the potential application of NASA Earth science research (missions, observations, models, visualizations) for policymaking and decision support. Note that because only two of the subtopics discussed align directly

⁶ U.S. Climate Change Technology Program, Research and Current Activities, DOE/PI-0001, U.S. Department of Energy, Washington, DC, November 2003.

with the U.S. Ocean Action Plan, alignment with this Administration initiative is only noted for the applicable subtopics. The information and analysis identifies both policy and management applications of NASA Earth science on national and international fronts, ranging from existing decision support systems with which NASA data and models are readily integrated to decision support systems under development that could be adapted for use with NASA data. This report concludes by recommending energy management issues and partnerships that NASA should consider investigating in more depth in the Part 2 report of this project.

1.3 Alignment with Broader Administration Initiatives

While the existing NASA Energy Management Program activities generally align with current Administration initiatives, it is useful to examine the strategies, plans, and activities of selected recent and highly visible Administration initiatives to identify energy management issues and opportunities for application of NASA Earth science resources to decision support tools. The following describes major Administration initiatives relevant to NASA Earth science: GEOSS, USGEO, CCSP, CCTP, and the U.S. Ocean Action Plan.

1.3.1 Group on Earth Observations and Related Initiatives

The first Earth Observation Summit was held in July 2003, launching an international project to develop a comprehensive, coordinated, and sustained Earth observation system. Since that time, the initiative has generated interest among international and U.S. organizations and initiatives, which include energy management as one of their key objectives. This section describes the history, partners, objectives, and energy management issues related to the Group on Earth Observations and related initiatives.

1.3.1.1 Group on Earth Observations and Global Earth Observation System of Systems

As a result of the first Earth Observation Summit, the Group on Earth Observations (GEO) was established as an *ad hoc* group to develop a 10-year implementation plan for building a comprehensive, coordinated, and sustained Global Earth Observation System of Systems (GEOSS).⁷ At the second

⁷ Declaration of the First Earth Observation Summit, July 31, 2003. Available at <http://earthobservations.org/docs/Declaration-final%207-31-03.pdf>.

summit in April 2004, a Framework document was approved.⁸ At the third summit in February 2005, GEO became a formal body with the Secretariat housed with the World Meteorological Organization in Geneva. As of May 2005, GEO had 58 member countries and 43 participating organizations. In addition to the secretariat, GEO has five subgroups: Architecture, Capacity Building, Data Utilization, International Cooperation, and User Requirements and Outreach.⁹

The GEOSS 10-year implementation plan¹⁰ was endorsed by 55 countries at the third summit. The 10-year implementation plan defines the purpose of GEOSS: “to achieve comprehensive, coordinated and sustained observations of the Earth system.” The plan defines the following nine societal benefit areas as the keys that define the purpose of GEOSS (emphasis added):

- Disasters: Reducing loss of life and property from natural and human-induced disasters
- Health: Understanding environmental factors affecting human health and well-being
- **Energy: Improving management of energy resources**
- Climate: Understanding, assessing, predicting, mitigating, and adapting to climate variability and change
- Water: Improving water-resource management through better understanding of the water cycle
- Weather: Improving weather information, forecasting, and warning
- Ecosystems: Improving the management and protection of terrestrial, coastal, and marine resources
- Agriculture: Supporting sustainable agriculture and combating desertification
- Biodiversity: Understanding, monitoring, and conserving biodiversity.

The societal benefit areas will be addressed using existing and future monitoring systems, improving their use through end user involvement and outreach, architecture and interoperability, data sharing, research facilitation, and capacity building. GEO will use GEOSS as a means to coordinate and promote Earth observations of all kinds (in situ and remote, from monitoring to information production).

⁸ From Observation to Action—Achieving Comprehensive, Coordinated, and Sustained Earth Observations for the Benefit of Humankind, Framework for a 10-Year Implementation Plan, as adopted by Earth Observation Summit II, April 25, 2004. Available at <http://earthobservations.org/docs/Framework%20Doc%20Final.pdf>.

⁹ Group on Earth Observations, <http://earthobservations.org/>. Accessed July 12, 2005.

¹⁰ Global Earth Observation System of Systems, GEOSS, 10-Year Implementation Plan, Group of Earth Observations, GEO 1000, February 2005.

According to the GEOSS 10-year implementation plan, within 2 years GEO plans to review gaps and methodologies, develop and facilitate communication among experts, establish baseline sites, conduct capacity building for each benefit area, and facilitate data access. Within 6 years, GEO will advocate funding of multinational projects, produce monitoring and evaluation of capacity building efforts, and facilitate education and training. Within 10 years, GEO will have enabled the capacity of all countries to acquire, analyze, and interpret Earth-observation data from global networks and systems, improve observations in areas with monitoring gaps, and develop priorities for capacity building.

Improving management of energy resources is one of the top priorities for GEOSS. For energy, the implementation plan and its companion reference document¹¹ discuss multiple areas where GEOSS can benefit the management of energy resources, including:

- Environmentally responsible and equitable energy management and proactive strategic energy planning, including power and pipeline distribution, facility operations, traffic congestion management, lighting/heating/cooling, and all aspects of energy planning
- Better matching of energy supply and demand in a sound, equitable, sustainable, and environmental responsible way that balances economic, social, and environmental agendas
- Reduction of risks to energy infrastructure due to weather, climate, water, oceanic, geological, and human threats
- More accurate inventories of greenhouse gases (GHGs) and pollutants for meeting and reporting on requirements under the UN Convention on Climate Change and the Kyoto Protocol and for long-term supply planning
- Better understanding and optimization of renewable energy potential, such as wind, solar, hydropower, and geothermal, including their development, siting, and incorporation into the electrical grid.

The reference report also mentions the importance of better integration of GEOSS data into databases and decision tools for efficient exploration, production, transportation and use of energy, while minimizing environmental risks.

Near-term targets for working with the energy community involve facilitating better use of existing products and the development of a strategic 5- to 10-year plan for realizing the benefits of the new generation of observational systems. Long-term targets involve implementation and tracking of

¹¹ Global Earth Observation System of Systems, GEOSS, 10-Year Implementation Plan Reference Document, Group of Earth Observations, GEO 1000R, February 2005.

actions under the implementation plan, capacity building, and improving relevant data and models. Data needs emphasize land type (terrain, land use, hydrological, agricultural), atmospheric (weather, air pollution, and climate), ocean data (temperature, color, tides, events) and solid Earth data (seismic, gravity anomalies, and magnetic fields).

1.3.1.2 United States Group of Earth Observations and the Integrated Earth Observation System

To implement the U.S. components of GEOSS, the U.S. Interagency Working Group on Earth Observations (IWGEO) was formed as an *ad hoc* group, which in March 2005 was formally renamed and established as the USGEO, a standing subcommittee of the National Science and Technology Council Committee on Environment and Natural Resources.¹² USGEO has representatives from 15 U.S. government agencies and three White House offices and is co-chaired by NASA, NOAA, and the Office of Science and Technology Policy (OSTP). USGEO was structured to mirror GEO, including an executive secretariat, a planning and integration team, and technical teams on architecture, data utilization, user requirements and outreach, capacity building, and international cooperation.

The main U.S. contribution to GEOSS is the development and coordination of the Integrated Earth Observation System (IEOS), and the first task of USGEO¹³ was to develop a strategic plan¹⁴ for IEOS. The strategic plan defines the overarching goal of USGEO as to “enable a healthy public, economy, and planet through an integrated, comprehensive, and sustained Earth observation system.” Similar to GEO, USGEO defined nine societal benefit areas although they differ in order and slightly in substance from the nine societal benefits defined in the GEOSS 10-year implementation plan. The USGEO societal benefit areas are (emphasis added):

- Improve Weather Forecasting
- Reduce Loss of Life and Property from Disasters
- Protect and Monitor Our Ocean Resource
- Understand, Assess, Predict, Mitigate and Adapt to Climate Variability and Change
- Support Sustainable Agriculture and Forestry and Combat Land Degradation
- Understand the Effect of Environmental Factors on Human Health and Well-Being
- Develop the Capacity to Make Ecological Forecasts
- Protect and Monitor Water Resources

¹² United States Group on Earth Observations, <http://iwgeo.ssc.nasa.gov/>. Accessed July 13, 2005.

¹³ For simplicity, we use the name USGEO to refer to both IWGEO and USGEO, regardless of the timing. IWGEO and USGEO both refer to the same organization; IWGEO became USGEO in March 2005.

¹⁴ Strategic Plan for the U.S. Integrated Earth Observation System, National Science and Technology Council Committee on Environment and Natural Resources, Washington, DC, 2005.

- **Monitor and Manage Energy Resources.**¹⁵

USGEO also emphasizes six near-term opportunities: Data Management, Improved Observations for Disaster Warnings, Global Land Observation System, Sea Level Observation System, National Integrated Drought Information System, and Air Quality Assessment and Forecast System. While energy management may benefit or relate to all of these opportunities, the near-term opportunities do not explicitly discuss energy management issues.

According to the USGEO strategic plan, the next steps are to commit necessary agency resources and implement specific governance actions, such as establishing formal interaction with external stakeholders, establishing a process for prioritizing investments, assessing and reporting, and defining the process of developing the architecture.

For monitoring and managing energy resources, the USGEO focus is on improved Earth observations to optimize decision-making, provide and protect energy supply, and protect the environment and human health. The energy management technical reference document¹⁶ discusses multiple possible application areas for IEOS data to support monitoring and managing energy resources, with considerable emphasis on climate change.

According to the IEOS Strategic Plan, the key agencies that use and provide data related to energy management are: DOE, U.S. Geological Survey (USGS), EPA, and Tennessee Valley Authority.¹⁷ The observation systems for energy can be divided into three categories: energy consumption (e.g., weather and climate data), energy exploration (e.g., search for fossil fuels and siting of renewable energy), and impacts (e.g., atmospheric emissions and climate change). Specific Earth observations rated in the IEOS Strategic Plan as of high or medium importance for energy management are:

- Land and sea surface temperature
- River runoff (volume, sediment, etc.)
- Atmospheric constituents (ozone, GHGs, black carbon, aerosols, etc.)
- Total and clear sky radiative flux

¹⁵ Ibid.

¹⁶ Monitoring and Managing Energy Resources Technical Reference Document, November 8, 2004. Available at http://iwgeo.ssc.nasa.gov/docs/review/Energy_Technical.pdf.

¹⁷ U.S. Organizations that primarily use but do not generally provide energy data are: National Institute for Standards and Technology, National Institute of Environmental Health Sciences, Federal Emergency Management Agency, Department of Transportation, National Science Foundation, Smithsonian Institution, and Agency for International Development.

- Space weather
- Precipitation
- Land use/land cover (crops, forests, urban, etc.)
- Ice and snow (cover and volume)
- Geology (bedrock and surficial) and soils.

Application of these observations to key energy issues will be presented in general in this report; application to specific decision support systems and models will be addressed in more detail in Part 2.

1.3.2 Climate Change Initiatives

President George W. Bush established the Climate Change Research Initiative (CCRI) as a follow-on initiative to the U.S. Global Change Research Program (USGCRP). The CCRI focuses on identifying the scientific information that can be developed within 2 to 5 years to assist the nation's evaluation of optimal strategies to address global change risks. The CCSP was established in 2002 to integrate USGCRP and CCRI activities. In parallel to the CCSP, the CCTP is responsible for climate change-related technology research and development. The relationship of the Administration to the CCSP and CCTP and the members of each program are shown in Figure 1.¹⁸ The history, partners, objectives, and energy issues related to CCSP and CCTP are described in the following sections.

¹⁸ Strategic Plan for the Climate Change Science Program Final Report, Climate Change Science Program and the Subcommittee on Global Change Research, July 2003. Available at <http://www.climate-science.gov/Library/stratplan2003/final/default.htm>.

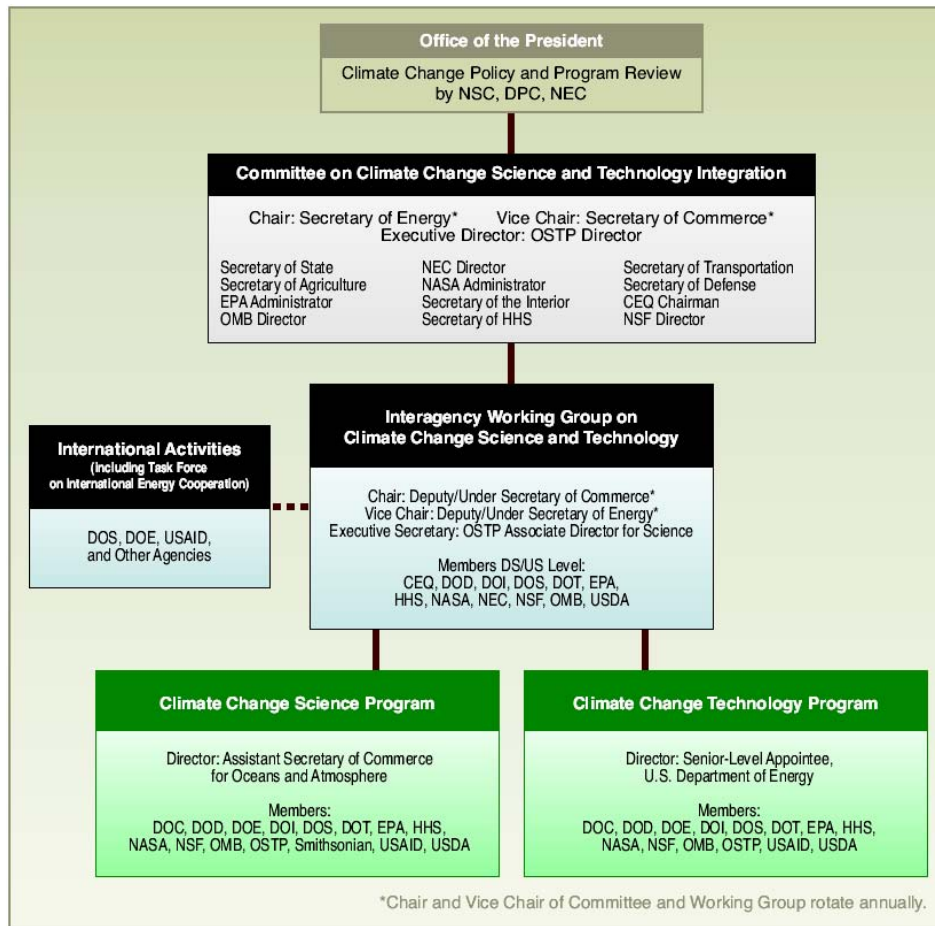


Figure 1. The Climate Change Science and Technology Programs are overseen by a cabinet-level management structure of the U.S. government.¹⁹

1.3.2.1 Climate Change Science Program

The CCSP integrates Federal research on climate and global change, as sponsored by 13 Federal departments and agencies²⁰ (including NASA) and overseen by the Office of Science and Technology Policy, the Council on Environmental Quality, the National Economic Council, and the Office of Management and Budget.²¹ The most recent CCSP Strategic Plan²² was completed in July 2003. The

¹⁹ Strategic Plan for the Climate Change Science Program Final Report, Climate Change Science Program and the Subcommittee on Global Change Research, July 2003. Available at <http://www.climatescience.gov/Library/stratplan2003/final/default.htm>

²⁰ National Science Foundation, Department of Commerce, Department of Energy, Environmental Protection Agency, National Aeronautics and Space Administration, Department of State, Agency for International Development, Department of the Interior, Department of Agriculture, Department of Health and Human Services, National Institutes of Health, Department of Transportation, Department of Defense, and Smithsonian Institution.

²¹ About the U.S. Climate Change Science Program, <http://www.climatescience.gov/about/default.htm>. Accessed July 6, 2005.

Strategic Plan’s vision is “a Nation and the global community empowered with the science-based knowledge to manage the risks and opportunities of change in the climate and related environmental systems” (Executive Summary). The mission is to develop a framework for acquiring and applying knowledge of the Earth’s global environment through four core approaches: scientific research, observations, decision support, and communication. These approaches are applied across the following five CCSP goals, each of which is tied to numerous, evolving, interdisciplinary research elements:²³

- Goal 1: Extend knowledge of the Earth’s past and present climate and environment, including its natural variability, and improve understanding of the causes of observed changes
- Goal 2: Improve understanding of the forces bringing about changes in the Earth’s climate and related systems
- Goal 3: Reduce uncertainty in projections of how the Earth’s climate and environmental systems may change in the future
- Goal 4: Understand the sensitivity and adaptability of different natural and managed systems to climate and associated global changes
- Goal 5: Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change.

While energy management issues are relevant to each of the five goals, the Strategic Plan specifically mentions energy-related activities and adaptation/mitigation options with respect to Goals 2 and 5:

- Energy Management and Goal 2: The Strategic Plan notes that combustion of fossil fuels, among other changes and activities, alters the composition of the atmosphere and important physical and biological properties of the Earth’s surface. One of the key research activities for Goal 2 is to “Improve capabilities to develop and apply emissions and related scenarios for conducting ‘If..., then...’ analyses in cooperation with the CCTP to explore the potential implications of different technological, economic, and institutional conditions for future emissions, climate, and living standards. The Strategic Plan notes that scenarios will be strengthened by an improved understanding of the interdependence among energy use in different sectors (e.g., electric power generation, transportation); economic growth;

²² Strategic Plan for the Climate Change Science Program Final Report, Climate Change Science Program and the Subcommittee on Global Change Research, July 2003. Available at <http://www.climate-science.gov/Library/stratplan2003/final/default.htm>.

²³ Atmospheric Composition, Climate Variability and Change, Global Water Cycle, Land-Use/Land-Cover Change, Global Carbon Cycle, Ecosystems, and Human Contributions and Responses.

population growth, composition, distribution, and dynamics (including migration); advancements in technologies; and pollutant emissions.

- Energy Management and Goal 5: The activities under Goal 5 are focused on improving the nation's and global community's understanding of the nature and extent of the challenges inherent in climate change and developing improved resources for evaluating options for adaptation and mitigation. Such options for adaptation and mitigation presumably include energy-related activities such as generating electricity without GHG emissions. The Strategic Plan notes that fulfilling Goal 5 will require development of a variety of resources including observations, databases, data and model products, scenarios, a variety of visualization products, and improved approaches for interacting with users. One of the key research activities for Goal 5 is to "Support policymaking by conducting comparative analyses and evaluations of the socioeconomic and environmental consequences of response options."

In addition to goals related to energy management, one of CCSP's core approaches, decision support, also links closely to energy management and NASA Earth Science Applications. The Strategic Plan emphasizes the need for knowledge gained from science to be available to decision-makers in usable formats to enable the development of new methods, models, and other resources that facilitate economic analysis, policy analysis, and environmental decision-making. The Strategic Plan specifically mentions applying satellite and ground-based observations and related analyses in resource management applications.

Finally, some of the research elements, most notably, the Human Dimensions of Global Change USGCRP Program Element,²⁴ have close links to energy management. One of the illustrative research questions highlighted in the Strategic Plan is: "What can be projected about the effectiveness, cost, and environmental and health effects of alternative energy and mitigation technologies, including sequestration options?" Another research question is: "How are climate variability, trends in climate, and sea-level rise likely to affect resource management (e.g., water, fish, agriculture, forestry, transportation, energy supplies)..." One of the key research needs listed is: "Development of integrated assessment models that introduce new energy and carbon sequestration technologies (including technologies under consideration in the CCTP) and incorporate new knowledge about innovation and diffusion.

²⁴ Human Dimensions of Global Change USGCRP Program Element, <http://www.usgcrp.gov/usgcrp/ProgramElements/human.htm>. Accessed July 6, 2005.

Over the next four years, CCSP will prepare Synthesis and Assessments to support informed discussion and decision-making regarding climate variability and change by policymakers, resource managers, stakeholders, the media, and the general public, in accordance with Section 106 of the 1990 Global Change Research Act (Public Law 101-606, 104 Statutes 3096-3104). Three Synthesis and Assessments relate specifically to energy management:

- Updating scenarios of GHG emissions and concentrations, in collaboration with the CCTP. Review of integrated scenario development and application. Effort to be led by DOE and completed in the 4th quarter of 2006.
- Analyses of the effects of global change on energy production and use. Effort to be led by DOE and completed in the 2nd quarter of 2007.
- Uses and limitations of observations, data, forecasts, and other projections in decision support for selected sectors and regions. Effort to be led by NASA and completed in the 4th quarter of 2006.²⁵

On a shorter time frame, CCSP is holding a workshop on November 14-16, 2005, in the Washington, DC, area, addressing the capability of climate science to inform decision-making. The workshop will serve as a forum to address the Program's progress and future plans, and is scheduled to include a breakout session focused on energy that is being organized by the NASA Energy Management Program Element. The workshop will include discussion of decision-maker needs for scientific information on climate variability and change, as well as expected outcomes of CCSP's research and assessment activities that are necessary for sound resource management, adaptive planning, and policy formulation.²⁶

1.3.2.2 Climate Change Technology Program

The CCTP is a multi-agency research and development (R&D) coordination activity, organized under the Cabinet-level Committee on Climate Change Science and Technology Integration (CCCSTI), established by President George W. Bush on February 14, 2002. The Cabinet-level CCCSTI is chartered to provide recommendations to the President on matters concerning climate change science and technology; address related Federal R&D funding issues; and coordinate with Office of Management and

²⁵ Updated Schedule and Scope of the Climate Change Science Program (CCSP) Synthesis and Assessment Products, Letter from Jim Mahoney (Director, CCSP) to Senator Jim DeMint (Republican, South Carolina), July 15, 2005, <http://www.climatescience.gov/Library/sap/letter-to-demint2005.htm>.

²⁶ U.S. Climate Change Science Program, Climate Science in Support of Decisionmaking, Workshop Update, June 27, 2005, <http://www.climatescience.gov/workshop2005/update27jun2005.htm>. Accessed August 2, 2005.

Budget. The Director of the CCTP is appointed by the Secretary of Energy and takes technical direction from DOE's designated representative to the CCCSTI's Interagency Working Group.

CCTP's mission is to focus R&D activities more effectively on the President's climate change goals. The CCTP provides a forum for interagency exchange of information on ongoing R&D activities, and is chartered to review the Federal R&D portfolio and make recommendations. The CCTP's multi-agency organizational structure, including NASA, provides an opportunity to develop, across the Federal government, a comprehensive, coherent, multi-agency, multi-year R&D program plan for the development of climate change technology. As part of these activities, the CCTP helps to inform near- and long-term technology planning activities, including scenario analyses and visioning exercises, aided by modeling. The CCTP works in close collaboration with the CCSP, calling on science findings to help define the needs for R&D for energy technologies and assisting the science evaluations by developing scenarios of energy technology performance, cost, and economic impacts.²⁷

The CCTP Vision and Framework for Strategy and Planning²⁸ is organized around six goals:

- Reducing emissions from energy use and infrastructure;
- Reducing emissions from energy supply
- Capturing and sequestering carbon dioxide
- Reducing emissions of other greenhouse gases
- Measuring and monitoring emissions, energy use, and sequestration
- Bolstering the contributions of basic science to climate change

The CCTP strongly emphasizes energy management issues. The introduction to the CCTP Research and Current Activities²⁹ begins, "Global climate change is a major, long-term energy and environmental challenge that may require a fundamental change in the way we produce and use energy in the 21st century." The portfolio of technologies addressed under CCTP are outlined in the Vision and Framework for Strategy and Planning, the Research and Current Activities report (profiling selected promising technologies), and the more complete Technology Options for the Near and Long Term.³⁰

²⁷ About the U.S. Climate Change Technology Program, <http://www.climatechange.gov/about/index.htm>. Accessed July 8, 2005.

²⁸ U. S. Climate Change Technology Program, Vision and Framework for Strategy and Planning, DOE/PI-0003, August 2005. Available at <http://www.climatechange.gov/vision2005/cctp-vision2005.pdf>.

²⁹ U.S. Climate Change Technology Program, Research and Current Activities, DOE/PI-0001, November 2003. Available at <http://www.climatechange.gov/library/2003/currentactivities/index.htm>.

³⁰ U.S. Climate Change Technology Program, Technology Options for the Near and Long Term, DOE/PI-0002, November 2003. Available at <http://www.climatechange.gov/library/2003/tech-options/index.htm>.

These include hydrogen fuel, carbon sequestration, clean coal technology, thermonuclear experimental reactor technology, wind energy, solar photovoltaic energy, biomass energy, methane recovery from coal mines, superconductivity, and energy efficiency for transportation and buildings, among other technologies.

A recent activity related to climate change technology was the President's announcement of the Asia-Pacific Partnership to develop, deploy, and transfer cleaner, more efficient technologies and to meet national pollution reduction, energy security, and climate change concerns. The vision statement³¹ of Australia, China, India, Japan, the Republic of Korea, and the U.S. mentioned a number of technologies that greatly overlap the focus of CCTP: energy efficiency, clean coal, integrated gasification combined cycle, liquefied natural gas, carbon capture and storage, combined heat and power, methane capture and use, civilian nuclear power, geothermal, rural/village energy systems, advanced transportation, building and home construction and operation, bioenergy, agriculture and forestry, hydropower, wind power, solar power, other renewables, hydrogen, nanotechnologies, advanced biotechnologies, next-generation nuclear fission, and fusion energy. Ongoing developments on the relationship between the Asia-Pacific Partnership and CCTP, and upcoming decisions and steps for both programs, are yet to be seen.

One source of information on current energy management activities coordinated through CCSP and CCTP is examination of DOE's USGCRP activities.³² Research supported by DOE's Office of Biological and Environmental Research is focused on the effects of energy production and use. DOE's Office of Science Climate Change Program includes research on climate and hydrology, atmospheric chemistry and carbon cycle, ecological processes, and human dimensions. The DOE Human Dimensions Program supports research on data, models, and methods to analyze and assess the economic, social, and environmental implications of climate change and of various potential policy options. Other DOE research has addressed technology innovation and diffusion and projections of energy demand and associated GHG emissions. Current research addresses improving the representation of hydrogen production, transportation, and use in integrated assessment models, and analysis and application of explicit models of non-CO₂ GHG emissions.

³¹ U.S. Department of State, Bureau of Oceans and International Environmental and Scientific Affairs, Vision Statement of Australia, China, India, Japan, the Republic of Korea, and the U.S. for a New Asia-Pacific Partnership on Clean Development and Climate Fact Sheet, July 28, 2005, <http://www.state.gov/g/oes/rls/fs/50335.htm>. Accessed August 2, 2005.

³² DOE Role in USGCRP, <http://www.usgcrp.gov/usgcrp/agencies/doe.htm>. Accessed July 6, 2005.

1.3.3 U.S. Ocean Action Plan

On December 17, 2004, President George W. Bush issued an executive order establishing a Committee on Ocean Policy as part of the Council on Environmental Quality (CEQ) and released the U.S. Ocean Action Plan.³³ The Administration's actions were taken in response to the U.S. Commission on Ocean Policy's final report, "An Ocean Blueprint for the 21st Century,"³⁴ containing 212 recommendations addressing all aspects of ocean and coastal policy as mandated by the Oceans Act of 2000 (Public Law 106-256). The 16 members of the Commission called on the President and Congress to take decisive, immediate action to carry out their recommendations to halt the steady decline of U.S. oceans and coasts.

The Committee on Ocean Policy is chaired by the CEQ chairman, and the membership consists of designated Federal officials as listed in the U.S. Ocean Action Plan including the NASA Administrator. The Committee's purpose is to coordinate the activities of executive branch departments and agencies regarding ocean-related matters in an integrated and effective manner to advance the environmental and economic interests of present and future generations of Americans. To support its work, the Committee established subsidiary bodies that coordinate with existing structures, including the following bodies in which NASA participates: Interagency Committee on Ocean Science and Resource Management Integration, National Science and Technology Council Joint Subcommittee on Ocean Science and Technology, and Subcommittee on Integrated Management of Ocean Resources. The work of these bodies is in the preliminary stages, focusing on developing priorities and plans. The Committee website³⁵ describes NASA's role in ocean stewardship, noting that "NASA's ability to study the Earth's oceans from space has become essential to progress in oceanography given the global reach of the Earth's oceans and their extensive interactions with the atmosphere in shaping the Earth's climate."

The intent of the U.S. Ocean Action Plan is to identify immediate, short-term actions that provide direction for ocean policy and outline additional long-term actions for the future. The Plan includes several references to Earth observations and limited references to specific energy management issues. The Plan notes that the U.S. Integrated Ocean Observing System will be a major element of the Global Ocean Observing System, which in turn is a substantial component of GEOSS. The Plan highlights NASA's planned 2008 launch of the Aquarius satellite to observe sea surface salinity. The Plan also

³³ U.S. Ocean Action Plan, The Bush Administration's Response to the U.S. Commission on Ocean Policy, undated, released December 17, 2004. Available at <http://ocean.ceq.gov/actionplan.pdf>.

³⁴ U.S. Commission on Ocean Policy, *An Ocean Blueprint for the 21st Century*, Final Report, Washington, DC, 2004. Available at http://www.oceancommission.gov/documents/full_color_rpt/welcome.html.

³⁵ U.S. Committee on Ocean Policy, <http://ocean.ceq.gov/activities/welcome.html>. Accessed October 10, 2005.

describes a Minerals Management Service program initiated in 2004 establishing an ocean current monitoring and data sharing program in the Gulf of Mexico based on data collected by deepwater oil and gas platforms operators. Finally, in terms of enhancing the use and conservation of ocean, coastal, and Great Lakes resources, the Plan highlights the need to manage energy development on the Outer Continental Shelf, including renewable energy projects such as wind, wave, and solar energy.

1.4 Alignment with NASA Goals and Objectives

The goals and objectives of NASA are described in NASA's 2003 Strategic Plan.³⁶ In the description of Objective 1.1 (Understand how Earth is changing, better predict change, and understand the consequences for life on Earth.), the Strategic Plan notes, "We are maturing a suite of observing capabilities and will hand them over to our operational observing partners, such as the National Oceanic Atmospheric Administration (NOAA)." The transition between NASA research and NOAA operations has been identified as a national issue by the National Research Council and the Commission on Ocean Policy.³⁷ The transition from NASA to NOAA of observational data, models, and forecasts that relate to energy management is an important consideration in the long-term sustainability of supporting and enhancing energy decision-support systems.

NASA and NOAA are addressing this issue through a joint Research to Operations initiative exploring and developing a host of near-term and longer-term actions. The capabilities to be transitioned includes the full range of activities including space hardware, calibration and validation, communications, and ground data system including archival, timely access to data, assimilation of data into models, and the generation of associated analyses and forecasts. The Research and Operations (R&O) management team establishes the framework for collaboration, sets bilateral policy and priorities, approves the Transition Plan, and oversees its execution. The R&O Joint NASA/NOAA Working Group prepares and executes the Transition Plan with assistance from R&O Transition Teams who prepare implementation plans for each identified capability.

As of September 2005, the Terms of Reference for the R&O Joint NASA/NOAA Working Group have been agreed to by both agencies, and the Transition Plan is scheduled to be available for high-level

³⁶ National Aeronautics and Space Administration, 2003 Strategic Plan, NP-2003-01-298-HQ, Washington, DC, February 2003. Available at http://www.nasa.gov/pdf/104084main_1968main_strategi.pdf.

³⁷ Transitioning Capabilities between NASA Research and NOAA Operations, Presentation to Cooperative Institute for Oceanographic Satellite Studies (CIOSS) Executive Board Meeting, August 30, 2005, (rev 25), http://cioss.coas.oregonstate.edu/CIOSS/workshops/Exec_Board_meeting/Exec_Board_Presentations/Wilson_R&O_for_CIOSS_083005.ppt. Accessed October 12, 2005.

agency review by the end of 2005. In the longer-term (3 to 8 years), the goal is the establishment and execution of a more formal process between the two agencies to facilitate the transitioning. Beyond 10 years, the goal is to engage in the NASA Strategic Roadmap process to identify and sustain key observations required for research and operational use.

An example of a NASA capability to undergo R&O transition is the sensors on the NASA Terra, Aqua, and Aura platforms. The suite of research sensors on these platforms provide an important and well-utilized earth observing dataset, supporting air and water quality monitoring, climate modeling, ocean observation, land change, and other geoscience applications. The extensive use of these datasets and products has proven their value for routine observations and decisionmaking and highlighted the need for similar data from long-term operational sensors. As such, many of the capabilities of these sensors have been incorporated into National Polar-Orbiting Operational Environmental Satellite System (NPOESS) sensors via the NPOESS Preparatory Project (NPP).³⁸ The NPOESS sensors will provide operational earth observations for air, water, and land, advancing and building on the success of NASA's research platforms. NPP will bridge the NASA earth observing research sensors and the NPOESS operational sensors by testing advanced technologies, including space and ground systems, validating algorithms, and providing early user evaluation of NPOESS data products.

For the energy management sector, the R&O transition is crucial. The energy sector requires both short-term reliable and operational datasets (such as for supply and load forecasting) and long-term continuous datasets (such as for understanding energy availability or the impact of climate change). NASA's role as a research agency is to develop and prove the sensors, algorithms, models, and products that are useful to the energy management sector and transition the successful capabilities to an operational program to address long-term needs. The R&O transition program will ultimately ensure the successful application of projects developed under the energy management program area.

³⁸ NPP, NPOESS Preparatory Project, <http://jointmission.gsfc.nasa.gov/>. Accessed October 17, 2005.

2.0 ENERGY PRODUCTION AND DISTRIBUTION

At the center of the energy sector are the production and distribution of energy, including the life cycle of exploration and acquisition of natural resources (e.g., oil, uranium, solar), processing of the energy source into fuel, generation of electricity, and distribution of fuels and electricity for end use. This section of the report briefly describes and evaluates the potential for application of NASA resources to broad energy types (renewable, traditional, and developing) and electricity generation and distribution (independent of energy source).

2.1 Renewable Energy

Renewable energy is defined as “Energy resources that are naturally replenishing but flow-limited... Renewable energy resources include: biomass, hydro, geothermal, solar, wind, ocean thermal, wave action, and tidal action.”³⁹ Renewable energy is critical to addressing climate change and energy independence.

Potentially Relevant NASA Resources

- Solar radiation and angle
- Meteorology data, specifically wind speed, cloud cover, aerosols, and rainfall
- Biomass parameters
- Reservoir height
- Water availability

Current Status/Relevant Issues

NASA datasets have been valuable to many sectors of renewable energy, particularly solar and wind energy through the identification of available peak solar and wind resources. For solar energy, NASA has developed the Surface meteorology and Solar Energy (SSE) prototype website⁴⁰ (as part of NASA’s Prediction Of Worldwide Energy Resource [POWER] project), a renewable energy resource website that provides online over 200 satellite-derived meteorology and solar energy parameters, both

³⁹ Energy Glossary, Energy Information Administration, U.S. Department of Energy, http://www.eia.doe.gov/glossary/glossary_main_page.htm. Accessed July 21, 2005.

⁴⁰ Surface Meteorology and Solar Energy database, Release 5.1, <http://eosweb.larc.nasa.gov/sse/>. Accessed July 27, 2005.

directly as datasets and charts, and as input to decision support systems, such as RETScreen.⁴¹ The SSE is hosted by NASA’s Langley Research Center Distributed Active Archive Center (DAAC) and also linked through the Federation of Earth Science Information Partners (ESIP).

Others areas such as geothermal, hydroelectric, and biomass are less mature in the application of useful NASA datasets. NASA has existing partnerships with the USDA to create scenario assessments for biomass energy sources. With the USDA’s Foreign Agricultural Service (USDA-FAS), NASA and other partners are monitoring lake and reservoir height variations for approximately 100 lakes located around the world using near-real time radar altimeter data.⁴² While the program is designed for monitoring droughts, crop production, and irrigation, similar datasets could be used for hydroelectric power. Exploration and identification of geothermal resources may benefit from the application of thermal data from sensors such as the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER).

The following table is included for this sub-topic (renewable energy) and all subsequent sub-topics reviewed in this report as a means of summarizing example projects with NASA involvement.

<i>Example Projects with NASA Involvement</i>	<i>Decision Support System / Database</i>	<i>Participants</i>
Prediction Of Worldwide Energy Resource (POWER) Project	National Solar Radiation Database	DOE, National Renewable Energy Laboratory (NREL)
-Surface meteorology and Solar Energy (SSE) Prototype Website	HOMER	NREL
	RETScreen	Canada Center for Mineral and Energy Technology (CANMET) Energy Diversification Research Laboratory
	Solar Sizer	Center for Renewable Energy and Sustainable Technology, Solar Energy International
	Energy production biomass scenario assessments	USDA
Crop Explorer	Global Reservoir and Lake Monitor	USDA

⁴¹ RETScreen International, <http://www.etscreen.net/>. Accessed July 27, 2005.

⁴² Global Reservoir and Lake Monitor, http://www.pecad.fas.usda.gov/cropeplorer/global_reservoir/. Accessed July 27, 2005.

Alignment with Administration Initiatives

Renewable energy is included under the GEOSS societal benefit area to monitor and manage energy resources and is included in the GEOSS 10-year implementation plan and supporting documents, specifically understanding and optimizing renewable energy potential (development, siting, and incorporation into the electrical grid).^{43,44} Continued application of NASA resources to the advancement of renewable energy aligns closely with the goals of GEOSS, especially when relevant datasets and models have global coverage.

Since renewable energy sources are essentially carbonless sources of energy, the advancement of renewables also aligns with CCSP and CCTP. For CCSP, renewables are one means to mitigate impacts, as called for under CCSP's Goal 5. For CCTP, the goal to reduce carbon emissions from the energy supply is directly supported by the advancement of renewable energy.

The U.S. Ocean Action Plan highlights the need to manage energy development on the Outer Continental Shelf, including renewable energy projects such as wind, wave, and solar energy. Thus, application of NASA resources to the management of Outer Continental Shelf renewable energy aligns with this Administration initiative.

*Potential Application of NASA Earth Science Research: **HIGH***

Key areas where NASA resources are applicable for renewable energy are the identification of the quantity of resources, location for siting generation facilities, and planning and optimizing production. (For discussion of the potential application of NASA resources to renewable distributed energy resources and grid interconnection, refer to Section 3.1). Application of NASA data and models to renewable energy is an established and successful application in several key areas (e.g., solar, wind). Potential for continuation in these established fields is high. The renewable energy field is still developing and is open to the use of new and innovative datasets. The number of applications of NASA Earth science products has increased significantly in the last 5 years. NASA has established relationships with leaders in renewable energy, particularly NREL. NASA has also started discussions on determining needs for biomass energy and has recently established partnerships with two agricultural crop modelers to provide near-real time (weekly) solar energy information. These partnerships and discussions are in the formative stages although NASA has plans to release a prototype agricultural data website in the near future. Thus,

⁴³ Global Earth Observation System of Systems, GEOSS, 10-Year Implementation Plan, Group of Earth Observations, GEO 1000, February 2005.

⁴⁴ Global Earth Observation System of Systems, GEOSS, 10-Year Implementation Plan Reference Document, Group of Earth Observations, GEO 1000R, February 2005.

potential for the use of NASA resources for new renewable energy applications (e.g., hydropower and biomass) is also considered high, given the development of relevant products and integration into appropriate decision support systems.

2.2 Traditional Energy Exploration, Processing, and Generation

This sector includes fossil fuels (oil, gas, and coal) and nuclear energy. The full cycle of traditional energy encompasses exploration of new energy sources, extraction of natural resources, processing into usable fuels, and generation of power.

Potentially Relevant NASA Resources

- Near-real time data on weather fluctuations and events affecting energy production
- Improved characterization of GHG and non-GHG emissions to help guide climate change assessment and mitigation

Current Status/Relevant Issues

Remaining U.S. oil fields are becoming increasingly costly to produce because much of the easy-to-find oil has already been recovered. However, for every barrel of oil that flows from U.S. fields, nearly two barrels remain in the ground. DOE's Fossil Energy program is exploring new technology to find and produce much of this "left-behind" oil.⁴⁵ NASA Earth science resources may be useful in such exploration issues. Another current oil and gas issue is exploration and production in relatively new areas (e.g., Alaskan National Wildlife Refuge). Other issues for consideration include oil and gas exploration, oil spill management, pipeline monitoring, and oil shale mining.

There has been a large increase in planned natural gas-fired power plants in recent years, and DOE reports that 900 of the next 1,000 U.S. power plants will use natural gas.⁴⁶ This increase has spurred natural gas pipeline additions and expansions. Proposals for new liquefied natural gas (LNG) import terminals to meet growing U.S. demand have also increased in recent years, with five currently operating in North America and another 55 proposed terminals.⁴⁷ Natural gas has also become increasingly popular

⁴⁵ U.S. Department of Energy, Energy Resources, Oil, http://www.doe.gov/engine/content.do?BT_CODE=OIL. Accessed July 21, 2005.

⁴⁶ U.S. Department of Energy, Energy Resources, Natural Gas, http://www.doe.gov/engine/content.do?BT_CODE=NATURALGAS. Accessed July 21, 2005.

⁴⁷ Natural Gas Intelligence, Power Market Today, North American LNG Import Terminals, <http://intelligencepress.com/features/lng/>. Accessed July 22, 2005.

as an alternative transportation fuel. NASA Earth science resources may be useful in siting/monitoring LNG terminals and natural gas pipelines.

For energy generation from fossil fuels, there are a variety of siting, permitting, and operating issues. Power plant siting and permitting issues include fuel location/transportation, grid interconnection, and environmental concerns. Meteorological and climatological information, in connection with supply and load forecasting, is used for operation planning. Currently utility companies have in-house or consultant-based expertise to help guide operations relying on private sector- and/or NOAA-produced data. While there is considerable sophistication and investment in existing operations systems, NASA has additional data and models to offer in this arena. The challenge for NASA will be showing the added value of NASA resources in the context of often proprietary and inaccessible datasets.

<i>Example Projects with NASA Involvement</i>	<i>Decision Support System / Database</i>	<i>Participants</i>
None identified.		

Alignment with Administration Initiatives

There is no strong alignment of the major areas of traditional energy extraction and production with GEOSS. One of the major traditional energy issues aligned with the CCTP is advanced coal-based power generation (e.g., Future Gen⁴⁸), which typically involves the gasification of coal prior to combustion and can include generation of hydrogen along with electricity and geologic sequestration of CO₂ emissions. Significant improvements in reducing CO₂ have been demonstrated via efficiency improvements and co-firing of coal and biomass. The G8 Gleneagles Plan of Action includes a statement of support for efforts “to make electricity generation from coal and other fossil fuels cleaner and more efficient...” and specific support for related work by the International Energy Agency (IEA).⁴⁹ A primary research focus for advanced coal-based power generation is on technology improvements.

Nuclear energy is a priority in the CCTP program due to its cited reliability, affordability, and lack of GHG emissions.⁵⁰ Research on nuclear energy is focused primarily on improving basic nuclear technology.

⁴⁸ U.S. Climate Change Technology Program, Research and Current Activities, DOE/PI-0001, <http://www.climatechange.gov/library/2003/currentactivities/index.htm>, November 2003.

⁴⁹ G8 Gleneagles Plan of Action, Climate Change, Clean Energy, and Sustainable Development, <http://www.number-10.gov.uk/output/Page7882.asp>, 2005.

⁵⁰ U.S. Climate Change Technology Program, Research and Current Activities, DOE/PI-0001, <http://www.climatechange.gov/library/2003/currentactivities/index.htm>, November 2003.

In addition to large, centralized power plants, the CCTP emphasizes distributed generation (small, modular energy resources located near where the energy is used). Distributed generation can include traditional energy sources such as gas-fired engines and turbines. NASA Earth science resources may be useful in distributed generation siting issues, although the primary challenges in this area focus on forecasting output from renewable distributed generation for grid integration purposes.

The U.S. Ocean Action Plan highlights the need to manage energy development on the Outer Continental Shelf. Thus, application of NASA resources to the management of Outer Continental Shelf energy resources aligns with this Administration initiative, although the U.S. Ocean Action Plan places added emphasis on renewable rather than traditional sources of energy.

*Potential Application of NASA Earth Science Research: **LOW***

The traditional energy sector has detailed knowledge of the locations and sources of natural resources based on geological surveys and deep sea exploration. Information from NASA resources and models that could contribute to traditional energy exploration and extraction would be limited and incremental. Land type data could contribute to mining, plant, and pipeline siting, but existing datasets from Landsat and aerial photography are generally adequate.

2.3 Developing Energy Sources: Hydrogen and Methane Hydrate Deposits

One of the most promising developments in the energy sector involves the use of hydrogen as an energy carrier. Research in this area focuses on the production, storage, and delivery of hydrogen. This sector also involves the possibility of methane hydrate deposits as a future energy source. Methane hydrate deposits are a stable form of methane that underlies the oceans in coastal trenches and polar permafrost.⁵¹ The volume of carbon contained in methane hydrates worldwide is estimated to be twice the amount contained in all fossil fuels on Earth.⁵²

Potentially Relevant NASA Resources

- Land use information for siting hydrogen distribution networks
- Geologic, ocean, or permafrost data for potential identification and mapping of methane hydrate deposits

⁵¹ University of Waterloo, Daily Bulletin, <http://www.bulletin.uwaterloo.ca/2002/jul/25th.html>, July 25, 2002.

⁵² U.S. Geological Survey, Natural Gas Hydrates- Vast Resource, Uncertain Future, <http://pubs.usgs.gov/fs/fs021-01/fs021-01.pdf>, USGS Fact Sheet FS-021-01, March 2001.

Current Status/Relevant Issues

While steam reforming of natural gas is currently the most common and economical hydrogen production method, hydrogen can also be produced from renewable energy, coal, oil and gas, or nuclear energy. A related issue is the efficient and economic use of hydrogen for stationary and mobile sources, either in fuel cells or directly in internal combustion engines. The G8 Gleneagles Plan of Action includes a statement of support for work on hydrogen by the IEA and International Partnership for the Hydrogen Economy (IPHE).⁵³ Under DOE leadership, the IPHE involves more than a dozen countries advancing cooperative R&D and commercial uses of hydrogen production, storage, transport, and distribution.⁵⁴ NASA Earth science resources may have applicability in transportation and distribution issues, although these issues are likely to be addressed on a long-term timeframe (decades rather than years).

The location of likely methane hydrate deposits worldwide has been determined at least preliminarily through geologic research and methods such as sonar techniques. The USGS Central Energy Team is currently researching the location, characteristics, quantity, quality, and feasibility of gas hydrates.⁵⁵ DOE's Office of Fossil Energy is also involved in methane hydrate research.

<i>Example Projects with NASA Involvement</i>	<i>Decision Support System / Database</i>	<i>Participants</i>
None identified.		

Alignment with Administrative Initiatives

Combustion of methane adds significantly less CO₂ to the atmosphere per output of energy than combustion of either coal or oil, and therefore can be considered to align with CCSP and CCTP objectives. Likewise, hydrogen as an energy carrier can be a carbon-neutral form of energy depending on its production method, and is aligned with CCSP and CCTP objectives. There is no direct link to GEOSS and USGEO.

*Potential Application of NASA Earth Science Research: **LOW***

Depending on the information required, it is possible that NASA Earth science resources could contribute to additional location and mapping of methane hydrate deposits. Discussion with USGS or

⁵³ G8 Gleneagles Plan of Action, Climate Change, Clean Energy, and Sustainable Development, <http://www.number-10.gov.uk/output/Page7882.asp>, 2005.

⁵⁴ CCTP Research and Current Activities, DOE/PI-0001, <http://www.climatechnology.gov/library/2003/currentactivities/index.htm>, November 2003.

⁵⁵ U.S. Geological Survey, Additional Oil and Gas Research, Gas Hydrates, <http://energy.cr.usgs.gov/oilgas/addoilgas/>. Accessed July 21, 2005.

DOE scientists involved in methane hydrate research may reveal some near-term opportunities in this relatively new field.

2.4 Electricity Transmission, Oil and Gas Pipelines, and Solid Fuel Transport

This sector includes transportation and distribution of energy resources such as the bulk transmission of electricity through power lines from power plant to substation, oil and natural gas pipelines to transport liquid fuels, and transportation of coal and other solid fuels via railways.

Potentially Relevant NASA Resources

- Land-use and high-resolution image data for transmission and pipeline siting and monitoring
- Climatological data in support of transmission and pipeline system operations
- Space weather data for transmission line operations

Current Status/Relevant Issues

Of most relevance to NASA's Energy Management Program, current issues for pipeline distribution involve siting, regulatory approval, construction monitoring, and ongoing maintenance and security. There may be a role for NASA Earth science resources to contribute land use and high-resolution image data for pipeline siting and monitoring.

As highlighted by the August 2003 Northeast's electricity blackout, the design and coordinated operation of U.S. and North American electricity transmission grid require continued attention. The siting and regulatory approval of new transmission lines takes years, contributing to pressure on existing transmission lines. Current issues include existing component optimization, new capacity infrastructure, system operations, and planning tools.⁵⁶ Additionally, the effect of severe geomagnetic storms on transmission lines can be considerable, as illustrated by a major transmission line failure in Quebec Canada in 1989.⁵⁷ There may be a role for NASA Earth science resources to contribute to system planning and operations, particularly by helping the private sector improve its decision support systems.

⁵⁶ Public Interest Energy Research Transmission Research and Development Program, <http://ciee.ucop.edu/trp.html>. Accessed July 21, 2005.

⁵⁷ The Vulnerability of the US Electric Power Grid to Space Weather and the Role of Space Weather Forecasting, Prepared Testimony of John G. Kappenman, Metatech Corp. Before the U.S. House Subcommittee on Environment, Technology, and Standards and the Subcommittee Hearing on "What is Space Weather and Who Should Forecast It?" October 30, 2003

As background on system planning and operations, electric utilities formed the North American Electric Reliability Council⁵⁸ (NERC) in 1968 to voluntarily oversee the bulk electric system in North America and ensure that it is reliable, adequate, and secure. NERC consists of ten regional reliability councils and encompasses essentially all the power regions of the contiguous United States, Canada, and Mexico.⁵⁹ There is a potential for NASA Earth science resources to support the decision-making tools of NERC and its members for system operation. However, the tools used by NERC and its members may be developed by outside research organizations such as EPRI and/or DOE national laboratories, and therefore these organizations may be the most appropriate direct partners for NASA.

<i>Example Projects with NASA Involvement</i>	<i>Decision Support System / Database</i>	<i>Participants</i>
None identified.		

Alignment with Administration Initiatives

The GEOSS implementation plan and its companion reference document⁶⁰ mention environmentally responsible and equitable energy management and proactive strategic energy planning, including power and pipeline distribution. Therefore such an application by NASA would support GEOSS objectives. In addition, the GEOSS implementation plan references reduction of risks to energy infrastructure due to weather, climate, water, oceanic, geological, and human threats. Energy distribution and transmission networks cross long distances (including remote areas) and therefore may be particularly vulnerable to such risks. There may be a role for NASA Earth science resources to contribute to risk reduction and event monitoring and response.

There is no strong alignment with CCSP and CCTP goals.

*Potential Application of NASA Earth Science Research: **MEDIUM***

The process of siting and evaluating transmission infrastructure and pipelines is highly data-intensive, particularly for land-use data, but existing datasets from Landsat and aerial photography are generally adequate. Other potential areas of application are assessment and planning related to temperature and solar weather effects on transmission lines.

⁵⁸ North American Electric Reliability Council, <http://www.nerc.com/>. Accessed July 21, 2005.

⁵⁹ Power Marketing Association, Electricity Glossary, <http://www.powermarketers.com/gloss-b.html>. Accessed July 21, 2005.

⁶⁰ Global Earth Observation System of Systems, GEOSS, 10-Year Implementation Plan, Group of Earth Observations, GEO 1000, February 2005.

3.0 ENERGY INTEGRATION, USE, SHORT-TERM FORECASTING, AND OPERATIONS

In order to meet increasing energy needs, Federal and state governments and private industry have enacted policies and developed decision tools to promote integration of renewable distributed generation into the grid, increased energy efficiency, and improved operations. This includes the reduction of energy use and urban heat island effects, accurate load forecasting to optimize supply costs, and responding to disruptive events.

3.1 Distributed Energy Generation and Grid Integration

Distributed generation is small, modular energy resources that are generally located near where the energy is used. Grid integration of distributed generation is the physical connection of a distributed energy resource with the electric power system, an interconnection that generally allows two-way power flow. This section focuses primarily on renewable energy sources.

Potentially Relevant NASA Resources

- Meteorology data, including temperature, cloud cover, and visibility
- Solar radiation
- Wind resources
- Reservoir height and rainfall
- Seasonal climatology models
- General circulation models

Current Status/Relevant Issues

For either renewable or non-renewable distributed energy sources, the challenges in interconnection relate to varying state interconnection requirements and economic disincentives for interconnection. A major issue for the grid integration of renewable distributed energy sources is understanding and forecasting the energy generation output for sources that vary over time such as wind and solar power, and to a lesser extent hydropower. This information is needed for efficient grid operations and also for crafting policies that appropriately credit distributed energy sources for their grid contributions.

NREL has developed a computer model called HOMER that simplifies the task of evaluating design options for both off-grid and grid-connected power systems including distributed generation applications. NASA is indirectly supporting this effort through its partnership with NREL aimed at improving the National Solar Radiation Database.

DOE is also working to develop a modular interconnection technology that can provide reasonably priced interconnection for all distributed generation sources while increasing functionality for energy management and grid support. This work includes the development of advanced control and monitoring technologies and operational concepts to enhance the integration and aggregation of distributed energy resources with electric power systems.⁶¹

<i>Example Projects with NASA Involvement</i>	<i>Decision Support System / Database</i>	<i>Participants</i>
None identified.		

Alignment with Administration Initiatives

The CCTP emphasizes distributed generation. In addition, as noted earlier, the advancement of renewable energy aligns with CCSP, CCTP, and GEOSS.

*Potential Application of NASA Earth Science Research: **MEDIUM***

NASA Earth science can help energy planners in the medium-term with predicting the output and timing from renewable distributed energy resources, ultimately supporting efficient grid operations and integration. The potential areas of focus should include solar and wind power and hydropower. NASA should consider building off its relationship with NREL to further explore this area.

3.2 Energy Efficiency

Energy efficiency is defined as “products or systems using less energy to do the same or better job than conventional products or systems. Energy efficiency saves energy, saves money on utility bills, and helps protect the environment by reducing the amount of electricity that needs to be generated.”⁶²

⁶¹ Department of Energy, Energy Efficiency and Renewable Energy, Integration Technology Development, http://www.eere.energy.gov/de/integration_tech_dev.html. Accessed August 18, 2005.

⁶² Glossary of Green Power Terms, EPA Green Power Partnership, U.S. Environmental Protection Agency, <http://www.epa.gov/greenpower/whatis/glossary.htm>. Accessed July 27, 2005.

Potentially Relevant NASA Resources

- Solar radiation and angle
- Meteorology and climatology data, specifically wind resources, cloud cover, and aerosols,
- Thermal infrared radiation

Current Status/Relevant Issues:

Energy efficiency is considered a best management practice for both industry and consumers, and is promoted by the EPA, DOE, local and regional electric utilities, and other environmental and energy organizations. Energy efficiency can be applied to buildings, consumer products, industrial operations, transportation, and almost any sector that uses energy.

For energy efficiency applications, NASA data and resources are most relevant for the design and operation of energy efficient buildings. This would include incorporation of passive and active solar systems, location and direction, and architectural design features. The design and construction of energy efficient buildings has become increasingly popular due to efforts to reduce heating and ventilation costs of operation for homes and office structures. For example, organizations such as the U.S. Green Building Council⁶³ have developed the Leadership in Energy and Environmental Design (LEED) Green Building Rating System®, a voluntary national standard for developing high-performance, sustainable buildings. Energy is a major component of LEED, including energy efficiency and green power. NASA is pursuing a partnership with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) to develop prototypes to provide solar radiation data for application in some aspects of building design. Expanded application of NASA solar radiation, solar angle, and meteorology data, in an applicable format or model, could help architects designing buildings to optimize the building direction and add architectural features to reduce heating and air conditioning costs.

<i>Example Projects with NASA Involvement</i>	<i>Decision Support System / Database</i>	<i>Participants</i>
POWER	Surface meteorology and Solar Energy for the National Solar Radiation Database ⁶⁴	NREL, DOE, ASHRAE

⁶³ U.S. Green Building Council, <http://www.usgbc.org/>. Accessed 1 August 2005.

⁶⁴ Surface Meteorology and Solar Energy database, Release 5.1, <http://eosweb.larc.nasa.gov/sse/>. Accessed July 27, 2005.

Alignment with Administration Initiatives

Energy efficiency is covered in general under the GEOSS societal benefit area to monitor and manage energy resources and has relevance to the GEOSS 10-year implementation plan and supporting documents, specifically environmentally responsible management of facility operations and lighting/heating/cooling.^{65,66} New application of NASA resources to the advancement of energy efficiency aligns with the goals of GEOSS, especially if relevant datasets and models were developed.

Since energy efficiency typically reduces dependence on carbon-based sources of energy, the advancement of energy efficiency also aligns in general with CCSP and CCTP.

*Potential Application of NASA Earth Science Research: **MEDIUM/HIGH***

The NASA information needed by the building design community is largely available through the Surface meteorology and Solar Energy database. The database is widely used by many ASHRAE members for building design. One benefit of the use of NASA data is its global coverage which makes it applicable for building designs outside the U.S., particularly in regions where local data is not readily available. Another benefit of the NASA data is the time-series available, which is needed by building modelers to model buildings in the long-term. Pursuit of additional partnerships with organizations such as ASHRAE and the U.S. Green Building Council to develop datasets with specific application to decision support systems used by architects and building operators would be a relatively simple extension of existing data to a growing application area.

3.3 Urban Heat Island

An urban heat island is the effect that occurs on warm summer days in which the air in urban areas is up to 10°F hotter than the air in its surrounding areas.⁶⁷ Causes of the heat island effect include dark surfaces that absorb more heat from the sun and less vegetation that would provide shade and cool the air.⁶⁸ The higher temperatures in urban heat islands increase air conditioning use and associated energy consumption, and raise pollution levels and heat-related illnesses and mortality.

⁶⁵ Global Earth Observation System of Systems, GEOSS, 10-Year Implementation Plan, Group of Earth Observations, GEO 1000, February 2005.

⁶⁶ Global Earth Observation System of Systems, GEOSS, 10-Year Implementation Plan Reference Document, Group of Earth Observations, GEO 1000R, February 2005.

⁶⁷ U.S. Environmental Protection Agency, Global Warming- Heat Island, <http://yosemite.epa.gov/oar/globalwarming.nsf/content/ActionsLocalHeatIslandEffect.html>. Accessed July 21, 2005.

⁶⁸ Lawrence Berkeley National Laboratory, Heat Island Group, Learning About Urban Heat Islands, <http://eetd.lbl.gov/HeatIsland/LEARN/>. Accessed July 21, 2005.

Potentially Relevant NASA Resources

- Land use, weather, climatological, and air pollution data to help quantify and plan for mitigation of urban heat islands

Current Status/Relevant Issues

A number of studies and research groups on urban heat islands began in the 1990s, and research in this area is ongoing. A 1992 collaborative NOAA study⁶⁹ was conducted to examine urban–rural differences and correlation between a vegetation index and minimum surface temperatures, using Advanced Very High Resolution Radiometer (AVHRR) data. The study authors concluded, “The use of satellite data may contribute to a globally consistent method for analysis of urban heat island bias.”

In 1996, NASA researchers conducted a study entitled “High Spatial Resolution Airborne Multispectral Thermal Infrared Data to Support Analysis and Modeling Tasks in EOS [Earth Observation System] Interdisciplinary Science (IDS) Project ATLANTA.”⁷⁰ This study observed, measured, modeled, and analyzed how the rapid growth of the Atlanta, Georgia, metropolitan area since the early 1970s impacted the region's climate and air quality. The approach was to relate land cover changes with modifications in the local and regional climate and in air quality, predicated on the analysis of remote sensing data in conjunction with in-situ data (e.g., meteorological measurements) employed to initialize local and regional-level numerical models of land-atmosphere interactions. The study authors noted that high-resolution Advanced Thermal and Land Applications Sensor (ATLAS) data offer a unique opportunity to measure, analyze, and model the state and dynamics of thermal energy responses across the Atlanta metropolitan landscape.

In 1997, as part of the Urban Heat Island Pilot Project, DOE’s Lawrence Berkeley National Laboratory analyzed the energy savings potential of heat island reduction measures in three metropolitan areas. Annual energy savings in the three metropolitan areas ranged from \$4 to 15 million (1997 dollars). Results suggested that implementing reduction measures would also result in significant peak power avoidance and a reduction in annual CO₂ emissions. For every 1°F increase in summertime temperature,

⁶⁹ Gallo, K.P., A.L. McNab, T.R. Karl, J.F. Brown, J.J. Hood, and J.D. Tarpley, The Use of NOAA AVHRR Data for Assessment of the Urban Heat Island Effect, *Journal of Applied Meteorology*, Vol. 32, pp. 899–908, 1993.

⁷⁰ Dale A. Quattrochi, NASA, Global Hydrology and Climate Center, Jeffrey C. Luvall, NASA, Global Hydrology and Climate Center, High Spatial Resolution Airborne Multispectral Thermal Infrared Data to Support Analysis and Modeling Tasks in EOS IDS Project ATLANTA, <http://www.ghcc.msfc.nasa.gov/atlanta/>, 1996.

peak utility loads in medium and large cities increase by an estimated 1.5 to 2.0 percent.⁷¹ Therefore, understanding and minimizing urban heat island effects also supports GEOSS and CCTP objectives.

In terms of decision support tools, the International Council on Local Environmental Initiatives, through a cooperative agreement with the Heat Island Reduction Initiative, has been developing and distributing information to local governments on heat island reduction strategies.⁷²

<i>Example Projects with NASA Involvement</i>	<i>Decision Support System / Database</i>	<i>Participants</i>
ATLANTA	High Spatial Resolution Airborne Multispectral Thermal Infrared Data to Support Analysis and Modeling Tasks	NASA Global Hydrology and Climate Center

Alignment with Administration Initiatives

There is no clear link to the GEOSS goals, although in general this could fit under the societal goal of improving management of energy resources. There is also no clear link to CCSP/CCTP goals, although an increased urban heat island effect would increase the emissions of GHG and could influence overall Earth surface heating patterns.

*Potential Application of NASA Earth Science Research: **MEDIUM***

Satellite data and other NASA aircraft data have already been applied to this issue, and have been found to be useful. Additional possibilities likely exist to support decision-makers in understanding and mitigating urban heat islands. However, the focus of urban heat island research and decisions is more on land use and air quality than energy, since increased energy use is more a result than a contributing factor to urban heat islands.

3.4 Supply and Load Forecasting

The energy sector uses near-term (1 hour to 2 weeks) and medium-term (monthly and seasonal) load forecasting models to adjust electricity generation to meet demand and to optimize generation and purchase of lower cost power sources. Load forecasting tools use inputs such as existing and historical

⁷¹ U.S. EPA, Heat Island Effect, Energy Savings, <http://www.epa.gov/heatisland/about/energysavings.html>. Accessed July 21, 2005.

⁷² U.S. EPA, Heat Island Effect, Research, <http://www.epa.gov/heatisland/research/index.html>. Accessed July 21, 2005.

loads, meteorological data including real-time and weather forecast data, economic data such as the cost of energy, and available energy sources.

Potentially Relevant NASA Resources

- Meteorology data, including temperature, cloud cover, and visibility
- Solar radiation
- Wind resources
- Reservoir height and rainfall
- Seasonal climatology models

Current Status/Relevant Issues:

Several basic load models exist, one of the most common types being artificial neural network models, which use historical loads and predicted temperature. Statistical regression models are also used to estimate load. Statistical economic models are used in conjunction with load forecasting models, although they are more difficult to predict than load.⁷³ Supply and load forecasting models have also been developed for specific types of energy, such as wind power, that incorporate relevant resource parameters.⁷⁴

A variety of nonprofit organizations and private companies have developed load forecasting software marketed to the energy industry. For example, the Electric Power Research Institute (EPRI) has developed the Artificial Neural Network Short-Term Load Forecaster, which forecasts hourly system loads from 1 hour to 35 days ahead with errors less than 3%.⁷⁵ NASA's contribution would be greater in medium-term forecasting, since NOAA as an operational agency provides the real-time data needed for short-term forecasting. NASA is establishing a partnership with EPRI focused on the possibility of integrating NASA data and models into EPRI's load forecasting decision support systems.⁷⁶

⁷³ Smith, M., Electricity Load and Price Forecasting Using Statistical Methods and Models, Second Moment, <http://www.secondmoment.org/articles/electricity.php>. Accessed August 2, 2005.

⁷⁴ Neural Network-Based Forecasting for Wind Generation, Strategic Science and Technology, EPRI, September 2003.

⁷⁵ Artificial Neural Network Short-Term Load Forecaster (ANNSTLF), Fact Sheet, EPRI, Available at <http://www.epriweb.com/public/000000000001011532.pdf>. Accessed August 2, 2005.

⁷⁶ Energy Management Program Element Plan: 2004-2008, Earth Science for Energy Management, Earth Science Applications Program, NASA Earth Science Enterprise, v. 4.5, 11 March 2005.

<i>Example Projects with NASA Involvement</i>	<i>Decision Support System / Database</i>	<i>Participants</i>
Energy Load Forecasting (in development)	Neural Net Load Forecast Tools and other Forecasting tools for Energy industry	EPRI, NOAA

Alignment with Administration Initiatives

Improved load forecasting assists in the GEOSS societal benefit to improve management of energy resources, specifically better energy planning. If models were revised so the emphasis incorporated more focus on renewables, supply and load forecasting could enable better matching of energy supply and demand in a sound, equitable, sustainable, and environmentally responsible manner that balances economic, social, and environmental agendas. Integration into load forecasting was recommended as an initiative in the GEOSS energy management technical reference document.⁷⁷

There is no clear link between short- to medium-term energy load forecasting and CCSP and CCTP.

Potential Application of NASA Earth Science Research: HIGH

Short- to medium-term load forecasting is typically a software-based decision support tool that requires numerous near-real time inputs for decision-making. NASA weather and energy resource data could be integrated relatively easily, provided that specific products were developed and available on a timely basis that could be applied to forecasting models. Given NASA's role as a research, not operational, agency, NASA's role would be to help develop the products to be tested in load forecasting decision support systems, which would then be taken over by operational datasets from NOAA and organizations that develop models for the energy industry such as EPRI.

3.5 Event Response

The operation of energy extraction facilities and the provision of electricity can be negatively impacted by natural and human-caused events, such as hurricanes, violent storms, heat waves, blizzards, wildfires, and regional power outages. The energy sector plans for and responds to these events to minimize power disruptions.

⁷⁷ Monitoring and Managing Energy Resources Technical Reference Document, November 8, 2004. Available at http://iwgeo.ssc.nasa.gov/docs/review/Energy_Technical.pdf.

Potentially Relevant NASA Resources

- Meteorological information, real-time and forecast, specifically those unique to NASA such as Tropical Rainfall Measuring Mission (TRMM)
- Wildfire extent and locations

Current Status/Relevant Issues

The energy sector currently uses meteorological information for operations planning, such as the evacuation of oil rigs in advance of hurricanes, issuance of requests for peak loading conservation during heat waves and periods of extreme cold, and planning response to power outages due to storms. All parts of the energy sector use weather data for event planning and response, although there is evidence that their application of these data could be increased, especially for longer-term forecasting.⁷⁸ Better weather forecasting has significantly improved the ability of utilities and power producers to plan for, predict, and respond to major weather events. However, storms and major events still have a significant effect on utility operations costs. For example, Duke Energy estimates a minimum of \$750,000 annually in lost revenue from storms, and major event (ice storms, hurricanes, tornados) costs range from \$1 to \$64 million.⁷⁹

<i>Example Projects with NASA Involvement</i>	<i>Decision Support System / Database</i>	<i>Participants</i>
None identified.		

Alignment with Administration Initiatives

GEOSS has several societal benefit areas related to event response by the energy sector, specifically improved weather forecasting, reduction of loss of property from disasters, and managing energy resources. USGEO has as a near-term opportunity improved observations for disaster warnings, which would assist with major but not more localized events. The 10-year plan specifically mentions reduction of risk to energy infrastructure due to weather-related threats as a benefit of GEOSS.

While changes in climate patterns may increase storm frequency and intensity, there is no clear link of event response to the goals of CCSP and CCTP.

⁷⁸ Altalo, M., M. Mondshine, J. Finsen, J. Doherty, C. Mahoney, and W. Keene, Defining the Requirements of the U.S. Energy Industry for Climate, Weather, and Ocean Information, Technical Report by the Science Applications International Corporation submitted to The Office of Oceanic and Atmospheric Research, The National Oceanic and Atmospheric Administration, July 2000. Available at http://www.saic.com/weather/pdf/Defining_Energy_Industry_Requirements.pdf.

⁷⁹ Findings and Recommendations to Enhance Reliability from the Summer of 1999. Report of the U.S. Department of Energy's Power Outage Study Team. U.S. Department of Energy. Final Report, March 2000.

*Potential Application of NASA Earth Science Research: **LOW***

While NASA resources may be applicable in some events, most of the needs for event planning and response would be part of NOAA's current operations. Additionally, initiatives under the NASA Disaster Management Program Element⁸⁰ would be relevant to planning and response for the energy sector. For example, NASA efforts in wildfire monitoring⁸¹ would be potentially useful in cases where fires could potentially affect facilities or transmission lines.

⁸⁰ NASA Science Mission Directorate, Earth-Sun System Applied Sciences Program, Disaster Management Program Element, FY2005-2009 Plan, v.1.1, March 16, 2005.

⁸¹ NASA Wildfire Response Team, <http://geo.arc.nasa.gov/sge/WRT/>. Accessed July 27, 2005.

4.0 EMISSIONS MONITORING AND MITIGATION

As one of the major industrial sectors in the world, the energy sector impacts the environment through atmospheric emissions (air pollution and GHGs), solid waste, and wastewater. In addition to prevention and monitoring of these emissions, researchers have been investigating innovative technologies such as carbon sequestration. All of these issues cross over with other NASA program areas, but those with relevance to the energy sector are described briefly in this section.

4.1 Atmospheric Emissions

Atmospheric emissions include air pollutants (e.g., SO₂, CO, fine particulates, hazardous air pollutants) and GHGs (e.g., CO₂). For the energy sector, sources can be from industrial power plants and from end uses such as transportation.

Potentially Relevant NASA Resources

- Aerosol optical depth, CO, and other air quality parameters from EOS sensors
- Global Ozone Chemistry Aerosol Radiation Transport (GOCART) model

Current Status/Relevant Issues

The energy sector is a major contributor to air pollution, both criteria pollutants (e.g., SO₂, CO, fine particulates) and GHGs (e.g., CO₂). For example, electric utilities generate 67% of SO₂⁸² and 22% of NO_x⁸³ emissions in the U.S., which also contribute to acid precipitation and fine particulates. Generating electricity is the single largest source (39%) of CO₂ emissions in the U.S.⁸⁴ Air pollution continues to be an important issue for the energy sector, especially related to recent EPA regulations.⁸⁵

The NASA Air Quality Application Program is actively working to support projects to integrate the use of NASA data and models into air quality decision support systems, primarily related to regulatory policy and event and fire monitoring. The ability to monitor regional-scale air pollution using

⁸² SO₂ - How Sulfur Dioxide Affects the Way We Live & Breathe, U.S. Environmental Protection Agency, <http://www.epa.gov/air/urbanair/so2/index.html>. Accessed July 28, 2005.

⁸³ NO_x - How Nitrogen Oxides Affect the Way We Live and Breathe, U.S. Environmental Protection Agency, <http://www.epa.gov/air/urbanair/nox/index.html>. Accessed July 28, 2005.

⁸⁴ Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003, EPA 430-R-05-003, U.S. Environmental Protection Agency, April 2005.

⁸⁵ For example, Clean Air Interstate Rule (70 FR 25162).

remote sensing has been proven⁸⁶ and is being actively promoted by the NASA Air Quality Application Program. However, it is not currently possible to use NASA remote sensing data and models to monitor individual emission sources or to extract the contribution of the energy sector to large-scale air pollution events. The integration of NASA and non-NASA datasets into air quality models may enable this, but this is largely outside the scope of the Energy Management Program Element, and is covered by the scope of the Air Quality Application Program Element.

<i>Example Projects with NASA Involvement</i>	<i>Decision Support System / Database</i>	<i>Participants</i>
3-D Air Quality System	EPA Air Quality System	EPA, University of Maryland Baltimore County, Battelle

Alignment with Administration Initiatives

Air quality is closely aligned with USGEO as it is one of the six near-term opportunities. Air quality initiatives under USGEO are quite advanced, particularly under the leadership of EPA, NOAA, and NASA. Under the energy management component, atmospheric emissions, including ozone, GHGs, black carbon, and aerosols, are specifically mentioned as important.

CCSP and CCTP are concerned with atmospheric emissions of GHG and also emissions of aerosols that may alter the climate system. As a major contributor to both types of atmospheric emissions, the energy sector falls clearly under CCTP’s goals to reduce emissions from energy supply and from energy end use and infrastructure.

*Potential Application of NASA Earth Science Research: **LOW***

While the potential for use of NASA resources for monitoring air pollution on a regional or global scale is high, the direct application to energy management is relatively low. This is due to the inability to monitor atmospheric emissions from single sources or sectors.

4.2 Waste and Water

This sector involves the monitoring and mitigation of solid wastes and water pollution associated with energy management activities. Solid wastes can include coal mine waste, oil and gas drilling muds, power plant ash, and other exploration, production, and processing wastes. Water pollution issues range

⁸⁶ For example, Engel-Cox, J., R. Hoff, and A. Haymet, Recommendations on the use of satellite remote-sensing data for urban air quality, Journal of Air and Waste Management, Volume 54, Number 11, pp. 1360-1371, November 2004.

from thermal pollution associated with power plants to energy resource exploration, production, processing, and transportation water discharges. This sector also encompasses renewable energy issues such as increased erosion and runoff associated with land disturbances for solar or wind power.

Potentially Relevant NASA Resources

- High-resolution land-use images may help monitor waste and water discharges
- Ocean, climate, and weather information may help planning and response to oil spills
- Real-time, high-resolution information on surface water body characteristics can help monitor thermal discharges or other pollutant discharges, e.g., from oil production platforms

Current Status/Relevant Issues

Management of waste and wastewater for the energy sector tends to be on a plant/facility scale, such as slag piles at coal-fired power plants or cooling water discharge into a river. Monitoring and modeling at this fine spatial resolution is not generally optimal for NASA resources. High-resolution land use data, such as managed by USGS, may be a more appropriate resource for waste monitoring.

EPA and NASA Stennis conducted a pilot project to monitor thermal effluent from power plants using Landsat with only limited success, particularly because the spatial resolution was coarse enough that the data pixels averaged in parts of the shoreline with the discharge plume.⁸⁷ The study recommended that higher resolution data (1 meter or less) would provide better monitoring capability. Other studies have used Landsat to monitor thermal plumes at a subpixel level⁸⁸ and there is an interest in understanding and monitoring the effects of cooling water discharge on water ecosystems.

Oil spill tracking and response have been successfully assisted by satellite-based remote sensing data,⁸⁹ but these activities require finer spatial and temporal resolution than available on most NASA sensors.

⁸⁷ Creation of Guidance for Assessment of Thermal Mixing Zones Associated with Power Plants, Applied Sciences Directorate, John C. Stennis Space Center, NASA, <http://www.esad.ssc.nasa.gov/project.aspx?GID=2372&b=app&app=water>. Accessed August 2, 2005.

⁸⁸ Gibbons, D.E., G.E. Wukelic, J.P. Leighton, and M.J. Doyle, Application of Landsat Thematic Mapper data for coastal thermal plume analysis at Diablo Canyon, Photogrammetric Engineering and Remote Sensing, Vol. 55, 1989.

⁸⁹ Envisat's ASAR reveals extent of massive oil spill off Spanish coast, ESA News, European Space Agency, http://www.esa.int/esaCP/ESAGFD7708D_index_0.html, November 20, 2002.

<i>Example Projects with NASA Involvement</i>	<i>Decision Support System / Database</i>	<i>Participants</i>
Guidance for Assessment of Thermal Mixing Zones Associated with Power Plants	CORnell MIXing zone expert system (CORMEX) model	EPA Region 7

Alignment with Administration Initiatives

Waste and wastewater issues link in general to GEOSS goals related to protecting ocean resources and protecting water resources. There is no link to goals under CCSP and CCTP.

*Potential Application of NASA Earth Science Research: **MEDIUM***

Prior work on thermal plumes and monitoring of oil spills with satellite remote sensing data indicates that there is potential for better application of NASA resources in monitoring wastewater and water pollution from the energy sector. Both thermal plume and oil spill monitoring require higher spatial resolution data and models to be effective. Thus, further sensor development, partnerships with private industry, and/or model and algorithm development would be required to advance this area.

4.3 Carbon Sequestration

Carbon sequestration is “the capture and secure storage of carbon that would otherwise be emitted to or remain in the atmosphere.”⁹⁰ Carbon sequestration includes ocean sequestration, sequestration by terrestrial ecosystems (soils and vegetation), and injection in geological formations.

Potentially Relevant NASA Resources

- Terrestrial biomass quantity, location, and change, including agriculture and forest lands
- Carbonaceous gases and aerosols
- Marine productivity, such as chlorophyll concentrations

Current Status/Relevant Issues

Carbon sequestration is considered a promising means to mitigate the emissions of carbon from major industrial processes, including the energy sector. DOE, USDA, and other organization are actively pursuing carbon sequestration as a means to address climate change. Of the three major types of carbon sequestration, sequestration by terrestrial ecosystems has the greatest potential for application of NASA data and models.

⁹⁰ Carbon Sequestration Research and Development, Office of Science and Office of Fossil Energy, U.S. Department of Energy, December 1999.

Currently, the NASA Carbon Management Program Element has promoted several projects and partnerships on carbon management. The energy sector is related since it is one the largest generators of CO₂ and other GHGs.

<i>Example Projects with NASA Involvement</i>	<i>Decision Support System / Database</i>	<i>Participants</i>
Development of guidelines for a voluntary program for sequestration of carbon in biomass and soils under the Energy Policy Act of 1992 (EPACT)	-	USDA, DOE, EPA
NASA-CASA Project	CASA Carbon Query and Evaluation Support Tools (CASA CQUEST) ⁹¹	U.S. Forest Service (USFS)
Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) ⁹²	Reflectance and disturbance products	USFS

Alignment with Administration Initiatives

GEOSS societal benefit areas include the mitigation of emissions that contribute to climate change. However, carbon sequestration is more closely tied to the goals of CCSP, which lists new carbon sequestration technologies as one of its key research needs, and CCTP, which has capturing and sequestering CO₂ as one of its five research initiatives.

*Potential Application of NASA Earth Science Research: **MEDIUM***

The NASA Carbon Management Program Element has promoted projects related to carbon sequestration in partnership with other government agencies. While it is a key area for the energy sector in terms of response to carbon emission mitigation, carbon management solutions are generalized and not specific to the energy sector.

⁹¹ NASA-CASA Project, CASA-CQUEST Viewer, <http://geo.arc.nasa.gov/sge/casa/cquest.html>. Accessed August 1, 2005.

⁹² Landsat Ecosystem Disturbance Adaptive Processing System, http://ledaps.nascom.nasa.gov/ledaps/ledaps_NorthAmerica.html. Accessed August 1, 2005.

5.0 LONG-TERM PLANNING AND THREATS

The development of new energy sources—ranging from new oil fields to advanced solar cells to power plant construction—takes decades. Thus, the energy sector forecasts long-term growth of the energy market in order to plan the development of new energy sources and technologies. Additionally, long-term threats or shifts in the environment and in economic markets factor strongly in considerations of the development of new power sources. In addition to long-term energy modeling and forecasting, this section focuses on two potential threat areas: impact of sea level rise on energy infrastructure and other effects of global climate change.

5.1 Long-Term Energy Modeling and Forecasting

The energy sector uses long-term (1 to 20 years) energy forecasting to plan for and develop electricity generation to meet long-term demand. Long-term forecasting includes everything from planning by utilities for expanding production over a 1- to 10-year period to long-term scenario analysis useful for setting regional and national energy policy. Long-term energy forecasting and scenario models use inputs such as historical and projected loads, average meteorological and climate data, available energy sources, resource availability, environmental impacts, and economic data. In other cases, individual models are linked or reconciled in an integrated assessment model that brings together a broader set of areas, methods, styles of study, or degrees of certainty, than would typically characterize a study of the same issue within the bounds of a single research discipline.

Potentially Relevant NASA Resources

- Meteorology data
- Climate models
- Renewable energy resources, such as solar radiation and wind sources, and expected changes to those resources due to long-term climate changes

Current Status/Relevant Issues

With climate change uncertainty and rapidly growing energy needs, the need for better and relevant data for long-term energy models is significant. A variety of government, non-profit organizations, and private companies conduct long-term energy forecasting to meet their own or support others' specific decision-making needs. For example, the Energy Information Administration (EIA), an

independent agency within DOE, designed and implements the National Energy Modeling System (NEMS).⁹³ This computer-based, energy-economy modeling system of U.S. energy markets for the midterm period through 2025 is used by EIA to project the energy, economic, environmental, and security impacts on the U.S. of alternative energy policies and different assumptions about energy markets. The model relies on input data such as economic information but does not (and cannot in the current model) incorporate direct and future environmental data. For example, the NEMS model does not have a relationship between load and temperature, and thus cannot use such data as long-term temperature and atmospheric changes as an input. In addition, EIA's System for Analysis of Global Energy Markets (SAGE) is an integrated set of regional models that provides a technology-rich basis for estimating regional energy supply and demand.⁹⁴

As another example, the IEA Energy Technology Systems Analysis Programme developed the MARKAL generic model as part of a cooperative multinational project. This model is tailored by the input data to represent 40 to 50 years of a specific energy system at the national, regional, state or province, or community level.⁹⁵ The MARKAL model has been used to perform analyses in support of national emission inventory and abatement studies, such as providing input for national communications in the United Nations Framework Convention on Climate Change process.

Two related examples of integrated assessment models are DOE/ Pacific Northwest National Laboratory's (PNNL) MiniCAM (Mini Climate Assessment Model) and SGM (Second Generation Model), under parallel development. The energy component of the MiniCAM is based on the Edmonds-Reilly-Barns (ERB) energy model. Additional model components include an agriculture and land-use model (AgLU), and the Model for the Assessment of Greenhouse-Gas Induced Climate Change (MAGICC) global climate model. The MiniCAM has been used for a wide range of studies of strategies to stabilize atmospheric concentrations, focusing on the role of technologies. The SGM is one of several process-based models that are used for focused studies. The SGM is a computable general equilibrium model with explicit energy technology detail and technology-capital-stock vintaging that is used for analysis of climate policies over the next several decades. Another model used at PNNL is EPIC (Environmental Policy Integrated Climate), which is a process-based model of agricultural systems. Key

⁹³ Energy Information Administration, The National Energy Modeling System: An Overview 2003, <http://www.eia.doe.gov/oiaf/aeo/overview/index.html>. Accessed August 1, 2005.

⁹⁴ Energy Information Administration, Annual Energy Outlook 2005, <http://www.eia.doe.gov/oiaf/aeo/issues.html>. Accessed August 4, 2005.

⁹⁵ Energy Technology Systems Analysis Programme, Annex III: Exploring Energy Technology Perspectives, MARKAL, <http://www.etsap.org/markal/main.html>. Accessed August 4, 2005.

systems in EPIC such as soil carbon-dynamics have been developed at PNNL in collaboration with Texas A&M University.

Both the MiniCAM and SGM have been implemented in the ObjECTS framework, a new flexible, object-oriented model implementation framework, which can incorporate data derived from satellite datasets. Preliminary work to incorporate NASA wind and solar data, at least in a simple manner, is underway. NASA has also funded a project at the PNNL Joint Global Change Research Institute (JGCRI) to incorporate NASA data into the carbon-cycle component of the ObjECTS framework. This project began in 2005 and is ongoing. A second NASA-PNNL project relates to long-term energy modeling focused on climate change.

<i>Example Projects with NASA Involvement</i>	<i>Decision Support System / Database</i>	<i>Participants</i>
Projections of Land-Use Change and the Carbon-Cycle	ObjECTS MiniCAM	PNNL (JGCRI), University of Maryland, Pennsylvania State University, University of Illinois
Energy Efficiency Renewable Energy (EERE)/Global Energy Technology Strategy Program (GTSP) Renewable Energy Technology Analysis	ObjECTS MiniCAM	PNNL (JGCRI)

Alignment with Administration Initiatives

Improved long-term forecasting assists in the GEOSS societal benefit to improve management of energy resources, specifically better energy planning, adaptation to climate variability, and reduction of risk to energy infrastructure due to climate change.

Activities under CCSP and CCTP will increase understanding of the potential effects of climate change and help assess vulnerability at regional and local scales. Better long-term planning by the energy sector can help feed into long-term modeling of carbon emissions and future energy sources, important for CCSP and CCTP goals.

*Potential Application of NASA Earth Science Research: **HIGH***

Long-term energy modeling could benefit from an understanding of long-term climate and meteorological changes affecting the entirety of the energy sector. NASA’s leadership in the development of models and integration of datasets in these areas makes NASA a potentially important source of information for long-term forecasting. NASA’s role as a research agency more closely aligns

with long-term forecasting and model development, compared to the more operational nature of short-term load forecasting. The NASA Energy Management Program Element plans to re-initiate discussions with EIA regarding use of NASA products in the NEMS modules such as the Renewable Fuels Module, although NASA involvement may need to be with upstream partners who are working to modify and improve energy market models in order to incorporate long-term environmental change.

5.2 Impact of Sea-Level Rise on Energy Infrastructure

This sector involves identification and potential mitigation of the impact of sea-level rise associated with global climate change on energy resources.

Potentially Relevant NASA Resources

- Climate change and sea-level rise data and models

Current Status/Relevant Issues

The Intergovernmental Panel on Climate Change (IPCC) estimates that between 1990 and 2100, global average sea level may rise between 3.5 to 35 inches as a result of climate change.⁹⁶ An increase in sea level could be destructive to low-lying coastal structures worldwide, including those associated with energy production, processing, and generation. An IPCC report⁹⁷ notes that some energy production and distribution systems may experience adverse impacts that would reduce supplies or system reliability while other energy systems may benefit. Climate change and sea-level rise would have “serious consequences” on infrastructure facilities including energy facilities in both developing and developed countries.⁹⁸ This issue aligns with the Human Dimensions of Global Change USGCRP Program Element, and specifically the research question on the effects of sea-level rise on resource management including energy supplies.

Considerable attention has been paid to modeling and mapping sea-level rise. For example, USGS is currently conducting a multi-year study on coastal change and the associated hazards in the

⁹⁶ California Energy Commission, Public Interest Energy Research, Climate Change and Sea Level Rise: The Economic Impacts on Coastal Structures in California, http://www.energy.ca.gov/pier/environmental/project_fact_sheets/500-97-043-b.html. Accessed 25 July 2005.

⁹⁷ Intergovernmental Panel on Climate Change, Climate Change 2001: Impacts, Adaptation and Vulnerability, Chapter 3.6. Human Settlements, Energy, and Industry, <http://www.ipcc.ch/pub/taroldest/wg2/016.htm>. Accessed July 25, 2005.

⁹⁸ Intergovernmental Panel on Climate Change, Climate Change 2001: Impacts, Adaptation and Vulnerability, Chapter 6.5.3 Impacts on Coastal Infrastructure, http://www.grida.no/climate/ipcc_tar/wg2/298.htm#652. Accessed July 25, 2005.

U.S.⁹⁹ Also, the University of Arizona, Department of Geosciences, Environmental Studies Laboratory has modeled sea-level rise associated with climate change and produced maps of susceptible areas.¹⁰⁰ In addition, studies have been conducted analyzing the economic impact of sea-level rise in the U.S.,¹⁰¹ and other studies have compiled the locations of power plants worldwide (e.g., the World Electric Power Plants Database¹⁰² includes records for more than 119,500 generating units in over 220 countries and territories). However, studies or decision-support tools that link all of this information together, either through identifying specific energy facilities that may be at risk or addressing future energy facility siting issues to mitigate sea-level rise impacts, appear to be lacking. The U.S. Department of the Interior Minerals Management Service addresses sea-level rise from the perspective of coastal erosion and sand and gravel resources for beach nourishment, but does not focus on impacts to energy infrastructure.

<i>Example Projects with NASA Involvement</i>	<i>Decision Support System / Database</i>	<i>Participants</i>
None identified (the projects cited above do not appear to use NASA data sets)		

Alignment with Administration Initiatives

Sea-level rise is strongly linked to GEOSS goals on energy, disasters, and climate, specifically reduction of risk to energy infrastructure due to climate and oceanic threats. USGEO identifies a sea-level observation system as a near-term opportunity.

CCSP is particularly concerned with adaptation of human activities to climate-related effects such as sea-level rise. CCTP seeks to inform long-term technology planning through scenario analysis to help industry adapt to changes. Thus, sea-level rise and its impact on the energy sector are closely related to CCSP and CCTP goals.

⁹⁹ U.S. Geological Survey, National Assessment of Coastal Change Hazards, <http://coastal.er.usgs.gov/national-assessment/index.html>. Accessed July 25, 2005.

¹⁰⁰ University of Arizona Department of Geosciences Environmental Studies Laboratory, http://www.geo.arizona.edu/dgesl/research/other/climate_change_and_sea_level/sea_level_rise/sea_level_rise.htm. Accessed July 25, 2005.

¹⁰¹ Intergovernmental Panel on Climate Change, Climate Change 2001: Working Group II: Impacts, Adaptation and Vulnerability, 6.5.2 Economic Costs of Sea-Level Rise, http://www.grida.no/climate/ipcc_tar/wg2/298.htm. Accessed July 25, 2005.

¹⁰² McGraw Hill Companies, Platts, Aisle 11: UDI Directories and Databases, World Electric Power Plants Database. Accessed July 26, 2005.

*Potential Application of NASA Earth Science Research: **MEDIUM***

While NASA data and models may contribute to evaluating and quantifying sea-level rise, evaluating and mitigating impacts on current or future energy facilities requires a combination of sea-level rise data with local socioeconomic data and regulatory and policy analysis and action. Collaborative research with a partner with GIS information on coastal regions, such as USGS, may provide an opportunity for NASA Earth science resources to contribute in this area, although existing or developing decision-support tools would need to be identified.

5.3 Impacts of Climate Change on Energy Sector

Climate change refers to long-term changes in the Earth's climate at global and regional scales, such as the average rise in surface temperature known as global warming. The United Nations Framework Convention on Climate Change defines climate change as having human causation due to the increase of emissions of GHGs from human activity.¹⁰³ In addition to having human causes, climate change will impact humans through a variety of ways including impacts on the energy sector.

Potentially Relevant NASA Resources

- General circulation models and other climate models

Current Status/Relevant Issues

Changes in long-term weather patterns could have an impact on the energy sector. Possible effects include:

- Increased storm frequency and intensity that could lead to increased disruptions in power production and transmission
- Sea-level rise that could impact coastal refineries and production facilities (see Section 5.2)
- Increased droughts and changes in precipitation patterns impacting water supply available for hydroelectric power generation
- Changes in cooling water availability for thermal power plants
- Changes in biomass location and quantity impacting biomass power generation and carbon sequestration
- Changes in percent cloud cover relevant to solar energy generation
- Changes in wind speed and wind patterns relevant to wind power

¹⁰³ Climate change, http://en.wikipedia.org/wiki/Climate_change. Accessed August 2, 2005.

- Increased demand for energy for cooling and air conditioning and reduced demand for energy for heating, depending on the expected temperature changes for a particular location

The IPCC estimates the greatest impact (both positive and negative) on hydroelectric power “because it is sensitive to the amount, timing, and geographical pattern of precipitation as well as temperature (rain or snow, timing of melting).”¹⁰⁴ Understanding the potential long-term changes, including what kind of changes are expected and where and when they may occur, is important for long-term planning and flexibility in the energy sector.

The IPCC has published information on the impact of climate change on human activities including energy production, although there have been relatively few studies on the effects of climate change on energy demand.¹⁰⁵ There are significant gaps in knowledge regarding the nature of changes and effects on both the responder and the response, making it difficult for the energy sector to plan for adapting to potential changes. The IPCC identified the highest priority needs for research on impacts, adaptation, and vulnerabilities in human settlements, particularly “improved understanding of the implications of climate variability and change for the well-being of human settlements as they relate to other sectors, other places, and the broader sustainable development process.”¹⁰⁶

As noted earlier, over the next four years CCSP will prepare Synthesis and Assessments to support informed discussion and decision-making regarding climate variability and change by policymakers, resource managers, stakeholders, the media, and the general public. Three Synthesis and Assessments relate specifically to energy management, and will likely touch upon aspects of climate change impacts on the energy sector:

- Updating scenarios of GHG emissions and concentrations, in collaboration with the CCTP. Review of integrated scenario development and application. Effort to be led by DOE and completed in the 4th quarter of 2006.
- Analyses of the effects of global change on energy production and use. Effort to be led by DOE and completed in the 2nd quarter of 2007.

¹⁰⁴ Climate Change 2001: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom.

¹⁰⁵ Ibid.

¹⁰⁶ Ibid.

- Uses and limitations of observations, data, forecasts, and other projections in decision support for selected sectors and regions. Effort to be led by NASA and completed in the 4th quarter of 2006.¹⁰⁷

<i>Example Projects with NASA Involvement</i>	<i>Decision Support System / Database</i>	<i>Participants</i>
None identified.		

Alignment with Administration Initiatives

Impacts of climate change on the energy sector are strongly linked to GEOSS goals on energy, disasters, and climate, specifically reduction of risk to energy infrastructure due to climate and oceanic threats.

CCSP is particularly concerned with adaptation of human activities to climate-related effects such as impacts on energy infrastructure. CCTP seeks to inform long-term technology planning through scenario analysis to help industry adapt to changes. Thus, climate change impacts on the energy sector are closely related to CCSP and CCTP goals.

Potential Application of NASA Earth Science Research: HIGH

NASA’s involvement and leadership in climate modeling give NASA the potential to make a contribution to the evaluation of the impact of climate change on energy production, transmission, and end use. Partnership with an organization such as EPRI would enable the development of a research program designed to support energy sector and energy policymaker decision support systems.

¹⁰⁷ Updated Schedule and Scope of the Climate Change Science Program (CCSP) Synthesis and Assessment Products, Letter from Jim Mahoney (Director, CCSP) to Senator Jim DeMint (Republican, South Carolina), July 15, 2005, <http://www.climate-science.gov/Library/sap/letter-to-demint2005.htm>.

6.0 RECOMMENDATIONS

Part 2 of this project is to prepare an in-depth evaluation and set of recommendations on the most promising applications of specific NASA Earth science research, results, and capabilities to energy management decision support tools. The following preliminary recommendations for further study in Part 2 are based upon the assessment of each sub-topic reviewed with respect to the alignment with Administration initiatives, the potential for application of NASA Earth science research, and the current involvement of NASA on the particular issue. NASA Earth science applications can be viewed as a continuum with one extreme being existing decision support systems with which NASA data and models are readily integrated, and the other extreme being decision support systems that do not yet exist but which could be developed and could use NASA data and models. In this continuum, the former are applications that are ranked as “Established” in this document in terms of current NASA involvement and are therefore not areas for focus in Part 2. The latter (future decision support systems that could incorporate NASA data) are at such formative stages that they are difficult to identify and near-term involvement by NASA would be premature, although the long-term promise of such applications is great. The recommendations provided in this section fall between these two extremes, focusing on existing decision-support systems with a “High” or “Medium” potential for application of NASA Earth science, “Limited” current NASA involvement, and alignment with at least one of the Administration initiatives discussed in Chapter 1. The following most promising applications have a “High” potential for NASA involvement:

1. **Supply and Load Forecasting.** Short- to medium-term load forecasting is typically performed using software-based decision support tools that require numerous near-real time inputs for decision-making. NASA weather and energy resource data could be integrated into these forecasting models relatively easily, provided that specific products were developed and available on a timely basis. NASA is already pursuing a partnership with EPRI who has an existing load forecast decision support system. Partnerships with NOAA would likely be required to ensure continued operational datasets and a smooth transition from research to operations. Load forecasting is closely aligned with GEOSS and has potential global application. With existing data, nascent partnerships, and alignment with GEOSS, supply and load forecasting would be an optimal subject for further development.

2. **Long-Term Energy Modeling and Forecasting and Impacts of Climate Change on the Energy Sector.** Long-term energy modeling depends on an understanding of long-term climate and meteorological changes. NASA’s leadership in the development of global climate models makes NASA a potentially important source of information for long-term forecasting. NASA’s involvement and leadership in climate modeling means it has the potential to make a contribution to the evaluation of the impact of climate change on energy production, transmission, and end use. Dialogue with the energy sector is needed to determine their specific needs in long-term modeling and forecasting, as well as to determine which sectors and organizations may be most open to partnerships to consider the implications of long-term climate change. As a science-based agency, NASA may be able to foster a link between global climate modelers and energy managers and planners on this key issue. Partnership with an organization such as EPRI would enable the development of a research program designed to support energy sector decision support systems, and partnership with NOAA would ensure transition from research to operations.

3. **Renewable Energy, Particularly Biomass and Hydroelectric Power.** While the application of NASA data and models to solar and wind renewable energy is established and successful, the potential for the use of NASA resources for additional renewable energy applications (e.g., hydropower and biomass) is also considered high. Application to these renewable energy sources would require the development of relevant products, integration into appropriate decision support systems, and partnership with NOAA to ensure transition from research to operations. NASA has established relationships with leaders in renewable energy, particularly NREL, and could explore expanding its work with NREL or other organizations to cover these new areas. Key areas where NASA resources are applicable for renewable energy are quantifying resources, siting new generation facilities, planning and optimizing production, and distributed generation and grid integration (see below).

In addition, four other areas should be considered for further exploration in Part 2 of this project. They were rated as having a “Medium” potential for application of NASA Earth science research and “Limited” current NASA involvement. These areas are **(1) electricity transmission and oil and gas pipelines, (2) distributed energy generation and grid integration, (3) waste and water emissions monitoring and mitigation, and (4) impacts of sea-level rise on energy infrastructure.** Further exploration of these potential areas and the major recommendations provided above is needed to confirm the energy sector players and decision support needs for policymaking and resource management. This analysis will be conducted in Part 2.