National Aeronautics and Space Administration (NASA)

NASA Earth Science Research for Energy Management

Part 2: Evaluation and Recommendations on the Potential for Application of NASA Earth Science Research to Energy Issues

by

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EXECUTIVE SUMMARY

The management of energy resources in the United States and around the world is an enduring environmental and social challenge as population and economies grow and develop. Effective, environmentally sound development, production, and delivery of energy depends on Earth monitoring information. The NASA Applied Sciences Program, and specifically the Energy Management application area, benchmarks practical uses of NASA-sponsored observations from Earth observation systems and predictions from Earth science models, in order to extend the benefits of Earth science research to decision support that can be adapted in applications worldwide. Energy management includes the full energy life cycle from exploration, production, processing, and transportation of fossil fuel, nuclear, and renewable energy resources; the generation and distribution of electricity; and the end use of energy in all forms. NASA science data products have been used extensively in the development of some renewable energy sources, and NASA is seeking to expand application of its Earth science data products, models, measurements, and observations into new areas within the energy management sector.

Building on an earlier overview of the entire energy sector, this report assesses three primary and two secondary areas of need within the energy sector with potential for new application of NASA Earth science resources. Table ES-1 identifies the areas of need, specific recommendations, candidate NASA science data products, and candidate decision support systems and partners.

In addition to recommendations listed in Table ES-1, it is further recommended that NASA consider the following in order to expand applications to benefit energy management:

- Form an energy sector working group to improve communications between NASA scientists and end users in the energy management sector. This working group may have subgroups that promote active involvement of stakeholders in data and product development.
- With end user partners, conduct or promote focused feasibility and rapid prototype development studies on specific projects for the areas listed in Table ES-1.
- Consider the temporal and spatial needs of key energy sector projects, particularly the availability and usability of NASA information at multiple scales from global to local.

By fostering the interaction of NASA scientists with end users in the energy sector, the NASA Applied Sciences Program can increase the breadth and depth of the application of NASA observations and models for energy management.

TABLE ES-1. APPLICATION OF NASA SCIENCE PRODUCTS TO ENERGY SECTOR NEEDS

Primary Energy Sector Needs	***Candidate NASA Science Data Products***	***Candidate Decision Support Systems and Partners***
Supply and Load Forecasting ▪ Need to enhance medium-term energy forecasting tools and services Long-Term Energy Modeling & Forecasting/ Climate Change Impacts on the Energy Sector ▪ Need to focus on applying long-term climate modeling to energy sector decision support systems	Sensors and Sensor Programs: ▪ Atmospheric Infrared Sounder (AIRS) ▪ Advanced Microwave Scanning Radiometer (AMSR) ▪ Moderate Resolution Imaging SpectroRadiometer (MODIS) ▪ Tropical Rainfall Measuring Mission (TRMM) ▪ Clouds and the Earth's Radiant Energy System (CERES) ▪ SeaWinds (ADEOS-II) ▪ National Polar-Orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP) ▪ Aura: Ozone Monitoring Instrument (OMI), Tropospheric Emission Spectrometer (TES), High Resolution Dynamics Limb Sounder (HIRDLS), Microwave Limb Sounder (MLS) ▪ Solar and Heliospheric Observatory (SOHO) ▪ Solar Radiation and Climate Experiment (SORCE) ▪ Jason-1 ▪ Orbiting Carbon Observatory (OCO) ▪ Global Precipitation Measurement (GPM) Models: ▪ Global Modeling and Assimilation Office Atmosphere Model (GMAO) ▪ Carnegie-Ames-Stanford Approach (CASA) ▪ Goddard Institute of Space Science (GISS) General Circulation Model ▪ NASA Seasonal to Interannual Prediction Project (NSIPP) ▪ Global Ozone Chemistry Aerosol Radiation and Transport (GOCART) Analysis Packages and Prototypes: ▪ Surface Meteorology and Solar Energy (SSE) prototype website ▪ Fast Longwave and Shortwave Radiative Flux (FLASHFlux) ▪ Global Energy and Water Cycle Experiment (GEWEX)	Supply and Load Forecasting: ▪ Commercial medium-term forecasting tools, by vendors such as Itron ▪ Partnership with EPRI to identify other potential decision-support systems Long-Term Energy Modeling & Forecasting/ Climate Change Impacts on the Energy Sector: ▪ National Energy Modeling System (NEMS) and System for the Analysis of Global Energy Markets (SAGE), by the Energy Information Agency ▪ Mini Climate Assessment Model (MiniCAM) and Second Generation Model (SGM), by the Pacific Northwest National Laboratory
Biomass and Hydroelectric Renewable Energy ▪ Need to focus on support for optimizing dam operations for hydropower and agricultural irrigation ▪ Need to focus on enhanced understanding and monitoring of potential biomass resources	Sensors and Sensor Programs: ▪ Advanced Microwave Scanning Radiometer (AMSR) ▪ Moderate Resolution Imaging SpectroRadiometer (MODIS) ▪ Gravity Recover and Climate Experiment (GRACE) ▪ Landsat and Landsat Data Continuity Mission (LDCM) ▪ Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) ▪ Jason-1 Models: ▪ Global Reservoir and Lake Monitor Analysis Packages and Prototypes: ▪ RiverWare and AWARDS ET-Toolbox ▪ Pacific Northwest Regional Collaboratory Water Resource Forecasting	▪ Explore partnerships with major dam operators: Army Corps of Engineers, Bureau of Reclamation, and Tennessee Valley Authority ▪ Develop partnership with Department of Energy Hydropower Program ▪ Expand partnerships with U.S. Department of Agriculture and National Renewable Energy Laboratory for biomass

Secondary/Long-Term Energy Sector Needs	***Candidate NASA Science Data Products***	***Candidate Decision Support Systems and Partners***
Distributed Energy Generation and Grid Integration ▪ Need to focus on improving data for using renewable energy sources on distributed networks (solar, wind, biomass, micro-hydro)	Sensors and Sensor Programs: ▪ Involves the sensors, models, and analysis packages and prototypes listed above for supply and load forecasting and renewable energy, depending upon the energy resource. ▪ Particular focus would be on sensors, models, and analysis packages that support solar, wind, micro-hydroelectric, and biomass energy sources.	▪ Partner with NREL to improve renewable modules in Hybrid Optimization Model for Electric Renewables (HOMER) decision support system
Space Weather Impacts on Transmission Systems ▪ Need for further stakeholder research to understand shortcomings and opportunities	Sensors and Sensor Programs: ▪ Advanced Composition Explore (ACE) ▪ Solar and Heliospheric Observatory (SOHO)	▪ Continue low-level dialogue with private sector and NOAA data providers

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ABBREVIATIONS

Abbreviation	Definition
ACE	Advanced Composition Explorer (NASA)
ADEOS-II	Advanced Earth Orbiting Satellite-II
AIRS	Atmospheric Infrared Sounder
AMSR	Advanced Microwave Scanning Radiometer
ANNSTLF	Artificial Neural Network Short-Term Load Forecaster
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATMS	Advanced Technology Microwave Sounder
AWARDS ET	Agricultural Water Resources Decision Support System Evapotranspiration (Toolbox)
CANMET	Canada Centre for Mineral and Energy Technology
CASA	Carnegie-Ames-Stanford Approach (model)
CCSP	Climate Change Science Program
CCTP	Climate Change Technology Program
CDC	Climate Diagnostics Center (NOAA)
CERES	Clouds and the Earth's Radiant Energy System
CPC	Climate Prediction Center (NOAA)
CrIS	Cosmic Ray Isotope Spectrometer
DOE	U.S. Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy (U.S. DOE)
EIA	Energy Information Administration
EPA	Environmental Protection Agency
EPIC	Environmental Policy Integrated Climate (model)
EPRI	Electric Power Research Institute
ERBE	Earth Radiation Budget Experiment
FAS	Foreign Agricultural Service (USDA)
FLASHFlux	Fast Long Wave and Short Wave Radiative Fluxes
GEOSS	Global Earth Observation System of Systems
GEWEX	Global Energy and Water Cycle Experiment
GIC	Geomagnetically induced current
GISS	Goddard Institute of Space Science
GMAO	Global Modeling and Assimilation Office
GOCART	Global Ozone Chemistry Aerosol Radiation and Transport
GPCP	Global Precipitation Climatology Project
GPM	Global Precipitation Measurement
GRACE	Gravity Recover and Climate Experiment

Abbreviation	**Definition**
GSFC	Goddard Space Flight Center
HELM	Hourly Electric Load Model
HIRDLS	High Resolution Dynamics Limb Sounder
HOMER	Hybrid Optimization Model for Electric Renewables
IEA	International Energy Agency
INL	Idaho National Laboratory
ISCCP	International Satellite Cloud Climatology Project
LDCM	Landsat Data Continuity Mission
MAGICC	Model for the Assessment of Greenhouse-Gas Induced Climate Change
MARKAL	Market Allocations
MiniCAM	Mini Climate Assessment Model
MLS	Microwave Limb Sounder
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NDVI	Normalized difference vegetation index
NEMS	National Energy Modeling System
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-Orbiting Operational Environmental Satellite System
NPP	NPOESS Preparatory Project
NREL	National Renewable Energy Laboratory
NSIPP	NASA Seasonal to Interannual Prediction Project
OCO	Orbiting Carbon Observatory
OMI	Ozone Monitoring Instrument
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory
POWER	Prediction of Worldwide Energy Resource
RETScreen	Renewable Energy Technology Screen
SAGE	System for the Analysis of Global Energy Markets
SEC	Space Environment Center (NOAA)
SGM	Second Generation Model
SOHO	Solar and Heliospheric Observatory
SORCE	Solar Radiation and Climate Experiment
SSE	Surface meteorology and Solar Energy
TES	Tropospheric Emission Spectrometer
TOPEX	[Ocean] Topography Experiment
TRMM	Tropical Rainfall Measuring Mission

Abbreviation	**Definition**
TVA	Tennessee Valley Authority
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USGEO	United States Group on Earth Observations
VIIRS	Visible Infrared Imager / Radiometer Suite

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. 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 and control of emissions; understanding of the relationship between energy and climate change; and carbon sequestration. Recognizing the importance of energy management, the NASA Applied Sciences Program fosters practical uses of NASA-sponsored observations from Earth observation systems and predictions from Earth science models, in order to extend the benefits of Earth science research to decision support that can be adapted in applications worldwide, including energy sector applications.[1] Given extensive NASA Earth science research on energy-related weather and climate parameters, and rapidly advancing energy technologies and applications, there is significant potential for increased extension of NASA Earth science research to selected energy management issues and decision support tools.

The demand for more detailed climate and sector-specific information is increasing as energy technologies become more advanced, energy demand grows, and the energy industry faces new pressures associated with deregulation, climate change, and other policy initiatives. Further, 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. In some cases, this demand for additional information is being filled by data and models from the National Oceanic and Atmospheric Administration (NOAA), NASA research on a prototype basis as part of the NASA-NOAA Research to Operations initiative, and services of the private sector. In other cases, information needs are new and evolving, and the full benefit that could be derived from NASA science data products and models is not being realized due to limited ongoing partnership and communication between NASA and energy sector stakeholders. NASA has expressed interest in expanding application of its Earth science research results into new areas within the energy management sector.

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[1] National Aeronautics and Space Administration, Earth Science Applications Plan, July 2004, http://science.hq.nasa.gov/strategy/AppPlan.pdf, Accessed February 7, 2006.

1.1 Purpose of This Study

An overview of the NASA Energy Management Program Element and energy management issues was presented in the Part 1 report[2] of this project along with a brief assessment of the potential application of NASA Earth science measurements and models to each of the energy management areas discussed. The Part 1 report also addressed the alignment of energy management issues with Administration initiatives including the Global Earth Observation System of Systems (GEOSS), United States Group on Earth Observations (USGEO), Climate Change Science Program (CCSP), Climate Change Technology Program (CCTP), and U.S. Ocean Action Plan, and the joint NASA-NOAA Research to Operations initiative. This Part 2 report builds upon Part 1 by examining selected energy management areas in greater detail, focusing on the major organizations and decision support tools with the greatest potential for application of NASA science data products and models. This report also includes a discussion of the direction and establishment of priorities for the NASA Energy Management Program Element, concluding with specific recommendations based on the research presented in this report.

1.2 Scope of This Study

NASA is interested in expanding the use of its innovative scientific capabilities to enhance energy management decision-support tools maintained and operated by government, non-government, and private energy sector organizations. These tools perform functions ranging from short- and long-term forecasting by electric utilities to assessment of energy policies and regulation strategies by government agencies. This report focuses on existing decision support tools with potential near-term or longer-term opportunities for integration of NASA science data products and models. Some of the decision support tools discussed in this report are already supported or maintained as an operational service by NOAA; for such tools, this report identifies potential opportunities for NASA involvement on the research aspects of the applications and coordination between NASA research and NOAA operations. The energy management topics covered in this report were selected based on the potential for new applications of NASA science data products and models in the energy management arena, in the context of helping NASA accomplish the goals of its Earth Science Applications Plan.[3]

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[2] National Aeronautics and Space Administration 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, Erica Zell and Jill Engel-Cox, Battelle, Subaward #CG0416, August 25, 2005, Revision 2, Revised October 24, 2005.
[3] National Aeronautics and Space Administration, Earth Science Applications Plan, July 2004, http://science.hq.nasa.gov/strategy/AppPlan.pdf, Accessed February 7, 2006.

Based on the preliminary Part 1 review, the following three energy management areas were considered of highest potential and of most interest for new or expanded application of NASA Earth science resources:

- Supply and Load Forecasting
- Long-Term Energy Modeling and Forecasting/Climate Change Impacts on the Energy Sector
- Renewable Energy (particularly biomass and hydroelectric power).

These primary/near-term opportunities are covered in Chapter 2. Note that there is a certain degree of overlap in the continuum of energy-related forecasting that runs on the timescales of minutes to hundreds of years. In this report, section 2.1 on Supply and Load Forecasting generally covers both short-term (defined as up to two weeks) and medium-term (monthly and seasonal) forecasting. Long-term (ranging from approximately 1 to 50 years) and very long-term (50+ years) forecasting are primarily covered in section 2.2 on long-term energy modeling and climate change.

The following two energy management areas were identified as having a moderate potential for new or expanded application of NASA Earth science resources, presenting opportunities that are likely to be long-term or less directly relevant to NASA resources:

- Distributed Energy Generation and Grid Integration
- Space Weather Impacts on Transmission Systems.

These secondary/long-term focus areas are covered in Chapter 3. For both the primary and secondary areas, a description, recommendations to NASA for further involvement, and a brief assessment of the benefits of new or expanded NASA involvement in the area are discussed. The report includes a discussion of the specific NASA science data products and models that should be explored for potential application in each area. Chapter 4 presents a discussion of the direction and establishment of priorities for the NASA Energy Management Program Element and concludes in Chapter 5 with specific recommendations based on the research presented in this report.

2.0 PRIMARY/NEAR-TERM FOCUS AREAS

The following three energy management activities are primary focus areas for new or expanded application of NASA Earth science resources in the near-term. These areas are: (1) Supply and Load Forecasting, (2) Long-Term Energy Modeling and Forecasting/Climate Change Impacts on the Energy Sector, and (3) Renewable Energy (particularly biomass and hydroelectric power). For each of these areas, this section provides a description, recommendations to NASA for further involvement, and a brief assessment of the benefits of new or expanded NASA involvement in the area.

2.1 Supply and Load Forecasting

2.1.1 Description

The energy sector uses short-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. Medium-term forecasting is also used by natural gas companies for distribution and storage planning. Load forecasting tools use inputs such as existing and historical loads, meteorological data including real-time and weather forecast data, economic data such as the cost of energy, and available energy sources.

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 economic trends related to energy costs are more difficult to predict than load.[4] Supply and load forecasting models have also been developed for specific types of energy, such as wind power, that incorporate relevant resource parameters.[5]

Currently, short- and medium-term load forecasting models make little or no use of climate forecasts, which provide probabilistic models of long-term climate outcomes. An initial study by the Scripps Institute of Oceanography that attempted to quantify the economic benefits to energy utilities from the use of climate forecasts showed that the energy industry on the whole is unfamiliar with climate

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[4] M. Smith, Electricity Load and Price Forecasting Using Statistical Methods and Models, Second Moment, http://www.secondmoment.org/articles/electricity.php. Accessed August 2, 2005.
[5] Neural Network-Based Forecasting for Wind Generation, Strategic Science and Technology, EPRI, document 1009393; September 2003.

forecasts, although millions of dollars could be saved annually by energy utilities through the use of climate forecasting outputs tailored to the utility's geographic area.[6] The report found that the challenges of integrating climate forecasts into short- and medium-term load forecasting are primarily related to communication between the energy industry and climate forecasters and overcoming regulatory constraints that restrict the operating flexibility of energy utilities.

2.1.2 Organizations and Decision Support Systems

A variety of nonprofit organizations, government entities, consulting companies, and electric utilities participate in the load forecasting arena. The role of each of these stakeholders along with the relevant decision-support systems are discussed in this section.

2.1.2.1 Electric Power Research Institute

The Electric Power Research Institute (EPRI) was heavily involved in short-term load forecasting in the 1980s and 1990s although this work has since been greatly reduced due to an unbundling of EPRI's services. There are currently two major load models that EPRI supports for forecasting, an older model called the Hourly Electric Load Model (HELM) and a newer model called the Artificial Neural Network Short-Term Load Forecaster (ANNSTLF). ANNSTLF forecasts hourly system loads from 1 hour to 35 days ahead with errors less than 3% based on historical load and temperature forecasts.[7] The temperature forecasts used by ANNSTLF are based on 10-day NOAA National Weather Service predictions, and also may rely on commercial weather forecasts.[8]

Since NOAA as an operational agency provides the real-time data needed for short-term forecasting, NASA's contribution would be greater in medium-term forecasting, as is provided by some commercial vendors, which are described in a subsequent section. EPRI is also involved in the development of regional and wind plant-specific energy forecasting systems and improved wind plant siting tools; refer to section 2.3 of this document for a discussion of renewable energy resources. In the past the NASA Energy Management Program made preliminary inquiries with EPRI regarding the

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[6] David W. Pierce, Scripps Institution of Oceanography, Climate Forecasts for the Energy Industry: Case Examples and Lessons Learned. National Renewable Energy Laboratory Seminar Series, Washington, DC, October 13, 2005. Presentation available online at http://www.nrel.gov/analysis/seminar/archive.html, Accessed November 17, 2005.
[7] Artificial Neural Network Short-Term Load Forecaster (ANNSTLF), Fact Sheet, EPRI, Available at http://www.epriweb.com/public/000000000001011532.pdf, Accessed August 2, 2005.
[8] Conversation between Erica Zell, Battelle, and Victor Niemeyer, niemeyer@epri.com, 650-855-2744, Electric Power Research Institute, November 10, 2005.

possibility of integrating NASA science data products and models into EPRI's load forecasting decision support systems.[9] However, no long-term relationship or joint EPRI-NASA projects were established.

The private consulting company EPRI Solutions (a wholly owned subsidiary of EPRI) conducted a research project entitled Load Forecasting Best Practices and Benchmarking.[10] This project began in April 2005 and was scheduled for completion in early 2006. The project is focused on identifying the short- and longer-term forecasting methods and tools (ranging from next day to 30 years) used across North America, including the data collected, forecasting tools and software being used, relation to regulatory requirements and other needs, and staff and consultants involved in the forecasting process. Preliminary results indicate that a majority of electric utilities conduct forecasting using in-house staff and either vendor-provided or internally developed tools and models.[11] These tools typically rely upon the Annual Energy Outlook produced by the U.S. Department of Energy (DOE) Energy Information Administration (EIA, refer to section 2.2.2.2 for a discussion of EIA) for information regarding demand by sector. Forecasts are based on typical weather patterns and conditions with certain adjustments for year-to-year variability. NASA should consider reviewing the results of this research project when available and making contacts with some of the stakeholders and researchers as an introduction and entry point into medium- and long-term energy forecasting.

2.1.2.2 Commercial Vendors, Electric Utilities, and Gas Companies

For short-term supply and load forecasting, many electric utilities rely on some combination of their own in-house forecasters and commercial vendors such as Itron, one of the largest commercial vendors of energy forecasting services.[12] The electric utilities and commercial vendors also perform some medium-term forecasting (i.e., roughly 6 months to one year) through examination of past weather trends and similar days to predict loads. In fact, Itron maintains a variety of energy forecasting products ranging from short-term to long-term (for long-term energy modeling, refer to section 2.2 of this document). Medium-term forecasting is quite common for natural gas companies as it is useful for gas distribution and storage decisions (as opposed to electricity, which cannot generally be stored). Medium-term gas forecasting is primarily a collective decentralized decision-making process involving financial traders,

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[9] Energy Management Program Element Plan: 2004-2008, Earth Science for Energy Management, Earth Science Applications Program, NASA Earth Science Enterprise, v. 4.5, March 11, 2005.
[10] Electric Power Research Institute, 2005 Portfolio, P028.004 Load Forecasting Best Practices and Benchmarking, http://www.epri.com/portfolio/product.aspx?id=535&year=2005, Accessed November 8, 2005.
[11] Conversation between Erica Zell, Battelle, and Ingrid Rohmund, EPRI Solutions, 760-943-1532, irohmund@eprisolutions.com, November 10, 2005.
[12] Itron, Energy Forecasting, http://www.itron.com/pages/products_category.asp?id=itr_000373.xml, Accessed November 10, 2005.

rather than the result of a single computer model or tool. The most promising area for NASA involvement with commercial vendors, electric utilities, and gas companies is through a major commercial vendor such as Itron, with which NASA could explore contributions to their medium-term forecasting. Such partnerships would need to be constructed carefully in the context of a competitive commercial vendor industry and would need to enhance rather than replace private-sector products and services.

2.1.2.3 NOAA

The mission of the NOAA Climate Diagnostics Center (CDC) is to advance national capabilities to interpret the causes of observed climate variations, to apply this knowledge to improve climate models and forecasts, and to develop new climate products that better serve the needs of the public and decision-makers. One of the CDC's goals is improving interactions and communications with potential external users of CDC's climate analyses and predictions (on time scales ranging from a few weeks to centuries) in areas such as energy, water, and environmental resources management.[13] The CDC maintains a large collection of relevant online data sets and forecasts. For example, the CDC internet-based Map Room[14] provides a focal point for monitoring and prediction products on climate variability, climate impacts, and climate-weather connections. The CDC Map Room encompasses a broad range of diagnostic products and enhanced visualization tools for weather and climate monitoring. Web usage statistics for the Map Room show that there is substantial interest in these products from national energy companies that monitor long-range weekly forecasts. The CDC has conducted studies to evaluate the usefulness of climate information and products, with an initial focus on a case study based on a decision calendar linking water resources management planning processes and operational issues with potential uses of variable lead-time forecasts and climate information. Future CDC climate applications research is anticipated to employ a similar approach, using the decision calendar framework to assess the role of climate information in decision-making related to energy and other areas.[15]

Another organization of potential relevance for supply and forecasting is the NOAA Climate Prediction Center[16] (CPC), part of the National Center for Environmental Prediction. The CPC assesses and forecasts the impacts of short-term climate variability with an emphasis on enhanced risks of

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[13] CDC Mission and Goals, http://www.cdc.noaa.gov/glance/mission.html/, Accessed November 28, 2005.
[14] NOAA-CIRES Climate Diagnostics Center, CDC Map Room, http://www.cdc.noaa.gov/map/, Accessed November 28, 2005.
[15] CDC 2001 Science Program Review, July 25-26, 2001, Boulder, Colorado, http://www.cdc.noaa.gov/review/, Accessed November 1, 2005.
[16] Climate Prediction Center, http://www.cpc.ncep.noaa.gov/, Accessed December 2, 2005.

weather-related extreme events. The CPC's products cover time scales from a week to seasons, extending into the future as far as technically feasible, and they cover the land, the ocean, and the atmosphere, extending into the stratosphere. The CPC has expressed interest in working with NASA to develop solar and wind products based on seasonal predictions.

NASA may be able to form a strategic partnership with CDC or CPC focused on contributions of NASA science data products, models, and forecasts to their respective programs, including an emphasis on forecasts and climate information for the energy sector. Such a partnership could be structured in the context of the Research to Operations relationship between NASA and NOAA.

2.1.3 Recommendations to NASA for Further Involvement

The primary area in which NASA science data products and models have the potential to contribute to supply and load forecasting decision support systems is in medium-term forecasting (seasonal and annual), given that NOAA as an operational agency provides the real-time data needed for short-term forecasting (e.g., through the National Weather Service and CDC). 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. NASA should consider exploring partnerships with commercial vendors of medium-term forecasting tools and services. As noted previously, such partnerships would need to be constructed carefully in the context of a competitive commercial vendor industry and would need to enhance rather than replace private-sector products and services. NASA may also consider exploring partnerships with individual electric utilities although this approach would reach a smaller audience (single utility) compared to partnering with a commercial vendor that serves multiple electric utilities. Finally, given EPRI's relationships with and understanding of electric utilities, NASA should consider pursuing a partnership with EPRI as an entry point into the medium-term forecasting arena.

The general parameters and models that may be useful for supply and load forecasting include:

- Meteorology data, including atmospheric temperature, cloud cover, and visibility
- Surface properties including vegetation, soil type, surface temperatures, soil moisture, and snow cover
- Solar radiation (and related quantities)
- Wind resources
- Reservoir height and rainfall
- Seasonal climatology models.

NASA has a suite of both existing and planned sensors providing meteorological and climate-related geophysical data along with multiple NASA-led and NASA-partnership climatology models and analysis packages or prototypes. In some cases processed information from a single sensor or combination of sensors may be most useful to energy stakeholders. However, sensors do not always provide the required time and space averaging, and therefore the output of models such as a climatology model may be a more appropriate finished product for energy stakeholder use. Climatological data sets are frequently used as a proxy to estimate the likelihood of future events. Thus, the use of deterministic seasonal prediction models should also be explored. Measurements of current and future sensors can be used to improve the initialization of these types of models that might have a more direct impact on medium-range forecasting. Some examples of the specific NASA sensors, models, and analysis packages or prototypes that should be explored for use in supporting supply and load forecasting are described in the following sections.[17]

2.1.3.1 Current and Future Sensors

- *Atmospheric Infrared Sounder (AIRS)*[18] is part of an innovative atmospheric sounding group of visible, infrared, and microwave sensors that provide measurements for temperature and humidity at newly improved accuracy. This information is provided globally at a spatial scale of 50 km, twice daily, and may be useful for medium-term forecasting through improved initialization.
- *Advanced Microwave Scanning Radiometer (AMSR)*[19] measures geophysical parameters supporting several global change science and monitoring efforts, including precipitation, oceanic water vapor, cloud water, near-surface wind speed, sea surface temperature, soil moisture, snow cover, and sea ice parameters. The information is provided globally with some exceptions at a spatial scale of 25 km, ranging from daily to monthly.
- *Moderate Resolution Imaging SpectroRadiometer (MODIS)*[20] sensors on Terra and Aqua platforms gather a wide range of parameters including sea surface temperature, land surface temperature, and a number of vegetation indices. This information is provided globally on time scales ranging from twice daily to monthly. This information may be useful in medium-

[17] NASA Data Appropriate for Energy Applications, http://appl-policy.saic.com/NASA_Data_Appropriate_For_Energy_Applications.html, Accessed November 15, 2005.
[18] AIRS, http://daac.gsfc.nasa.gov/AIRS/index.shtml, http://appl-policy.saic.com/AIRS-EM.html
[19] AMSR-E, http://weather.msfc.nasa.gov/AMSR/, http://appl-policy.saic.com/AMSR.html
[20] MODIS, http://modis.gsfc.nasa.gov/, http://appl-policy.saic.com/MODIS_(Data).html

term forecasting given the connections between sea surface temperature and climate in certain regions.

- *Tropical Rainfall Measuring Mission (TRMM)*[21] studies tropical rainfall and enhances understanding of land, air, and sea interactions that impacts global rainfall. The information is provided globally on time scales ranging from daily to monthly. This information may be useful directly in southerly locations in the U.S. and also as inputs to NASA global climate models.
- *SeaWinds*[22] sensor on the *ADEOS-II* satellite monitors sea surface winds and is an important data source to establish wind resource in the open ocean. It may help to establish boundary conditions for winds near coastal areas.
- *The Solar and Heliospheric Observatory (SOHO)*[23] and the *Solar Radiation and Climate Experiment (SORCE)*[24] missions are important for the measurement and modeling of the sun's output and variability. The measurements are key to better understanding the sun and its output for future predictions.
- *National Polar-Orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP)*[25] is a joint mission intended to follow on the Terra/Aqua missions with the Visible Infrared Imager / Radiometer Suite (VIIRS), Cosmic Ray Isotope Spectrometer (CrIS), Advanced Technology Microwave Sounder (ATMS), and CERES instruments that are aimed to retrieve atmospheric properties (clouds, aerosols, temperatures) and surface properties (temperatures, soil moisture, vegetation types, solar radiation, etc.). This instrument is scheduled for launch in 2006.

2.1.3.2 Models

- *Global Modeling and Assimilation Office (GMAO) Atmosphere*[26] model is a NASA-led unified atmospheric model intended for use in a wide range of applications, including numerical weather prediction, data assimilation, seasonal forecasting, climate prediction, atmospheric chemistry studies, atmosphere-land interactions, and prediction of extreme weather events. The output from this model may feed into medium- to long-term forecasting,

[21] TRMM, http://trmm.gsfc.nasa.gov/, http://appl-policy.saic.com/TRMM.html
[22] Winds, http://winds.jpl.nasa.gov/missions/seawinds/
[23] SOHO, http://sohowww.nascom.nasa.gov/
[24] SORCE, http://lasp.colorado.edu/sorce/
[25] NPP, http://jointmission.gsfc.nasa.gov/
[26] GMAO Atmosphere, http://www.esa.ssc.nasa.gov/m2m/model_report.aspx?model_id=101, http://www.esa.ssc.nasa.gov/m2m/model_report.aspx?model_id=113

research such as that being conducted by the Seasonal Forecast Group with the GMAO,[27] including climate change analysis.

2.1.3.3 Analysis Packages and Prototypes

- *Surface meteorology and Solar Energy (SSE) prototype website*[28] (as part of NASA's Prediction Of Worldwide Energy Resource [POWER] project) is a renewable energy resource website that provides over 200 satellite-derived meteorology and solar energy parameters online, both directly as datasets and charts, and as input to decision support systems. The prototype is updated as NASA-led science projects like the International Satellite Cloud Climatology Project and the Surface Radiation Budget project improve and lengthen climate-related data sets.
- *Fast Long wave and Short wave Radiative Fluxes (FLASHFlux)*[29] is a prototype operational system that gives fast long-wave and short-wave radiative fluxes using global Clouds and the Earth's Radiant Energy System (CERES) and MODIS sensors observations, which are important for understanding the impact of changes to the Earth's surface and the state of the atmosphere. This information is archived up to six months from real-time. A variety of industrial applications require surface flux information including hydrological monitoring of watershed storage processes, agricultural usage to help gauge soil moisture changes, and the engineering, monitoring, and design of solar power related applications.

2.1.4 Benefits

Improved load forecasting assists energy planners in achieving the GEOSS societal benefit to improve management of energy resources. Improvements in supply and load forecasting may also allow better incorporation of renewable energy into energy planning, which can balance energy, environmental, and social agendas. However, there is a distinction between an overall societal benefit from improved supply and load forecasting and a benefit to a specific electric utility or gas company, which is essentially a transfer of a benefit from one entity to another. An example of an overall societal benefit is improved forecasting of natural gas needs such that storage for a certain period can be maintained at a lower level and overall prices can be reduced. On the other hand, improved load forecasting that allows a utility to secure a lower price for a power purchase in advance benefits the purchasing utility but not the power

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[27] GMAO Seasonal Forecast Group, http://nsipp.gsfc.nasa.gov/

[28] Surface Meteorology and Solar Energy database, Release 5.1, http://eosweb.larc.nasa.gov/sse/, Accessed July 27, 2005.

[29] FLASHFlux Data, http://eosweb.larc.nasa.gov/PRODOCS/flashflux/table_flashflux.html

vendor.[30] In this context, the initial study by the Scripps Institute of Oceanography that attempted to quantify the economic benefits to energy utilities from the use of climate forecasts showed that millions of dollars could be saved annually by energy utilities through the use of climate forecasting outputs tailored to the utility's geographic area.[31]

2.2 Long-Term Energy Modeling and Forecasting/Climate Change Impacts on the Energy Sector

2.2.1 Description

The energy sector uses long-term energy forecasting to plan for and develop electricity generation and other energy infrastructure to meet long-term demand. Long-term forecasting includes everything from planning by utilities for expanding production over a 1- to 30-year period to long-term scenario analysis useful for setting regional and national energy policy on long-term (10 to 50 years) and very long-term (50+ years) timescales. 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. Integrated assessment models, which often focus on very long-term scales, link individual models, bringing 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. Due to changes in the structure of the electricity industry, in recent years electric utilities have had a reduced focus on justifying long-term demand to state commissions in order to receive project approval. Instead the focus has shifted to economic/business analysis of potential projects by electric utilities and investors, which includes consideration of resource availability, prices, and demand, among other factors.

A related aspect of long-term energy forecasting is the impact of climate change on energy management, although this impact has received little attention in current energy forecasting models. Policymakers in the government and researchers may be interested in climate change information on a variety of different scales. On the other hand, the most relevant information for electric utility planners is the regional and temporal allocation of climate change (down to a local level) rather than information on

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[30] Conversation between Erica Zell, Battelle, and Victor Niemeyer, niemeyer@epri.com, 650-855-2744, Electric Power Research Institute, November 10, 2005.

[31] David W. Pierce, Scripps Institution of Oceanography, Climate Forecasts for the Energy Industry: Case Examples and Lessons Learned. National Renewable Energy Laboratory Seminar Series, Washington, DC, October 13, 2005. Presentation available online at http://www.nrel.gov/analysis/seminar/archive.html, Accessed November 17, 2005.

overall, long-term global trends. Changes in climatology (assumptions about average and extreme weather), which form the basis for system design and contingency planning, could have a variety of impacts on the energy sector, including:

- 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
- 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
- Increased storm frequency and intensity or wildfires that could lead to increased disruptions in power production and transmission
- Sea-level change that could impact coastal refineries and production facilities.

With climate change uncertainty and rapidly growing energy needs, the need for better and relevant data for long-term energy models is significant.

2.2.2 Organizations and Decision Support Systems

A variety of government agencies, non-profit organizations, and private companies conduct long-term energy forecasting to meet their own or support others' specific decision-making needs. In the past a number of national laboratories along with EPRI and other groups produced energy forecasts. However, due to a number of factors including deregulation, many of these forecasts are no longer produced, leaving the U.S. DOE's EIA models and publications as important sources that feed into multiple models and decision-support tools.[32] The EIA is a major player in this area since it develops and maintains a number of related long-term energy models. Other organizations involved include individual electric utilities, commercial vendors, DOE's Pacific Northwest National Laboratory (PNNL), the International Energy Agency (IEA), and the U.S. Environmental Protection Agency.

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[32] Conversation between Erica Zell, Battelle, and Ingrid Rohmund, EPRI Solutions, 760-943-1532, irohmund@eprisolutions.com, November 10, 2005.

2.2.2.1 Commercial Vendors and Electric Utilities

For long-term planning and forecasting, many electric utilities rely on some combination of their own in-house forecasters and commercial vendors. One example of such a commercial vendor is Itron,[33] which maintains a variety of energy forecasting products including those focused on the longer term. A new comprehensive source of information on long-term forecasting by utilities, including both in-house and vendor services, is the EPRI Solutions Load Forecasting Best Practices and Benchmarking research project, with results expected to be available at the end of 2005 (see section 2.1.2.1). This research project covers utility forecasts out to a period of 30 years. As discussed for short- and medium-term forecasting, the most promising area for NASA involvement with commercial vendors and electric utilities is through a major commercial vendor such as Itron, although the issue of favoring a single vendor would need to be addressed.

2.2.2.2 Energy Information Administration

Created by Congress in 1977, the EIA is an independent statistical agency of the DOE. The EIA provides policy-independent data, forecasts, and analyses to promote sound policy making, efficient markets, and public understanding regarding energy and its interaction with the economy and the environment.[34] EIA issues a wide range of weekly, monthly, and annual reports on energy production, stocks, demand, imports, exports, and prices, and prepares analyses and special reports on topics of current interest. Some key releases of integrated information are the Monthly Energy Review, the Annual Energy Review, the Short-Term Energy Outlook, the Annual Energy Outlook, and the International Energy Outlook. Two of the major tools that EIA uses for its forecasts are the National Energy Modeling System (NEMS) and the System for the Analysis of Global Energy Markets (SAGE), as described in the following sections.

EIA collects most of its own data through statistical surveys to energy producers, users, transporters, and certain other businesses, and direct reporting from companies, households, and trade associations, along with information provided by other government agencies. The National Solar Radiation Database is incorporated into the renewable energy portion of NEMS. Through NASA's partnership with DOE's National Renewable Energy Laboratory (NREL), NASA's Surface meteorology

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[33] Itron, Energy Forecasting, http://www.itron.com/pages/products_category.asp?id=itr_000373.xml, Accessed November 10, 2005.

[34] Energy Information Administration, About Us, http://www.eia.doe.gov/neic/aboutEIA/aboutus.htm, Accessed October 24, 2005.

and Solar Energy (SSE) prototype website[35] (as part of NASA's Prediction Of Worldwide Energy Resource [POWER] project) is a renewable energy resource website. This site provides online more than 200 satellite-derived meteorology and solar energy parameters; it also provides information that will help to update the National Solar Radiation Database, which will be incorporated into the renewable energy portion of NEMS. EIA has established working groups that are developing methodologies for forecasting renewable energy resources and has invited NASA to join this effort to provide input on integration of NASA science data products and models.[36]

NEMS: The EIA designed and implements NEMS.[37] This computer-based, energy-economy modeling system of U.S. energy markets for the mid-term 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.[38] The model achieves a supply/demand balance in the end-use demand regions by solving for the prices of each energy product that will balance the quantities producers are willing to supply with the quantities consumers wish to consume. The system reflects market economics, industry structure, and existing energy policies and regulations that influence market behavior. The results of NEMS runs are published in the Annual Energy Outlook, a yearly EIA publication that includes reference cases and various scenarios based on White House, Congressional, or Departmental/Agency requests. Output from NEMS feeds into numerous other agency and organization decision systems such as EPA's analysis of environmental impacts as described in Section 2.2.2.4.

As shown in Figure 1, NEMS consists of four supply modules (oil and gas, natural gas transmission and distribution, coal, and renewable fuels); two conversion modules (electricity and petroleum refineries); four end-use demand modules (residential, commercial, transportation, and industrial); one module to simulate energy/economy interactions (macroeconomic activity); one module to simulate world oil markets (international energy activity); and one integrating module.

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[35] Surface Meteorology and Solar Energy database, Release 5.1, http://eosweb.larc.nasa.gov/sse/. Accessed July 27, 2005.
[36] SAIC NASA Task, National Energy Modeling System, http://appl-policy.saic.com/, Accessed November 18, 2005.
[37] 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.
[38] NEMS is run by EIA, and is also installed (in full or part) at selected DOE national laboratories, EPRI, and several private consulting firms.

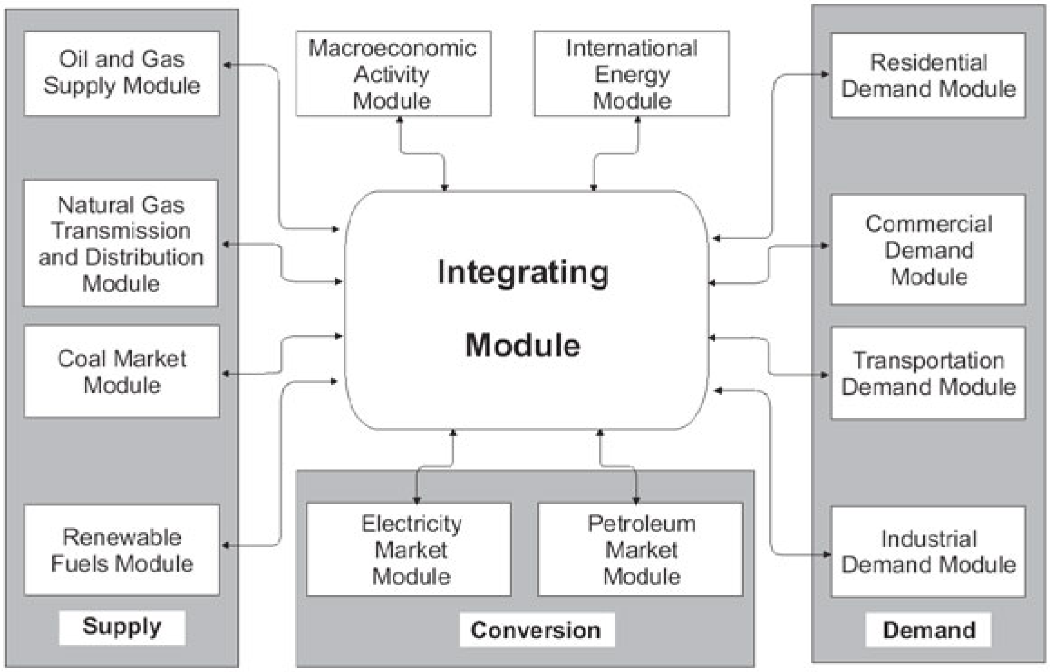

Figure 1: National Energy Modeling System[39]

The model relies on input data such as economic information and historical environmental information from a variety of sources, but does not incorporate current or projected (modeled) environmental data. The modules for which NASA science data products and models may have the most relevance are the renewable fuels module and the demand modules, given the wealth of NASA science data products and models that provide insights on renewable resources and climate variation and change, ultimately impacting energy demand.

The NEMS renewable fuels module represents renewable energy resources and large-scale technologies used for grid-connected U.S. electricity supply. The Assumptions to the Annual Energy Outlook 2005[40] provides some insights into EIA's sources of data including renewable resource and technology data. For example, geothermal resource data is based on a Sandia National Laboratories 1991 geothermal resource assessment. Wind power is based on available land area and wind speed as provided by NREL and PNNL. Solar power data are based on seasonal solar availability, also provided by NREL. Hydroelectric information is provided by the Federal Energy Regulatory Commission along with

[39] Energy Information Administration, The National Energy Modeling System: An Overview 2003, http://www.eia.doe.gov/oiaf/aeo/overview/figure_2.html, Accessed November 21, 2005.
[40] Energy Information Administration, Assumptions to the Annual Energy Outlook 2005, Available at http://www.eia.doe.gov/oiaf/aeo/assumption/pdf/0554(2005).pdf.

estimates prepared by the Idaho National Laboratory. Research recently completed for the NASA Energy Management Program reviewed the potential for NASA science data products and models to contribute to multiple renewable energy areas that feed into NEMS through partnership with NREL. The researchers found that in most cases there is a potential for contributions by NASA science data products and models, but this potential is impeded by a lack of funding to do the necessary preliminary work to develop and test appropriate products for model integration.[41] An exception to this is solar energy, an area where NASA has been successfully working with NREL toward integrating its data through projects such as SSE.

The other NEMS modules that may be of interest to the NASA Energy Management Program are the demand modules, and in particular the residential demand module, which is strongly influenced by weather for space heating and cooling needs. Electricity demand is represented by load curves, which vary by region, season, and time of day. Over the projection period, the residential module uses a 30-year average for heating and cooling degree-days by census division, adjusted by projections in state population shifts. One of the "Issues in Focus" that is examined in the Annual Energy Outlook 2005[42] is the impact of temperature variation on energy demand in buildings. An average of the previous 30 years' data is used for normal weather, and two alternative cases (one warmer and one cooler) are examined based on hypothetical changes in the number of heating degree days and cooling degree days. Such analysis of various climate scenarios is an area where NASA models and forecasts may be useful in helping define the temporal and spatial distribution of climate variation and change. However, as noted previously, in its current state, NEMS is not ready for direct input of NASA science data products or model outputs.

SAGE: Another EIA model is SAGE, an integrated set of regional models that projects world energy consumption. Projections of world oil prices over the 25-year forecast horizon are provided to SAGE from the NEMS International Energy Module. Output from SAGE is published in EIA's International Energy Outlook.[43] This publication is provided as a service to energy managers and analysts, both in government and in the private sector. The projections are used by international agencies, Federal and State governments, trade associations, and other planners and decisionmakers.

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[41] Conversation between Erica Zell, Battelle, and Fred Vukovich, SAIC, fvukovich@raliegh.saic.com, 919-836-7563, November 8, 2005.

[42] Energy Information Administration, Annual Energy Outlook 2005, http://www.eia.doe.gov/oiaf/aeo/issues.html, Accessed August 4, 2005.

[43] Energy Information Administration, International Energy Outlook 2005, Report #:DOE/EIA-0484(2005), Released Date: July 2005, Appendix I: System for the Analysis of Global Energy Markets (SAGE), http://www.eia.doe.gov/oiaf/ieo/appi.html, Accessed October 17, 2005.

For each region, reference case estimates of 42 end-use energy service demands (e.g., car, commercial truck, and heavy truck road travel; residential lighting; steam heat requirements in the paper industry) are developed on the basis of economic and demographic projections. Projections of energy consumption to meet the energy demands are estimated on the basis of each region's existing energy use patterns, the existing stock of energy-using equipment, and the characteristics of available new technologies, as well as new sources of primary energy supply. SAGE draws on energy balance information from sources such as the International Energy Agency's World Energy Outlook. While SAGE is not currently ready to incorporate direct and future environmental data, EIA has indicated interest in discussions with NASA on this topic.[44] Specifically, EIA has indicated that if a NASA Earth science product can be identified that will improve SAGE's capabilities, EIA would accelerate the development of SAGE in this area. EIA has asked NASA to provide a list of data products that may benefit their EIA's understanding of international renewable energy resource availability.[45]

2.2.2.3 Pacific Northwest National Laboratory

PNNL has developed two related examples of integrated assessment models: MiniCAM (Mini Climate Assessment Model) and SGM (Second Generation Model). The energy component of the MiniCAM is based on the Edmonds-Reilly-Barns energy model. Additional model components include an agriculture and land-use model 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. For example, the MiniCAM has been used to perform simulations for CCTP. The SGM is one of several process-based models that are used for focused studies. The SGM is a computable general equilibrium model with energy technology detail that is used for analysis of climate policies over the next several decades. Another model used at PNNL is Environmental Policy Integrated Climate (EPIC) model, which is a process-based model of agricultural systems. Key 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

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[44]Conversation between Erica Zell, Battelle, and Fred Vukovich, SAIC, fvukovich@raliegh.saic.com, 919-836-7563, November 8, 2005.

[45] SAIC NASA Task, System for the Analysis of Global Energy Markets, http://appl-policy.saic.com/, Accessed November 18, 2005.

manner, is underway. For example, NASA solar irradiance data[46] are being used to develop regional solar energy resource curves. These projects are examples of ongoing NASA involvement in long-term energy modeling. This work is funded by a combination of DOE Energy Efficiency Renewable Energy and Global Energy Technology Strategy Program Renewable Energy Technology Analysis projects, utilizing tools developed under NASA funding for a PNNL carbon cycle project.

2.2.2.4 Environmental Protection Agency

While the EPA is not directly involved in the development of long-term energy forecasting tools and models, the EPA draws upon information from long-term energy forecasts to support some of its work. For example, EPA's National Risk Management Laboratory uses NEMS and Market Allocations (MARKAL) for development of emissions scenarios that include assumptions regarding residential, commercial, and industrial (including energy) emissions.[47] The use by EPA of NEMS and MARKAL in its own decision-support tools illustrates the broad potential impact of the integration of NASA science data products, models, and forecasts into commonly used energy models. In terms of climate change, EPA is primarily focused on encouraging the deployment of available technologies rather than long-term energy forecasting. (Note that the encouragement of available technologies is similar to the HOMER program that NASA has supported through NREL for incorporation of renewable energy technologies; while coordination with the EPA may be a possibility for a HOMER-like initiative, such an application is beyond the scope of this section.)

2.2.2.5 International Energy Agency

The IEA Energy Technology Systems Analysis Programme developed the MARKAL generic model as part of a cooperative multinational project over a period of approximately 20 years. 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. The starting point of the MARKAL model is specific types of energy or emission control technologies, from which the model selects the combination of technologies that minimizes total energy system cost. Typically, a series of model runs is made, examining a range of alternative futures (e.g., with respect to carbon management and climate change). MARKAL models can be used for a variety of purposes including:

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[46] Surface meteorology and Solar Energy (release 5.1), http://earth-www.larc.nasa.gov/solar/, Accessed 14 December 2005.

[47] Conversation between Erica Zell, Battelle, and Bill Rhodes, Environmental Protection Agency National Risk Management Laboratory, Atmospheric Protection Branch Chief, rhodes.bill@epa.gov, 919-541-2853, November 14, 2005.

- Identifying least-cost energy systems or cost-effective responses to restrictions on emissions, performing prospective analysis of long-term energy balances under different scenarios
- Evaluating new technologies and priorities for research and development
- Evaluating the effects of regulations, taxes, and subsidies
- Projecting inventories of greenhouse gas emissions
- Estimating the value of regional cooperation.

The number of users of the MARKAL family of models is growing, currently approximately 77 institutions in 37 countries including many developing countries. The results are mainly used by governments, international bodies such as IEA, and by organizations that fund research and development for energy technology. The results are also used for development of environmental strategies, energy policy making, industrial policy making, and evaluation of policy instruments. In the United States, the MARKAL model has been used by the EPA and DOE among others.[48] Given the technology focus and structure of the MARKAL model, it is not currently a good fit for incorporation of NASA science data products and models.[49]

2.2.3 Recommendations to NASA for Further Involvement

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 two major avenues through which NASA should consider exploring further involvement in long-term energy modeling are with the DOE national laboratories and with EIA, which maintains multiple long-term energy forecasting models. For long-term energy modeling, partnership directly with commercial vendors or individual electric utilities is not recommended.

NASA has already had considerable success working with EIA in the area of solar energy. NASA should continue to pursue partnerships with EIA to address an expanded range of renewable resources and explore opportunities to contribute to NEMS demand modules. The challenge for NASA is

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[48] Energy Technology Systems Analysis Programme, Annex III: Exploring Energy Technology Perspectives, MARKAL, http://www.etsap.org/markal/main.html, Accessed August 4, 2005.
[49] Conversation between Erica Zell, Battelle, and Fred Vukovich, SAIC, fvukovich@raliegh.saic.com, 919-836-7563, November 8, 2005.

that NEMS and SAGE cannot currently accept direct inputs of NASA science data products or models. Given the considerable background and validation work needed to incorporate NASA science data products and models into NEMS or SAGE, NASA's efforts to integrate with EIA 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. NASA should consider issuing research announcements that support the required development work to create prototypes that serve as a connection to long-term energy models.

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. NASA can explore opportunities to expand upon its current partnership with PNNL and/or NREL. Currently the partnership between NASA and PNNL is informal, with NASA providing custom data extractions. However, there are opportunities to go beyond this. For example, energy resource modelers at PNNL and beyond have identified specific areas for which more direct use of satellite data could replace current, somewhat arbitrary assumptions such as wind variance, particularly over coastal areas. Staff at the PNNL/Joint Global Change Research Institute have made an initial inquiry with the NASA Energy Management Program regarding these possibilities.[50] The exploration of integrating climate change information must be done with consideration given to the overall uncertainty in both climate change information and the other complex sets of assumptions and calculations that are part of long-term energy modeling.

The general parameters and models that may be useful for long-term modeling are as follows:

- 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
- General circulation models and other climate models.

NASA has a suite of both existing and planned sensors providing meteorology and climate data along with multiple NASA-led and NASA-partnership climatology models and analysis packages or prototypes. Some examples of the specific NASA sensors, models, and analysis packages or prototypes

[50] E-mail from Steve Smith, stevesmi@wam.umd.edu, Pacific Northwest National Laboratory to Erica Zell, Battelle, November 29, 2005.

that should be explored for use in supporting long-term energy forecasting are described in the following sections.[51]

2.2.3.1 Current and Future Sensors

- *Clouds and the Earth's Radiant Energy System (CERES)*[52] sensors measure both solar-reflected and Earth-emitted radiation from the top of the atmosphere to the Earth's surface. Analysis of CERES data contributes to a better understanding of the role of clouds and the energy cycle in global climate change. CERES provides a continuation of the *Earth Radiation Budget Experiment (ERBE).*[53]
- *Advanced Microwave Scanning Radiometer (AMSR)*[54] measures geophysical parameters supporting several global change science and monitoring efforts, including precipitation, oceanic water vapor, cloud water, near-surface wind speed, sea surface temperature, soil moisture, snow cover, and sea ice parameters. The information is provided globally with some exceptions at a spatial scale of 25 km, ranging from daily to monthly.
- *Moderate Resolution Imaging SpectroRadiometer (MODIS)*[55] sensors on Terra and Aqua platforms gather a wide range of parameters including sea surface temperature, land surface temperature, and a number of vegetation indices. This information is provided globally on time scales ranging from twice daily to monthly.
- The sensors on the *Aura* satellite platform, including *Ozone Monitoring Instrument (OMI)*, *Tropospheric Emission Spectrometer (TES)*, *High Resolution Dynamics Limb Sounder (HIRDLS)*, and *Microwave Limb Sounder (MLS)*, measure ozone, trace gases including greenhouse gases (i.e., methane, water vapor), and aerosols within the atmosphere.[56] Establishing a climatology of the distributions and changes of these gases and aerosols will improve atmospheric chemistry modeling and will become important as energy sector stakeholders factor greenhouse gas emissions into their decision planning.
- *SeaWinds*[57] sensor on the *ADEOS-II* satellite monitors sea surface winds and is an important data source to establish wind resource in the open ocean and may help to establish boundary conditions for winds near coastal areas.

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[51] NASA Data Appropriate for Energy Applications, http://appl-policy.saic.com/NASA_Data_Appropriate_For_Energy_Applications.html, Accessed November 15, 2005.
[52] CERES, http://asd-www.larc.nasa.gov/ceres/
[53] ERBE, http://asd-www.larc.nasa.gov/erbe/ASDerbe.html
[54] AMSR, http://weather.msfc.nasa.gov/AMSR/, http://appl-policy.saic.com/AMSR.html,
[55] MODIS, http://modis.gsfc.nasa.gov/, http://appl-policy.saic.com/MODIS_(Data).html
[56] Aura, http://science.hq.nasa.gov/missions/satellite_22.htm
[57] Winds, http://winds.jpl.nasa.gov/missions/seawinds/

- The *Solar and Heliospheric Observatory (SOHO)*[58] and the *Solar Radiation and Climate Experiment (SORCE)*[59] missions are important for the measurement and modeling of the sun's output and its variability. The measurements are key to better understanding the sun and its output for future predictions.
- *Tropical Rainfall Measuring Mission (TRMM)*[60] studies tropical rainfall and enhances understanding of land, air, and sea interactions that impact global rainfall. The information is provided globally on time scales ranging from daily to monthly. This information may serve as an input to NASA global climate models.
- *Jason-1*[61] Satellite gathers sea-surface height data throughout the world. This information contributes to the understanding of ocean circulation and its effect on global climate.
- *Global Precipitation Measurement (GPM)*[62] will initiate the measurement of global precipitation, a key climate factor. This information will be useful in predicting climate and improving the accuracy of weather and precipitation forecasts. This instrument is scheduled for launch in 2010.
- *National Polar-Orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP)*[63] is joint mission intended to follow on the Terra/Aqua missions with the Visible Infrared Imager / Radiometer Suite (VIIRS), Cosmic Ray Isotope Spectrometer (CrIS), Advanced Technology Microwave Sounder (ATMS), and CERES instruments that are aimed to retrieve atmospheric properties (clouds, aerosols, temperatures) and surface properties (temperatures, soil moisture, vegetation types, solar radiation, etc.). This instrument is scheduled for launch in 2006.
- *Orbiting Carbon Observatory (OCO)* [64] is a mission aimed at measuring atmospheric carbon dioxide. These measurements will become important to the energy sector as emissions inventories become an increasingly important factor in energy sector decisions. This instrument is scheduled for launch in 2008.

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[58] SOHO, http://sohowww.nascom.nasa.gov/
[59] SORCE, http://lasp.colorado.edu/sorce/
[60] TRMM, http://trmm.gsfc.nasa.gov/, http://appl-policy.saic.com/TRMM.html
[61] Jason, http://www.nasa.gov/missions/earth/jason_1.html
[62] GPM, http://science.hq.nasa.gov/missions/satellite_57.htm
[63] NPP, http://jointmission.gsfc.nasa.gov/
[64] OCO, http://oco.jpl.nasa.gov/

2.2.3.2 Models

- *Global Ozone Chemistry Aerosol Radiation and Transport (GOCART)*[65] is an atmospheric model that simulates major tropospheric aerosol components. This information is provided globally on a daily basis at a scale of 2° by 2.5°.
- *NASA Goddard Institute of Space Science (GISS) General Circulation*[66] model is a NASA-led climate model used for climate change research. The model is also used in Intergovernmental Panel on Climate Change (IPCC) climate change scenario impact assessments. The scenario assessment simulations could potentially be used for analyzing long-term impacts on energy markets.
- The *Carnegie-Ames-Stanford Approach (CASA)*[67] model simulates fluxes of all major biogenic greenhouse gases and reactive tropospheric gases and includes parameters related to carbon content and ecosystems. This information is provided globally and regionally on a monthly basis.
- *Global Modeling and Assimilation Office (GMAO) Atmosphere*[68] model is a NASA-led unified atmospheric model intended for use in a wide range of applications, including numerical weather prediction, data assimilation, seasonal forecasting, climate prediction, atmospheric chemistry studies, atmosphere land interactions, and prediction of extreme weather events. The output from this model may feed into long-term forecasting, including climate change analysis.
- *NASA Seasonal to Interannual Prediction Project (NSIPP)*[69] is focused on coupled (ocean-atmosphere-land-surface) climate modeling and prediction and on ocean and land data assimilation.

2.2.3.3 Analysis Packages and Prototypes

- *Surface Meteorology and Solar Energy (SSE) prototype website*[70] (as part of NASA's Prediction Of Worldwide Energy Resource [POWER] project) is a renewable energy resource website that provides online more than 200 satellite-derived meteorology and solar

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[65] GOCART, http://appl-policy.saic.com/GOCART.html, http://code916.gsfc.nasa.gov/People/Chin/gocartinfo.html
[66] GISS, http://www.giss.nasa.gov/research/modeling/gcms.html
[67] CASA, http://geo.arc.nasa.gov/sge/casa/, http://appl-policy.saic.com/CASA_(Data_Set).html
[68] GMAO Atmosphere, http://www.esa.ssc.nasa.gov/m2m/model_report.aspx?model_id=101, http://www.esa.ssc.nasa.gov/m2m/model_report.aspx?model_id=113
[69] GMAO, http://gmao.gsfc.nasa.gov/aboutgmao.php
[70] Surface Meteorology and Solar Energy database, Release 5.1, http://eosweb.larc.nasa.gov/sse/. Accessed July 27, 2005.

energy parameters, both directly as datasets and charts, and as input to decision support systems.

- *Global Energy and Water Cycle Experiment (GEWEX)*[71] includes a number of components such as the International Satellite Cloud Climatology Project (ISCCP), the Surface Radiation Budget (SRB) project, and the Global Precipitation Climatology Project (GPCP), all of which are used to contribute to SSE and provide data on the Earth's water and energy cycle.

2.2.4 Benefits

Improved long-term forecasting assists energy planners in achieving the GEOSS societal benefit of improving management of energy resources, specifically better energy planning, adaptation to climate variability, and reduction of risk to energy infrastructure due to climate change. In addition, 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. Creating a better understanding of the causes, uncertainty, and spatial and temporal distribution and impacts of climate change will have great societal benefit by fostering an environment for more informed policy decisions that affect the energy sector and society as a whole. It is important to note that the energy sector end users would be most interested in the results of the climate models, including predictions and uncertainty, not in the data from many of the sensors listed here that feed the models.

2.3 Biomass and Hydroelectric Renewable Energy

2.3.1 Description

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."[72] NASA datasets have been valuable to the solar and wind energy sector through the identification of available peak solar and wind resources, most notably the SSE prototype website.[73]

Of the other significant forms of renewable energy, hydroelectric and biomass are the most promising for new application of NASA datasets. There are approximately 75,000 dams in the United

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[71] GEWEX, http://www.gewex.org/

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

[73] Surface Meteorology and Solar Energy database, Release 5.1, http://eosweb.larc.nasa.gov/sse/. Accessed July 27, 2005.

States,[74] of which 3% are used for hydroelectric power generation.[75] Hydroelectric power is an established energy source; the total U.S. hydroelectric capacity (including pumped storage) is 103.8 GW (8 to 12% of total U.S. electricity generation) and 20% of the electricity in the world.[76] Washington, California, Oregon, and New York generate over 60% of the U.S. conventional hydropower.[77]

Biomass energy includes liquid fuels, electricity, and industrial heat/steam derived from plants and plant-derived materials, including wood, food crops, grassy and woody plants, residues from agriculture or forestry, and the organic component of municipal and industrial wastes.[78] Biomass is the only renewable source of liquid fuels, including biodiesel (animal fat or vegetable oil transformed with alcohol as a substitute or blend for diesel fuel) and ethanol (grain, especially corn, alcohol used as an alternative fuel or as an octane-boosting, pollution-reducing gasoline additive).[79] Electricity is generated by direct firing biomass or cofiring with fossil fuels to run gas or steam turbines to generate electricity. Biomass is the largest source of non-hydro renewable electricity.[80] The industrial sector, particularly the paper, chemical, and food-processing industries, produces heat, steam, and electricity from biomass primarily from combined heat and power facilities. The forest products industry consumes 85% of all wood waste used for energy in the U.S.[81]

While hydroelectric and biomass are very different sources of renewable energy, they are linked by their dependence on water and precipitation. In the western U.S. particularly, agriculture and electricity are dependent on the water stored in reservoirs; thus key measurements include rainfall, reservoir height, and snowpack. For example, the EIA uses meteorology data (specifically precipitation)

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[74] Graf, W. L., Dam nation: A geographic census of American dams and their large-scale hydrologic impacts, Water Resources Research 35, 1305-1311, April 1999.
[75] Hydro Facts, National Hydropower Association, http://www.hydro.org/hydrofacts/facts.asp. Accessed November 2, 2005.
[76] Ibid.
[77] Net Generation from Hydroelectric (Conventional) Power by State by Sector (Table 1.13.b), Electric Power Monthly, DOE/EIA-0226 (2005/11), November 2005 with data for August 2005, Energy Information Administration, U.S. Department of Energy, Washington, DC. Also available at http://www.eia.doe.gov/cneaf/electricity/epm/table1_13_b.html.
[78] Biomass Energy Basics, Learning about Renewable Energy and Energy Efficiency, National Renewable Energy Laboratory, http://www.nrel.gov/learning/re_biomass.html, Accessed November 15, 2005.
[79] Biomass Program, Energy Efficiency and Renewable Energy, U.S. Department of Energy, http://www.eere.energy.gov/biomass/, Accessed November 15, 2005.
[80] Renewable Energy Trends 2003 with Preliminary Data For 2003, DOE/EIA-0603, Energy Information Administration, U.S. Department of Energy, Washington, DC, July 2004. Available at http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/rea.pdf.
[81] Biomass Program, Energy Efficiency and Renewable Energy, U.S. Department of Energy, http://www.eere.energy.gov/biomass/industrial_process.html, Accessed November 15, 2005.

from the NOAA National Data Climatic Center to assess hydroelectric power production.[82] Availability of surplus corn for ethanol and soybeans for biodiesel depends on crop yields that are highly dependent on precipitation and availability of water for irrigation. Thus, the two largest renewable energy sources are closely linked by water resources.

2.3.2 Organizations and Decision Support Systems

The organizations involved in hydro and biomass energy include key federal agencies; the public, semi-public, and private organizations that run hydroelectric facilities; and non-profit industry associations. Following is a selection of the key organizations and programs.

2.3.2.1 DOE Hydropower Program

As an established energy source, hydroelectric power has a separate program at the U.S. DOE Office of Wind and Hydropower Technologies. The mission of the DOE Hydropower program is to "conduct research and development… that will improve the technical, societal, and environmental benefits of hydropower and provide cost-competitive technologies that enable the development of new and incremental hydropower capacity, adding diversity to the nation's energy supply."[83] In addition to coordination at DOE in Washington DC, the program is primarily implemented at three DOE National Laboratories with leads in three areas:

- Idaho National Laboratory (INL), engineering and program management
- Oak Ridge National Laboratory (ORNL), environmental and computational support
- Pacific Northwest National Laboratory (PNNL), biological testing and technology development studies, including fish and test facilities.[84]

The focus of the DOE Hydropower Program is research and development. The program has conducted or sponsored research in areas such as advanced turbines, hydrology and geomorphology relevant to impacts on fish, contributions related to carbon dioxide reduction, hydropower resource assessment, and technology transfer. The program's decision support systems include the Hydropower Evaluation Software to evaluate the environmental impact of hydropower sites, Virtual Hydropower Prospector to locate and assess natural stream water energy resources, and state and national hydropower

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[82] Hydroelectric, Renewables, Energy Information Administration, http://www.eia.doe.gov/cneaf/solar.renewables/page/hydroelec/hydroelec.html, Accessed November 15, 2005.
[83] Hydropower, Idaho National Laboratory, http://hydropower.id.doe.gov/, Accessed 23 November 2005.
[84] Ibid.

resource assessment reports. Coordination with the DOE Hydropower Program would be a natural for NASA with its existing relationships with DOE and several national laboratories.

2.3.2.2 Hydroelectric Facility Operators

Hydroelectric facilities in the U.S. are operated by both federal and non-federal organizations, with the larger dams operated by the federal government. Non-federal, licensed conventional hydroelectric capacity is 40.0 GW at 2,162 sites in the U.S; the federal government has 38.2 GW at 165 sites.[85] The National Hydropower Association[86] is an industry group that represents the hydropower industry, including state and private operators of hydroelectric facilities. While their mandate includes advocacy, they also sponsor research and annual and regional conferences.[87]

The federally run hydroelectric power plants are operated by agencies with varying degrees of federal support and authority. For example, the Tennessee Valley Authority (TVA) is a federal corporation and the largest U.S. public power company; TVA operates 29 dams.[88] The U.S. Army Corps of Engineers (USACE) operates 75 hydroelectric facilities producing one-fourth of the U.S. electric power.[89] The USACE Institute for Water Resources[90] supports some of the decision support systems for hydroelectric power, such as the Hydrological Modeling System.[91] The Bonneville Power Administration is a federal agency under the U.S. DOE that markets power and transmission services for 21 dams operated by the U.S. Army Corps of Engineers and 10 dams operated by the Bureau of Reclamation.[92] As part of their operations, the facilities use temperature, precipitation, stream flow volume, snowpack/runoff, and reservoir height to make decisions in operations. For the Pacific Northwest, these data are provided by NOAA's National Weather Service Northwest River Forecast Center.[93] For other regions, the data appear to come from a combination of National Weather Service and gauges and monitors operated by the organizations running the dams. It is recommended that NASA initially focus on the large federally run dams, such as USACE, Bureau of Reclamation, and TVA. As larger facilities with more centralized federal coordination than at the smaller private dams, initial coordination and

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[85] Ibid.
[86] National Hydropower Association, http://www.hydro.org/, Accessed 23 November 2005.
[87] The National Hydropower Association's next annual conference is April 2-5, 2006 in Washington DC.
[88] Tennessee Valley Authority, http://www.tva.gov/, Accessed 23 November 2005.
[89] USACE, Services for the Public, http://www.usace.army.mil/public.html, Access 23 November 2005.
[90] USACE Institute for Water Resources, http://www.iwr.usace.army.mil/, Accessed 23 November 2005.
[91] HEC-HMS, Hydrologic Modeling System, http://www.hec.usace.army.mil/software/hec-hms/hechms-hechms.html, Accessed 23 November 2005.
[92] Bonneville Power Administration, http://www.bpa.gov/, Accessed 23 November 2005. Also, BPA Fast Facts, May 2005, Available at http://www.bpa.gov/corporate/about_BPA/Facts/FactDocs/BPA_Facts_2004.pdf.
[93] NOAA National Weather Service Northwest River Forecast Center, http://www.nwrfc.noaa.gov/, Accessed 23 November 2005.

integration of NASA information into their decision support systems would be more streamlined. Successful applications could be made available to smaller facilities in the long term.

2.3.2.3 DOE and USDA Biomass Programs

The development of biomass energy was given a federal priority through the Biomass Research and Development Act of 2000 (Title III of P.L.106-224) and the subsequent Energy Policy Act of 2005, which authorized funding and launched federal initiatives to promote the use of biomass energy sources and biobased products. One of those programs is the Biomass Research and Development Initiative, a partnership among DOE, USDA, and other Federal agencies to coordinate and accelerate all Federal biobased products and bioenergy research and development.[94] They recently announced a joint USDA-DOE solicitation for research on the development of biomass based products, bioenergy, biofuels, and related processes; up to $2 million in DOE funding and $12 million in USDA funding are available for this solicitation.

NREL coordinates the biomass research and development programs and activities as the lead DOE National Laboratory. NREL's Biomass Program focuses on biomass characterization, thermochemical and biochemical biomass conversion technologies, biobased products development, and biomass process engineering and analysis, as well as biomass in photochemical and environmental applications.[95] NREL is also the lead national laboratory of the National Bioenergy Center. The National Bioenergy Center supports and coordinates national biomass research, including implementing the agenda of the DOE Office of the Biomass Program. The Center is a collaboration of industrial, academic, related Office of Energy Efficiency and Renewable Energy (EERE) programs, and other governmental research, development, and commercialization efforts.[96]

NASA has long-standing partnerships with USDA that demonstrated that measurements from Earth observing spacecraft provide valuable information on crop production, yield, and condition.[97] Current work with the USDA National Agricultural Statistics Service and Foreign Agricultural Service (USDA-FAS) has focused on global and domestic crop assessments to assist end users in making decisions on planting, harvesting, marketing, commodity export and pricing, drought monitoring, and

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[94] Biomass Research and Development Initiative, http://www.bioproducts-bioenergy.gov/
[95] NREL Biomass Research, http://www.nrel.gov/biomass/, Access 23 November 2005.
[96] Ibid.
[97] Agricultural Efficiency Program Element FY 2005-2009 Plan, NASA Science Mission Directorate, Earth-Sun System Applied Sciences Program, Version 1.2, March 15, 2005.

food assistance.[98] NASA science data products related to leaf area index, normalized difference vegetation index, precipitation, and soil moisture are used to assess crops and productivity, including crops such as soybeans that are relevant to biomass energy.

With the 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.[99] The program is designed for monitoring droughts, crop production, and irrigation, and thus is relevant to biomass. Similar datasets could be used for hydroelectric power planning, providing a dual application related to water resources.

2.3.3 Recommendations to NASA for Further Involvement

Application of NASA science data products and models to renewable energy is established and successful in several keys areas (e.g., solar, wind). Potential for continuation in these established fields is high, but as a research agency, NASA should begin to explore new sectors such as hydroelectric and biomass within the renewable market. The renewable energy field, including research and new applications, is still developing and thus is generally open to the use of new and innovative datasets. The critical ingredient for success is the involvement of champions from both NASA and the relevant energy sector. As a basic first step, increased participation of NASA Energy staff in DOE workshops on renewable resources and other relevant meetings of experts from the renewable sector would begin to develop the understanding needed to apply NASA resources to new areas of the renewable energy sector. NASA has recently begun to participate in these events, which has yielded some promising potential partnerships. Through these events and work in solar and wind energy, NASA has established relationships with leading organizations in renewable energy, particularly NREL, which could lead to contacts beyond solar and wind energy.

Another consideration is that hydroelectric power is a mature energy source and major reservoirs have been completed. Nevertheless, the operation and relicensing of these facilities require considerable amounts of environmental information. The construction of dams internationally continues while developing nations seek new sources of power. Issues such as endangered fish, overallocated water resources, and climatic weather changes also depend on new and better sources of information on water

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[98] Ibid.
[99] Global Reservoir and Lake Monitor, http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/, Accessed July 27, 2005.

availability and use, which NASA science data products and models may be able to provide. One example of a relevant project that NASA is already funding focuses on improving water resources management in the Western U.S. through the use of remote sensing data (e.g., snow cover and soil moisture data) and seasonal climate forecasts.[100]

Key general areas where NASA resources are applicable for renewable energy are the identification of the quantity of resources, location for siting generation facilities, and the planning and optimization of production. (For discussion of the potential application of NASA resources to renewable distributed energy resources and grid interconnection, refer to Section 3.1). NASA has existing initiatives relevant to hydroelectric and biomass that should be approached for further development. General potentially relevant NASA resources relevant to hydroelectric and biomass energy include:

- Solar radiation and angle
- Meteorology data, specifically wind speed, cloud cover, aerosols, and rainfall
- Surface properties including vegetation, soil type, surface temperatures, soil moisture, and snow cover
- Biomass parameters
- Reservoir height
- Water availability.

Below are details on existing initiatives, programs, and sensors that are recommended to further develop the application of NASA resources to hydroelectric and biomass renewable energy.

2.3.3.1 Current and Future Sensors

- *Advanced Microwave Scanning Radiometer (AMSR)* (see section 2.1.3.1), specifically snow water equivalent.
- *Moderate Resolution Imaging Spectroradiometer (MODIS)* (see section 2.1.3.1), specifically snow cover and normalized difference vegetation index (NDVI).
- *Gravity Recover and Climate Experiment (GRACE)*[101]satellites, which measure the Earth's gravity field and would be applicable for hydroelectric and water allocation through its identification of regional-scale changes in terrestrial water storage, including ground water, surface water, and snowpack.

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[100] Lettenmaier, Dennis. University of Washington: Improving Water Resources Management in the Western U.S. through Use of Remote Sensing Data and Seasonal Climate Forecasts. Award announcement at http://research.hq.nasa.gov/code_y/nra/current/NNH04ZYO010C/winners.html.
[101] GRACE, http://www.csr.utexas.edu/grace/

- *Landsat*[102] and *Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)*[103] (on *Terra*) missions are aimed at mapping the Earth's surface at high resolution to determine vegetation, soil types, and other land surface related parameters.
- *Landsat Data Continuity Mission (LDCM)*[104] is a planned continuation of the Landsat program as noted above. This instrument is scheduled for launch in 2006.

2.3.3.2 Models

- *Global Reservoir and Lake Monitor.* With the USDA-FAS, NASA and other partners are monitoring and modeling lake and reservoir height variations for approximately 100 lakes located around the world.[105] This project has applied radar altimeter data from *TOPEX/Poseidon* and its followup mission, *Jason-1*,[106] to provide time-series of water level variations for some of the world's largest lakes and reservoirs.[107] While the program is designed for monitoring droughts, crop production, and irrigation, similar datasets could be used for hydroelectric power and could assist in predicting biomass crop yields in irrigated regions.

2.3.3.3 Analysis Packages and Prototypes

- *RiverWare and AWARDS ET-Toolbox.* The NASA Goddard Space Flight Center (GSFC) Hydrological Sciences Branch is developing, testing, and applying algorithms for multiple remote sensors to develop relevant measures, such as soil moisture content, snow mass, precipitation, evapotranspiration, and vegetation density.[108] They have partnered with the U.S. Bureau of Reclamation to "integrate, validate, and benchmark NASA Earth Science products, involving a suite of remotely sensed datasets and model produced output, in two heavily used decision support systems at Reclamation: (1) RiverWare and (2) the Agricultural WAter Resources Decision Support system, Evapotranspiration Toolbox (AWARDS ET-Toolbox)."[109] They are combining land surface modeling (e.g., Land

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[102] Landsat 7, http://landsat.gsfc.nasa.gov/
[103] ASTER, http://asterweb.jpl.nasa.gov/
[104] LDCM, http://ldcm.usgs.gov/
[105] Global Reservoir and Lake Monitor, http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/. Accessed July 27, 2005.
[106] Jason-1, http://oceantopo.jpl.nasa.gov/mission/jason-1.html
[107] Ibid, Accessed November 23, 2005.
[108] NASA Goddard Space Flight Center, Hydrological Sciences Branch Code 614.3, http://neptune.gsfc.nasa.gov/hsb/, Accessed November 23, 2005.
[109] RiverWare and AWARDS ET-Toolbox – 2005 Annual Report, NASA Science Mission Directorate, Earth Science Water Management Application Program, November 10, 2005.

Information System) with satellite products for snow cover (e.g., snow water equivalent), and evaporation and moisture into models for streamflow forecasting and decision support systems for reservoir regulation.[110]

- *Pacific Northwest Regional Collaboratory Water Resource Forecasting*. The Pacific Northwest Regional Collaboratory is a NASA-funded collaboration of Federal, state, tribal, and private organizations in the U.S. Pacific Northwest whose mission is to increase to application of NASA and other earth monitoring resources in the region.[111] One of their initiatives is to improve water resource and streamflow forecasting in snow-dominated basins in the Pacific Northwest, important to hydroelectric and agricultural water resource managers in the region. Specifically, the project incorporates remote sensing data such as Landsat into models to support streamflow prediction, such as the Snowmelt Runoff Model and the Distributed Hydrologic Soil Vegetation Model.[112] If this initiative proves successful, then a more specific link to the hydroelectric dams operated in the region by the U.S. Army Corps of Engineers and the U.S. Bureau of Reclamation could be possible.

2.3.4 Benefits

As the U.S. and the world seek to diversify energy sources, promote renewables, and mitigate climate change, the application of new datasets to optimize the development of renewables will yield both short- and long-term benefits. Since renewable energy sources are essentially carbonless sources of energy, the advancement of renewables also aligns with CCSP and CCTP. Renewable energy is included under the GEOSS societal benefit area to better 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).[113,114] NASA's work supporting solar and wind energy make it a trusted partner and its consistent global datasets, when made easily available to specialists in the renewable sector, are highly applicable. Hydroelectric and biomass power are the two largest renewable energy sources that would benefit from additional data, enabling their expansion in a manner that maximizes overall environmental benefit.

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[110] Conversation between Jill Engel-Cox and David Toll, Hydrological Sciences Branch, NASA Goddard Space Flight Center, 301-614-5801, david.l.toll@nasa.gov, December 9, 2005.
[111] Pacific Northwest Regional Collaborative, http://www.pnwrc.org/, Accessed November 23, 2005.
[112] Pacific Northwest Water Resources Research, http://waterresources.pnwrc.org/, Accessed November 23, 2005.
[113] Global Earth Observation System of Systems, GEOSS, 10-Year Implementation Plan, Group on Earth Observations, GEO 1000, February 2005.
[114] Global Earth Observation System of Systems, GEOSS, 10-Year Implementation Plan Reference Document, Group on Earth Observations, GEO 1000R, February 2005.

3.0 SECONDARY/LONG-TERM FOCUS AREAS

Two other energy management areas are secondary focus areas with a moderate potential for new or expanded application of NASA Earth science resources, presenting opportunities that are likely to be long-term rather than near-term: (1) Distributed Energy Generation and Grid Integration, and (2) Space Weather Impacts on Transmission Lines. For each of these areas, this section provides a description, recommendations to NASA for further involvement, and a brief assessment of the benefits of new or expanded NASA involvement in the area.

3.1 Distributed Energy Generation and Grid Integration

3.1.1 Description

Distributed energy generation is the use of 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. While distributed energy sources can use non-renewable (e.g., diesel generators) and renewable (e.g., solar roof) energy sources, this section focuses primarily on renewable energy sources as they may benefit most from NASA science data products.

The two key issues related to the advancement of distributed energy generation are selection and use of the appropriate energy source (e.g., solar, wind, microhydro) to the location and the integration into the larger electrical grid, where unused energy would be incorporated into the larger energy network. The first requires a decision by an independent person or organization that may need information about the available energy resources for a specific location. The second is important to the local and regional power authorities who are required to buy the excess power and who wish to maximize the use of inexpensive power sources on the grid. 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. In this latter case, the integration and operation of distributed energy sources ties closely with supply and load forecasting (section 2.1).

3.1.2 *Organizations and Decision Support Systems*

For the individual decision making of choosing, siting and maintaining distributed energy sources, the organizations and programs relevant to the application of renewable energy would be directly applicable. This includes the database and decision support systems under the NASA POWER project, such as SSE and National Solar Radiation Database (with DOE NREL), RETScreen (with CANMET), and the Solar Sizer (with the Center for Renewable Energy and Sustainable Technology and Solar Energy International).

Distributed energy is being addressed by NREL through 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. HOMER is a model for specific distributed energy projects, although NREL has run the system for an entire state as a means of more regional planning.[115] HOMER is most used for off- and on-grid modeling of solar energy systems, and NASA is currently indirectly supporting this effort through its partnership with NREL aimed at improving the National Solar Radiation Database. However, a survey of HOMER's 9,000 users (with responses from about 1,000 users) revealed that 13% used HOMER for modeling hydroelectric runoff to the river systems, and another 13% modeled biomass gasification systems.[116] This survey highlighted for HOMER managers significant data needs that could be addressed through NASA resources, including:

- Hourly temperature data synchronized with solar radiation data
- Regional low-cost hourly or daily wind resources data to supplement airport based TMY data and an algorithm to convert NASA wind data to a relevant surface wind speed
- Monthly streamflow for small and micro-scale hydropower
- Monthly geospatial biomass resources analysis.[117]

For the operation of a distributed energy system, many of the same organizations relevant to supply and load forecasting are important. This includes EPRI and the NOAA Climate Diagnostics Center. 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

[115] Conversation between Jill Engel-Cox, Battelle, and Peter Lilienthal, Senior Economist, International Programs, National Renewable Energy Laboratory, 303-384-7444, Peter_Lilienthal@nrel.gov, December 9, 2005.
[116] Ibid.
[117] Ibid.

monitoring technologies and operational concepts to enhance the integration and aggregation of distributed energy resources with electric power systems.[118]

3.1.3 Recommendations to NASA for Further Involvement

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. Specifically, NASA should work with NREL to make the current decision support systems (e.g., HOMER) for siting renewable energy applicable to designing distributed energy systems. This may be as simple as initiating a discussion of how distributed energy works and enhancing the datasets for the renewable energy modules to estimate the energy flow to and from the grid under varying solar and wind conditions. Making this kind of planning software available online would enable individuals and small organizations to select the optimal distributed energy source(s) for their location. The advantage of this approach is that it builds on existing systems, relationships, and end users.

Applications by public power suppliers should be incorporated into efforts in supply and load forecasting (see section 2.1). An excellent opportunity would be to address the specific data needs of HOMER as related to distributed renewables, including solar, wind, micro-hydro, and biomass.

3.1.4 Benefits

Many renewable energy sources benefit from distributed generation. For example, the surface area required by solar panels benefits from application on multiple building roofs rather than large solar power installations. Distributed energy also potentially increases grid reliability and energy independence. Better data in the siting and utilization of these distributed energy sources could promote their use. Additionally, the CCTP emphasizes distributed generation as a means to promote carbon-free energy sources throughout the world.

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[118] 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.

3.2 Space Weather Impacts on Transmission Systems

3.2.1 Description

The electrical grid consists of a network of interconnected electric transmission line grids that span the continent and provide rapid response to the diverse energy demands of users in the United States, Mexico, and Canada. This unique energy service requires instantaneous coordination of electrical supply, demand, and delivery. Solar activity can disrupt these complex power grids, and many portions of the North American power grid are vulnerable to geomagnetic storms, especially in the northern latitudes. Variations in ionized particles carried by the solar wind hitting the Earth's magnetic field can cause sudden and severe magnetic storms, subjecting portions of the Earth's surface to fluctuations in the planet's normally stable magnetic field. When this occurs, strong geomagnetically induced currents (GICs) can flow through the electrical power system. These fluctuations induce electric fields in the Earth that create potential differences in voltage between grounding points, which in turn cause GICs to flow through transformers, power system lines, and grounding points. Transformer operations can be disrupted by only a few amps, and in fact over 100 amps have been measured in the grounding connections of transformers in affected areas.[119]

On October 30, 2003, the U.S. House of Representatives Subcommittee on Environment, Technology and Standards convened a session titled "What is Space Weather and who should forecast it?" The following is an excerpt from the testimony given:

> …Space weather or geomagnetic disturbances directly attack the high voltage transmission circulatory system and because both have continental footprints, these disturbances can rapidly erode reliability of these infrastructures and can therefore threaten widespread blackout for extreme disturbance events. Space weather differs from ordinary weather in that it has a big footprint and attacks the system across many points simultaneously, causing at times of severe events multi-point failures on the network that can threaten the integrity of the network. Therefore, geomagnetic storms may be one of the most important hazards and is [sic] certainly the least understood threat that could be posed to the reliable operation of these networks... [120]

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[119] John Kappenman. Geomagnetic Storms Can Threaten Electric Power Grid. Earth in Space, Vol. 9, No. 7, March 1997, pp.9-11. Available at http://www.agu.org/sci_soc/eiskappenman.html.
[120] US House of Representatives, Subcommittee on Environment, Technology and Standards, "What is Space Weather and who should forecast it?", Testimony by John Kappenman, Manager, Applied Power Systems, Metatech Corporation, http://www.metatech-aps.com/Advisories.html, October 30, 2003, Accessed November 16, 2005.

Both satellite and ground-based sensors can detect geomagnetic storms and can send warnings and forecasts to those that may be affected. Information on space weather is currently collected by NASA, NOAA, and military satellites, and is collected and disseminated through the organizations discussed in the following section.

3.2.2 Organizations and Decision Support Systems

A number of stakeholders are involved in collecting data, providing forecasts and warnings, and conducting analysis of specific electric transmission systems with regard to space weather impacts. The major organization that provides real-time monitoring and forecasting of solar and geophysical events is the NOAA Space Environment Center (SEC), drawing upon multiple sources of data including NASA satellite data. A number of commercial vendors also draw upon outputs from the SEC in providing tailored forecasts and analysis to utilities and transmission operators. EPRI has also established a service for electric utilities focused on space weather impacts.

3.2.2.1 Space Environment Center

The NOAA-National Weather Service SEC[121] is one of the nine National Centers for Environmental Prediction; it provides real-time monitoring and forecasting of solar and geophysical events, conducts research in solar-terrestrial physics, and develops techniques for forecasting solar and geophysical disturbances. The SEC Forecast Center is jointly operated by NOAA and the U.S. Air Force and is the national and world warning center for disturbances that can affect people and equipment working in the space environment. The SEC continually monitors and forecasts Earth's space environment; provides solar-terrestrial information; conducts and leads research and development programs to understand the environment and to improve services; advises policy makers and planners; plays a leadership role in the space weather community; and fosters a space weather services industry. Forecasters at SEC provide space weather forecasts and warnings to users in government and industry and to the general public, while the Air Force and private-sector users take these forecasts and tailor them for their organizations' specific needs. The SEC works with many national and international partners who contribute data and observations. NASA provides many of the satellites on which the relevant sensors are carried.

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[121] NOAA National Weather Service Space Environment Center, http://www.sec.noaa.gov/index.html, Accessed November 16, 2005.

3.2.2.2 Commercial Vendors

A number of commercial vendors provide geomagnetic storm forecast services to electric power industry end-users. For example, Metatech Corporation[122] provides continuous space weather forecasting services for companies that operate the electric power grids of England and Wales, and has supported vulnerability and risk assessments for the U.S. electric power grid. Because the SEC provides only a broad and generic level of service to end-users of space weather forecasts, these services are not well formatted to extrapolate potential impacts to complex technology systems such as electric power grids. Therefore, a need for targeted information has developed and is being filled by the private sector to provide highly specialized forecast services to end-users. This service sector came into development over the past several years. As an example of the services of one provider, Metatech provides notifications that range from one hour in advance to several days in advance, along with longer-term forecasts that provide a general outlook for a period of several years into the future. In addition, Metatech provides continuous real-time observations to verify impacts that are being caused by a storm occurrence.[123]

3.2.2.3 Electric Power Research Institute

EPRI has a long history of involvement in space weather impacts on electricity infrastructure. One current EPRI project related to space weather is the SUNBURST Network for Geomagnetic Current.[124] This network is available to member electric utilities that subscribe to this service, providing advanced warnings and near real-time data to operators via the Internet. The network combines GIC information from ground-based monitors and compares this information to satellite-based information from the NASA Advanced Composition Explorer satellite. The network provides a number of information products including displays summarizing the current state of the system, summaries of warnings and past GIC activity, and graphs of individual site data. EPRI encourages participation by U.S. utilities above the 30th parallel and European utilities above the 40th parallel. EPRI has expressed interest in collaboration with NASA focused on comparison and verification of ground-based and satellite-based data.[125]

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[122] Metatech Corporation, http://www.metatechcorp.com/aps/apsmain.html, Accessed November 17, 2005.
[123] US House of Representatives Subcommittee on Science Testimony, Testimony of John Kappenman, October 13, 2003, http://www.metatech-aps.com/Advisories.html, Accessed November 17, 2005.
[124] Electric Power Research Institute, SUNBURST Network for Geomagnetic Current, Project Opportunity, 2005, http://www.epriweb.com/public/000000000001011779.pdf, Accessed November 17, 2005.
[125] Conversation between Erica Zell, Battelle, and Barry Ward, Electric Power Research Institute, 650-855- 2717, November 17, 2005.

3.2.3 Recommendations to NASA for Further Involvement

NASA is already involved in gathering and analyzing data related to solar activity and geomagnetic storms. For example, NASA's *Advanced Composition Explorer (ACE)* [126]satellite and resulting solar and wind monitoring greatly improved the capability to provide accurate short-term forecasts of severe geomagnetic storm events. The *Solar and Heliospheric Observatory (SOHO)*[127] is important for the measurement and modeling of the sun's output and variability.

NASA has been less involved in the application end of this issue, such as in providing direct input to decision-support systems, geographically tailored information, and longer lead times on warnings of geomagnetic storms. (One notable exception is that NASA is involved in aviation impacts of space weather through a project with the High Altitude Observatory at the National Center for Atmospheric Research). While it appears that the electric utility sector needs are being addressed by the combination of the SEC, EPRI, and commercial vendors, there may still be opportunities for increased integration of NASA science data products, models, and forecasts. Care would need to be taken to avoid interfering with private-sector functions. More in-depth interviews with the major stakeholders discussed above may yield opportunities to address shortcomings and collaborate with ongoing NASA work.

3.2.4 Benefits

Oak Ridge National Laboratory estimated that a solar storm event only slightly stronger than the one that caused the Quebec blackout in 1989 could involve the Northeast United States in a cascading blackout. The experts figured that about $3 to $6 billion in damages and lost wages could result from such a widespread involvement. [128] The North American Electric Reliability Council placed the March 1989 and October 1991 storm events in a category equivalent to Hurricane Hugo or the 1989 Loma Prieta Earthquake in San Francisco. But, many consultants for the power industry dispute this estimate, saying that it is much too low. The $6 billion estimate may not properly include collateral impacts such as lost wages and productivity, spoiled food, and a myriad of other human costs that could easily run the losses into the tens of billions of dollars and impact more than 100 million people.[129]

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[126] Advanced Composition Explorer, http://www.srl.caltech.edu/ACE/
[127] http://sohowww.nascom.nasa.gov/
[128] John Kappenman, Geomagnetic Storms Can Threaten Electric Power Grid, Earth in Space, Vol. 9, No. 7, March 1997, pp. 9-11. Available at http://www.agu.org/sci_soc/eiskappenman.html.
[129] Ibid.

In 1998, NOAA's SEC forecasters were able to alert electric power customers 40 minutes before a similar geomagnetic storm hit the Earth. In response, electric power utilities diverted power and increased safety margins on certain parts of the grid to avoid stress on the power system. This example demonstrates the benefits of the NASA science data products that feed into the SEC, ultimately preventing equipment damage and power failure.[130]

[130] US House of Representatives, Subcommittee on Environment, Technology and Standards, Hearing Charter, "What is Space Weather and who should forecast it?", http://www.house.gov/science/hearings/ets03/oct30/charter.pdf, October 30, 2003, Accessed November 16, 2005.

4.0 NASA ENERGY MANAGEMENT PROGRAM ELEMENT DIRECTION AND PRIORITIZATION

NASA Earth science has unique capabilities and resources to monitor the Earth's environment, including energy resources and parameters related to energy demand, management, and impacts. NASA has also developed models to inform various aspects of energy management. To maximize the use of NASA science data products and models for energy management, it is important for the Energy Management Program to implement a process to periodically survey the energy management arena, maintain contact with key experts and stakeholders, and develop partnerships around both existing and potential new decision-support systems.

This report serves as a baseline survey of energy management. A preliminary engagement of interested parties and potential stakeholders occurred in a breakout session on "Earth Observation Systems and Energy Programs" at the National Council for Science and the Environment's national conference.[131] The breakout session participants represented government agencies, academia, private industry, and private citizens. The participants developed a set of recommendations to improve the use of remote sensing for energy management. The recommendations relevant to NASA were as follows:[132]

- Driven by the requirements of the private energy sector, NASA, NOAA, and NSF should work together to determine the value of earth observation systems and then plan and create long-term data sets and operational sensor networks for energy applications:
  - NASA, NOAA, DOD, DOE, and USGS should fund the next generation of sensors to provide data needed for energy management.
  - NASA and NOAA should communicate more with the private energy sector and with DOE to develop better earth observation products through research that adds value to the products.
- NASA should identify prototype projects that link researchers and energy sector end users to demonstrate the use of earth observation data for energy projects for technical and economic benefits.

[131] National Council for Science and the Environment, 6th National Conference, Energy for a Sustainable and Secure Future, Washington, D.C., January 26-27, 2006.
[132] The full set of recommendations will be available at the conference website, http://www.ncseonline.org/ncseconference/2006conference/.

The key points in these recommendations are better communication and prototyping of projects to foster the development of partnerships and more useful products for the energy sector. To that end, a working group composed of a range of research-oriented experts, government decision-makers, and energy sector end-users would be a beneficial first step. This working group may draw upon their own experiences along with available literature sources to identify current and evolving issues and prioritize areas that may offer the greatest potential for new NASA applications. Based upon their suggestions, additional focused feasibility studies or surveys may be conducted to narrow down potential new prototypes to be developed with specific partners. The joint development of rapid prototypes will enable the funding and support for full-scale integration of NASA resources into energy sector-relevant decision support systems.

The formation of a working group would have the additional advantage of creating connections between NASA and various energy sector stakeholders. The current method that the NASA Energy Management Program utilizes for making connections between its products and energy sector stakeholders leaves stakeholder involvement as one of the last steps. The involvement of stakeholders at an earlier stage would allow them to help guide and direct the data and models that would be most useful for their own decision needs. Further, NASA should consider partnering with stakeholders at such an early stage that the actual development of a decision-support system by a partner can be based on integration of current or future NASA science data products. In the case of solar energy, the involvement of dedicated grassroots stakeholders in the solar energy field and a focused national laboratory significantly improved the availability and usability of NASA solar energy relevant data. This model should be applied to other renewable and distributed energy applications. For more centralized initiatives, such as federally run hydroelectric facilities and medium- and long-term energy forecasting, working with a core set of existing partners, specifically the USACE and the U.S. DOE (EIA, NREL, and other national laboratories), would be the most effective means to bring NASA resources to the energy sector.

An issue that has already been raised by energy sector experts, and which may be further focused through involvement of the working group, is the importance of regional information for energy sector planning. More broadly, the NASA Energy Management Program should consider both the spatial and temporal scale of data that are needed to support decisions by various stakeholders. Decisionmakers in government may need information ranging from a global or national to regional or local scale. On the other hand, individual electric utilities are likely to need local or regional information for planning and operation at the facility or local infrastructure level.

Overall, the Energy Management Program needs to focus on continuing to improve involvement with others in the energy sector through presentations and meetings at key events, developing projects with specific partners, and formalizing stakeholder input and communications.

5.0 CONCLUSIONS AND GENERAL RECOMMENDATIONS

This report examines selected energy management areas, focusing on the major organizations and decision support tools with the greatest potential for application of NASA science data products and models. This report also includes discussion of the direction and establishment of priorities for the NASA Energy Management Program Element. Based on the information presented, the following actions are recommended for the NASA Energy Management Program.

In the near term, NASA should:

- Establish a working group to help guide the NASA Energy Management Program and foster connections throughout the energy sector as discussed in section 4.0.
- Pursue a partnership with EPRI as a potential entry point into medium-term forecasting, possibly leading to partnerships with commercial vendors, as discussed in section 2.1.3.
- Investigate the issuance of research announcements to build the bridges necessary to connect with EIA models such as NEMS and SAGE, and concurrently maintain and pursue new contacts with EIA, as discussed in section 2.2.3.
- Work with PNNL to explore ways to expand upon current collaboration on long-term energy modeling, as discussed in section 2.2.3.
- Explore partnerships with Army Corps of Engineers, Tennessee Valley Authority, and/or the Bureau of Reclamation to expand and develop information used for optimizing dam operations for hydropower and irrigation, as discussed in section 2.3.2.
- Partner with NREL to improve renewable modules in HOMER decision support system, particularly for wind, biomass, micro-hydro, and enhanced solar, as discussed in section 3.1.2.

Of potential lower priority, NASA could:

- Expand partnerships with USDA for to optimize biomass energy sources, as discussed in section 2.3.2.
- Explore partnerships with the NOAA Space Environment Center and commercial vendors involved in space weather impacts on transmission systems to better understand energy sector needs in this area, as discussed in section 3.2.2.

These partnerships should be reinforced through the development and support of prototype energy sector projects. By establishing these partnerships and developing a process and projects to maintain and build upon them, the NASA Energy Management Program will set itself up for better integration with decision support systems across the energy sector, providing benefits to energy sector stakeholders and society as a whole.