TECHNICAL REFERENCE DOCUMENT

MONITORING AND MANAGING ENERGY RESOURCES

1. Introduction

Energy has been an engine of economic growth for modern civilizations since the earliest days of the industrial revolution and remains today an essential input to economic well being. Likewise, future growth of the world's economies will depend on sustained, secure, and reasonably priced energy. Apart from its importance to economic growth, energy also lies at the root of potential technological solutions to many other challenges facing 21st Century civilization. Ensured access to clean water, adequate food supplies, and shelter; improved sanitation and human health; and expanded opportunities for less developed regions—all could be made more easily achievable by the existence of abundant, affordable, reliable, and secure energy supplies.

Forecasts of long-term energy demand suggest world energy consumption may increase three- to five-fold, or more, over the course of this century (IPCC 2000). The IPCC's *Special Report on Emission Scenarios* reports long-term energy demand for 40 different future energy scenarios. These scenarios suggest that by 2100, primary energy demand may be as much as 6.5 times higher than it is today. In addition, demand for electricity is expected to grow faster than demand for fuels for heat and mobility, calling special attention to how electricity will be produced and used. Structural changes in the world economy and accelerated improvement in energy efficiency are expected to slow the rate of growth in total energy demand, compared to that for economic growth in general, but even under these circumstances, demand for fuels and power is expected to grow significantly.

Most energy supply today is derived from the combustion of fossil fuels, accompanied by emissions of the combustion byproducts, mainly carbon dioxide (CO_2). In 2000, CO_2 emissions accounted for about 80 percent of all greenhouse gas emissions, making CO_2 the most important of the greenhouse gases. If favorable economics of fossil fuels were to continue indefinitely, such fuels would likely supply much of the world's energy well into the 21st Century, and beyond.

The National Energy Policy[1] outlines policies to enhance energy security while reducing greenhouse gas emissions and recommends aggressively developing alternative fuels and hydrogen, advancing carbon sequestration technologies, and promoting energy efficiency and renewable energy.

Based on the National Energy Policy's recommendations, President Bush announced his commitment targeting "breakthrough technologies." On June 11, 2001, President Bush initiated two complementary research efforts: a science-focused Climate Change Research Initiative

(CCRI), and a technology-focused National Climate Change Technology Initiative (NCCTI). Among other things, the President charged the NCCTI to develop improved technologies for measuring and monitoring greenhouse gas emissions.[2] Establishing the Climate Change Technology Program (CCTP) was one of the actions to implement the President's NCCTI.[3] The CCTP's strategic vision has six complementary goals:[4]

1. Reducing emissions from energy use and infrastructure;
2. Reducing emissions from energy supply;
3. Capturing and sequestering CO_2;
4. Reducing emissions of other greenhouse gases;
5. Measuring and monitoring emissions; and
6. Bolstering the contributions of basic science.

2. User Requirements

Measurement and monitoring systems provide the capability to evaluate the efficacy of efforts to reduce greenhouse gas emissions through the use of: (1) low-emission fossil-based power systems; (2) energy supply technologies that are reportedly greenhouse gas-neutral, such as biomass energy systems, geothermal, and other renewable energy technologies; and (3) end-use technologies for greater efficiencies. The energy resources functional requirements are:

- Continuity of operations,
- Continuous, real-time data streams,
- Time scales of hours, days, seasons, years and decades
- Geographic scales including point source, regional, and global scale,
- Efficient sharing of information products, in formats that are adapted to users' needs.

Observations using measurement and monitoring technologies can be used to establish informational baselines necessary for analytical comparisons. Climate and weather records required for the optimization of energy production, use, and distribution systems can be established and updated. Carbon storage and greenhouse gas fluxes can be measured across a range of scales, from individual locations to large geographic regions. If such baselines can be established, the effectiveness of implemented energy optimization and greenhouse gas-reduction technologies can be assessed against a background of prior or existing conditions and other natural phenomena. Many of the measurement and monitoring technologies and the systems they can enable would benefit from the ongoing research and development under the Climate Change Science Program, and from other Earth observation activities that are currently underway. All such measurement and monitoring systems and interactions need further development and constitute an important component of a comprehensive CCTP research and development portfolio.

Measurement and monitoring of the environment is required for the design and specification of energy optimization and integration technologies in energy production and consumption. The integration of satellite-based, suborbital, and surface platforms containing such information and providing mechanisms for rapid, reliable, and accessible dissemination of the needed environmental information is crucial to energy optimization strategies. Many times the integration of global environmental information is achieved through atmospheric and oceanic models and analysis. Such a system of global climate data offers the potential to:

- Characterize local climates with weather and environmental information from long-term to more recent past at sufficient resolution for useful incorporation into design of buildings, planning of energy producing crops, estimation of electricity demands, computation of energy grid efficiencies, and incorporation of renewable energy sources (solar, wind) into estimated energy supply and demand needs for particular grids.
- Provide information of changes and trends of these climates for adaptation of these systems.
- Provide information of near-real time weather fluctuations and events that effect energy production, consumption, and dissemination.

Developing an Integrated Observation System

Ideally, an integrated observation system strategy would measure and monitor the sources and sinks of all gases that have an impact on climate change, using the most cost-effective mix of techniques ranging from local *in situ* sensors to global remote sensing satellites. This would involve technologies aimed at a spectrum of applications, including CO_2 from energy-related activities (including end-use, infrastructure and energy supply; CO_2 capture and storage) and greenhouse gases other than CO_2 (including methane, nitrous oxide, fluorocarbons, ozone, and other greenhouse gas-related substances, such as black carbon/soot). An integrating system architecture, if developed, could serve as a guide for many of the step-by-step development activities required in these areas. It could establish a framework for research and development that places measurement and monitoring technologies in context with the other CCTP technologies (see Figure 1).

Such a framework could facilitate coordinated progress over time toward effective solutions and common interfaces of the gathered data and assessment systems. An integrating architecture would function within the context of and in coordination with other Federal programs (e.g., CCSP, the Interagency Working Group on Earth Observations, the U.S. Weather Research Program) and international programs (e.g., the World Meteorological Organization, the Intergovernmental Panel on Climate Change) that provide or use complementary measurement and monitoring capabilities across a hierarchy of temporal and spatial scales. It could, therefore, take advantage of the synergy between observations to measure and monitor greenhouse gas mitigation strategies and the research observation systems for the Climate Change Science Program, as well as the operational observations systems for weather forecasting.

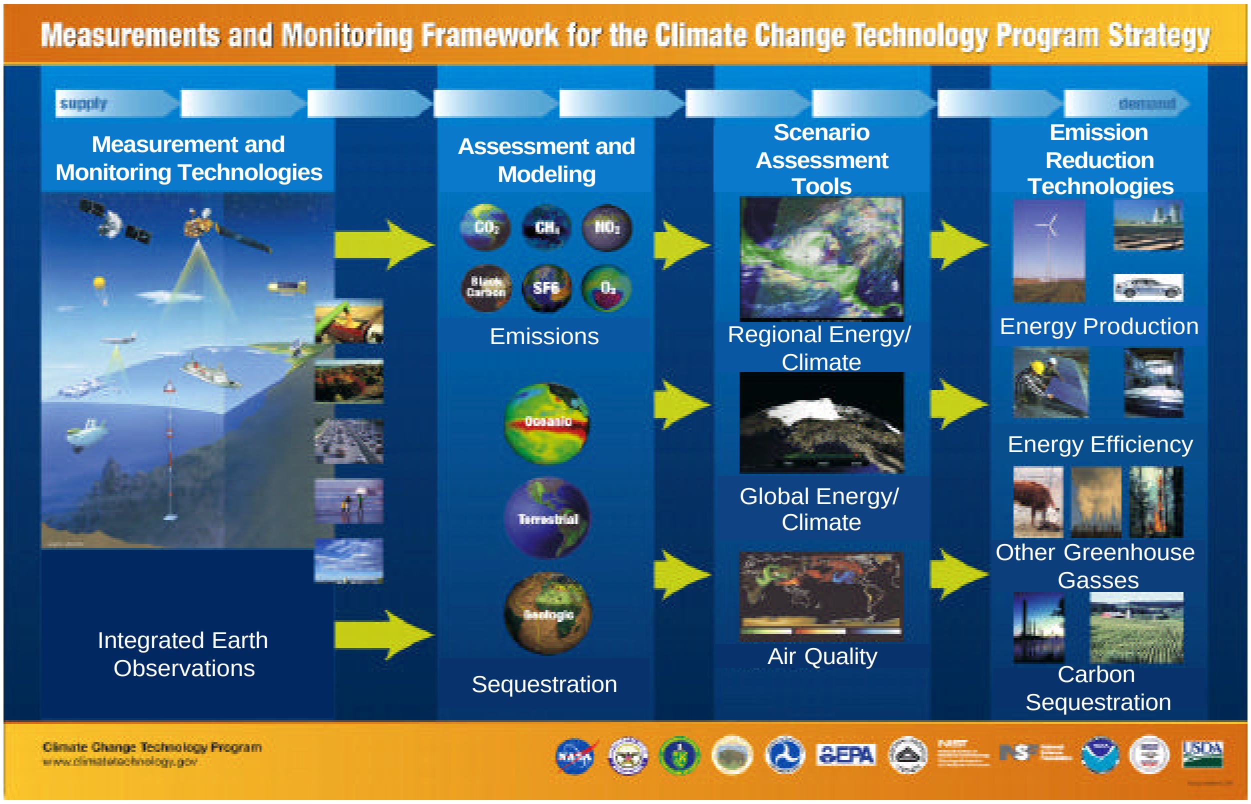

Figure 1: Measurement and Monitoring Technologies

In the near term, advancing greenhouse gas measuring and monitoring systems is an integral element of the CCTP research and development program and initiatives. Other measurement and monitoring efforts focus on monitoring the significant emission sources and sinks, and on measurement and monitoring of carbon sequestration and storage projects. Technology also can be developed to address knowledge gaps in greenhouse gas emissions and to improve inventories. In some cases it is not necessary or cost effective to measure emissions directly. In such cases, emissions can be estimated indirectly, by measuring related parameters, such as feedstock, fuel, or energy flows (referred to as "parametric" or "accounting-based" estimates), or by measuring changes in carbon stocks. Under CCTP, there is a need to undertake research to test, validate, and certify such uses of proxy measurements.

Measuring Emissions Parameters
The technologies that are emphasized in the following sections have been selected on the basis of several criteria:

- Is the measurement and monitoring technology critical to the successful implementation and validation of a technological option that mitigates a substantial quantity of U.S. greenhouse gas emissions, on the order of a gigatonn of carbon equivalent or more over the course of a decade?

- Will the measurement and monitoring technology reduce a key uncertainty associated with a mitigation option?

- Is the measurement and monitoring technology sufficiently differentiated from, or adequately integrated with, comparable research efforts in the Climate Change Science Program or other operational Earth observation systems?

- Is the measurement and monitoring technology essential to ensuring that a proposed technology does not threaten either human health or the environment?

Table 1 summarizes the proposed research and development portfolio for measurement and monitoring technologies. In the near-term, technologies are needed that measure multiple gases across spatial dimensions. In the long-term, a system (or systems) must be developed to provide the capacity for measurement and monitoring at a distance and for accounting of emissions. These long-term systems should be designed to add to and build upon the near-term development.

Greenhouse Gas Emission Source	**Nature of Emissions and Scale**	**Research and Development Portfolio of Measurement and Monitoring Technology**
Power Generation	Large point sources	Component and system-level technologies to enable and demonstrate direct measurements, continuous emission monitoring, on-board diagnostics, remote sensing, data transmission and archiving, inventory-based reporting, and decision support systems.
Industrial Facility	Many different processes, but mostly point sources	
Residential and Commercial Buildings	Point sources	
Transportation	Many mobile sources and widely distributed	

Table 1. Proposed Portfolio for Measurement and Monitoring of Energy Production

Research and development programs for measurement and monitoring technologies that span the federal complex are focused on a number of areas, including the following:

- High-temperature sensors for NOx and ozone, ammonia and other gas emissions, with application in caustic industrial environments (e.g., steel mills, pulp and paper industries)
- Engine diagnostics and controls
- Fast-response mass spectrometers
- Continuous emissions monitors (CEMs) for measuring multiple gases at point sources

- Light Detection and Ranging (LIDAR) for remote monitoring of truck emissions
- Development of an International Measurement and Verification Protocol for estimating energy savings resulting from efficiency improvements.

For more details on the current research and development activities see: http://www.climatetechnology.gov/library/2003/ tech-options/tech-options-5-2.pdf

There are several areas identified for consideration in future portfolio planning for new or increased emphasis. These include the following:

- Improvements in performance, longevity, autonomy, spatial resolution of measurements, and data transmission of CEMs, along with the ability to measure multiple gases
- More thorough process knowledge and life-cycle analysis
- Tower, aircraft and satellite-based sensors for direct measurement of CO_2 and other gases or indicators, tracers, and isotopic ratios
- Low cost, multiple wireless micro-sensor networks to monitor migration, uptake, and distribution patterns of CO_2 and other greenhouse gases in soil, forests, vehicles, and facilities
- Data protocols and analytical methods for producing and archiving specific types of data to enable interoperability and long-term maintenance of data records, data production models, and emission coefficients that are used in estimating emissions
- Direct measurements to replace proxies and estimates when direct measurements are more cost-effective in optimizing emissions and in better understanding the processes behind the formation of greenhouse gases.

Measuring Greenhouse Gas Emissions

Greenhouse gases are global in their effect upon the atmosphere. The primary greenhouse gases, unlike many local air pollutants like carbon monoxide, oxides of nitrogen, and volatile organic compounds, are considered stock pollutants. A stock air pollutant is one that has a long lifetime in the atmosphere, and therefore can accumulate over time. Stock air pollutants are also generally well mixed in the atmosphere. As a consequence of this mixing, the impact a greenhouse gas has on the atmosphere is mostly independent of where it was emitted. These characteristics of greenhouse gases imply that they should be addressed on a global (i.e., international) scale.

The sources of greenhouse gas emissions are varied and complex, as are the potential mitigation strategies afforded by advanced climate change technologies. Anthropogenic emissions of greenhouse gases occur in every country of the world. These emissions result from many of the industrial, transportation, agricultural, and other activities that take place in each country. Countries that are signatories to the United Nations Framework Convention on Climate Change (UNFCCC) are committed to reporting their anthropogenic emissions of greenhouse gases to the Secretariat of the convention.

Industry and the federal government are researching new energy production and consumption technologies that increase energy efficiency or integrate alternative forms of energy that result in reduced emissions. Measurement and monitoring systems will be needed to optimize and complement these technologies in order to assess their efficacy and sustainability. Contributing measurement and monitoring systems for greenhouse gas emissions cover a wide array of greenhouse gas sensors, measurement platforms, monitoring and inventorying systems, and associated analytical tools, including databases and inference methods. Similarly, energy production and use optimization strategies will depend upon the availability of accurate environmental data from space-based and surface platforms with associated analysis methods. Development and application of such systems can provide accurate characterizations of advanced technologies, enable increased understanding of performance, guide further research, reduce costs, and improve effectiveness. Further research and development on these systems will be required to facilitate and accelerate their adoption.

Measurement and monitoring systems are important to addressing uncertainties associated with cycling of greenhouse gases through the land, atmosphere, and oceans, as well as in measuring and monitoring greenhouse gas-related performance of various advanced climate change technologies. These systems offer the potential to:

- Characterize inventories, concentrations and cross-boundary fluxes of CO_2 and other greenhouse compounds, including the size and variability of the fluxes;
- Characterize the efficacy and durability of particular mitigation technologies or other actions, and verify and validate claims for results;
- Measure (directly or indirectly through proxy measurements) anthropogenic changes in sources and sinks of greenhouse gases and relate them to causes, in part, to understand better the role of various technologies and strategies for mitigation;
- Identify opportunities and guide research investments;
- Explore relationships among changes in greenhouse gas emissions, fluxes and inventories due to changes in surrounding environments; and
- Optimize the efficiency, reliability, and quality of measurement and monitoring that maximizes support for understanding and decision making, while minimizing the transaction costs associated with mitigation activities.

Meeting the greenhouse gas measuring and monitoring challenge would be possible with a thoughtful system design that includes near- and long-term advances in technology. In the near-term, it is possible, for example, to: (1) incorporate transportation measurement and monitoring sensors into the onboard diagnostic and control systems of production vehicles; (2) prepare geologic sequestration measurement and monitoring technologies for deployment with planned demonstration projects; (3) exploit observations and measurements from current and planned Earth observing systems to measure atmospheric concentrations and profiles of greenhouse gases from planned satellites; (4) undertake designs and deploy the foundation components for a national, multi-tiered monitoring system with optimized measuring, monitoring, and verification systems; (5) deploy sounding instruments, biological and chemical markers (either isotopic or fluorescence), and ocean sensors on a global basis to monitor changes in ocean chemistry; (6) maintain *in situ* observing systems to characterize local-scale dynamics of the carbon cycle under changing climatic conditions; and (7) maintain *in situ* observing systems to monitor the effectiveness and stability of CO_2 sequestration activities.

In the long-term, with sustained future investments, it may be possible, for example to: (1) enhance the capability to model emissions based on a dynamic combination of human activity patterns, emission source processes, and chemical processes; (2) develop process-based models that reproduce the atmospheric physical and chemical processes (including transport and transformation pathways) that lead to the observed vertical profiles of greenhouse gas concentrations due to surface emissions; (3) determine to what degree natural exchanges with the surface affect the net national emissions of greenhouse gases; (4) develop a combination of space-borne, airborne (including satellite, aircraft, and unmanned aerial vehicles) and surface-based scanning and remote sensing technologies to produce three-dimensional, real-time mapping of atmospheric greenhouse gas concentrations; (5) develop specific technologies for sensing of global methane "surface" emissions with resolution of 10 km; (6) develop remote sensing methods to determine spatially resolved vertical greenhouse gas profiles, rather than column-averaged profiles; and (7) develop space-borne and airborne monitoring for soil moisture at resolutions suitable for measurement and monitoring activities.

With continuing progress in greenhouse gas measuring and monitoring systems, policy decisions and research plans for the development and deployment of advanced climate change technologies could be informed and guided by field data. Additionally, the technology components of future strategies to reduce, avoid, capture or sequester CO_2 and other greenhouse gas emissions need to be expanded and evaluated.

3. Existing Capabilities and Commonalities

Energy production levels are becoming increasingly out of balance with demands for energy resources. The expanding economy, the world's growing population, and the rising standard of living put more demands on available energy resources. Energy availability, use, and cost (as well as influence on the environment and human health) vary regionally and internationally. Focused efforts with improved Earth observations can help to optimize decision-making, and help supply needed energy and maintain the environment and human health. For example, improving weather forecasting accuracy could provide information critical to timely, safe, and cost effective transport of energy resources.

One significant demand on energy use is in the building environment. Residential, commercial, and institutional buildings account for about one-third of primary global energy demand (IPCC 2000). In the U.S. alone, buildings account for 65% of electricity use and 36% of total energy consumption. U.S. buildings also account for 36% of carbon dioxide emissions and 30% of greenhouse gas emissions (Environmental Building News, 2001). Growth in global energy demand in buildings averaged 3.5 percent per year since 1970 (IPCC 2000). Thus, optimizing energy consumption and gaseous emissions by integrating renewable energy technologies and "sustainable" design techniques in buildings is becoming increasingly important toward managing energy resources. It has been has noted that industry now has the capability to design and construct buildings that use 50% less energy at no increase in construction cost, if accurate environmental data are available (Balcomb and Curtner, 2000). Therefore, environmental data (various temperature, solar radiation, illumination, winds, cloud cover, and humidity parameters) become the key to the energy and emission reduction strategies.

Alternative and Renewable Energy Sources
Alternative and Renewable energy resources use naturally occurring flows of energy to produce electricity. Alternative and renewable energy sources include renewable energy systems (such as solar, wind and hydrological power) biomass and biofuels, and geothermal systems. Hydrogen and fuel cell technologies have the potential to solve the major energy security and environmental challenges that face America today—dependence on petroleum imports, poor air quality, and greenhouse gas emissions. The challenge for developing a viable hydrogen economy is to develop a cost-effective source that does not depend on fossil fuels.

Renewable Energy
Renewable energy sources like wind, solar, geothermal, hydrogen and biomass play an important role in the future of our nation. Estimating renewable energy resources requires climatological information on the duration of sunshine and solar elevation of an area, the cloudiness, the wind fields and the precipitation. Hydrological power also requires information about the water shed basin that drains into the river, which is subsequently dammed for power production.

Traditionally, meteorological parameters required for the design of these systems originated exclusively from ground measurements or extrapolations of ground site measurements. Increasingly, such parameters are being estimated from satellite based measurements and atmospheric assimilation model systems. A current portfolio for renewable energy map parameters includes the following:

- Solar resource maps (NREL – see map sect 2; NASA)
- Cloudiness maps (NREL, USAF, NASA)
- Wind resource maps (NREL – see map sect. 2; NASA)
- Hydrological resource maps (NREL – see map sect. 2; NASA)
- Temperature/Humidity maps (NOAA NCEP, NASA).

The current portfolio in surface measurements includes the following:

- Temperature (AFOS - NOAA)
- Humidity (AFOS – NOAA)
- Wind (AFOS – NOAA)
- Solar Radiation (SurfRad, BSRN, and ISIS – NOAA, ARM - DOE; other networks)

- GPCP rain gauge network (NOAA).

Geothermal Energy

Geothermal systems use steam and hot water generated by the heat from the Earth to produce energy. There are two types of geothermal systems. The first is geothermal power harnessed from heated steam from molten rock. Locating areas for power generation facilities requires information of the solid Earth. Remote sensing technologies in space such as LandSat, ASTER, SAR measurements can be used to identify solid Earth formation and rock constituents likely associated with geothermal power sources. The second system, ocean floors, is also a potential source for geothermally produced systems. Information on geothermal energy generation and capability is available on http://www.eia.doe.gov/cneaf/solar.renewables/page/geothermal/geothermal.html.

Alternatively, new heating and air conditioning systems today use the fact that the ground temperatures are more stable than surface temperatures. In winter, below-ground temperatures are warmer than surface and vice versa in summers. Thus, circulating water a few meters underground will act to save energy and reduce emissions either at the home (if the home uses natural gas, coal, oil or propane heating systems) or at the electrical plant (if heating is electric). The optimization of geothermal systems requires information regarding soil type, moisture, vegetation cover, etc. These parameters are observable from the surface and from space-based platforms. Currently, this information can be found in the following:

- Land surface/land cover atlas (IGBP)
- Soil type maps (USDA, USGS)
- Soil moisture maps (USDA, USGS)

Biomass and Biofuels

Biomass is organic matter that can be used to provide heat, make fuel, and generate electricity. Wood, the largest source of biomass, has been used to provide heat for thousands of years. Other types of biomass are also used as an energy source, such as plants, residue from agriculture or forestry, and organic materials from municipal and industrial wastes. Biomass can also be converted into liquid fuels, called biofuels, to meet transportation needs. Biomass uses include ethanol, biodiesel, biomass power and industrial process energy.

Carbon Sequestration

Carbon sequestration is one of the most promising ways for reducing the buildup of greenhouse gases in the atmosphere. In fact, even under the most optimistic scenarios for energy efficiency gains and the greater use of low- or no-carbon fuels, sequestration will likely be essential if the world is to stabilize atmospheric concentrations of greenhouse gases at acceptable levels.
The federal government is supporting research that investigates the fundamental science of carbon sequestration, as well as research that seeks to transform the fundamental science into a portfolio of practical, affordable and safe technologies and mitigation strategies that the energy industry can use to reduce emissions of greenhouse gases. Microbes and plants play substantial roles in the global cycling of carbon through the environment. The federal government is also supporting research that leverages new genomic DNA sequence information on microbes important to the

global carbon cycle by characterizing key biochemical pathways or genetic regulatory networks in these microbes.

Technology Strategy
The measurement and monitoring systems associated with terrestrial sequestration will require a research and development portfolio that provides for integrated, hierarchical systems of ground-based and remote sensing technologies. The system must be applicable to a wide range of potential activities and a very diverse land base, have sufficient accuracy to satisfy reporting requirements of the 1605(b) voluntary reporting system (EIA 1994), and be deployable at a low cost so that measurement and monitoring does not outweigh the value of the sequestered carbon. A balanced portfolio should address the following:

- Low-cost remote sensing and related technology for land cover and land cover change analysis, biomass and net productivity measurements, vegetation structure
- Low-cost portable, rapid analysis systems for *in situ* soil carbon measurements;
- Flux measurement systems;
- Advanced biometrics from carbon inventories;
- Carbon and nutrient sink/source tracing and movement, including using isotope markers; and,
- Analysis systems that relate management practices (e.g., life cycle environmental assessments for forest products, changes in agriculture rotations, energy use in ecosystem management, and others) to net changes in emissions and sinks over time (e.g., changes in agriculture rotations, energy use in ecosystem management, and others)

The following table identifies the needed measurements and observational scale:

In situ	**Local**[1]	**Regional**[2]	**Continental/ Oceanic**	**Global**
i. Soil carbon and nitrogen content (forest inventory and ecological surveys; lab analysis [dry combustion, light induced breakdown spectroscopy]; on-site testing) ii. Soil moisture content (direct measurement) iii. Standing biomass 1. Leaf area and stem diameter (direct measurement) 2. Vegetation structure [altimetry] (Lidar, radar from	i. Standing biomass (field sampling; airborne Lidar [LVIS or radar], 3-D videography, inventories) ii. Land cover, land use and land cover change (multispectral airborne or space borne instrument (IKONOS, QuickBird, OrbView, Landsat, ASTER) iii. Vegetation properties (from remote sensing and inventories) 1. Leaf area and canopy closure (Landsat, MODIS)	i. Vegetation characterization – type, condition, density, etc (Optical remote sensing from space borne platforms – Landsat, MODIS, VIIRS, MISR, ADEOSII, Envisat; data from inventories) 1. Phenology (Landsat, MODIS) ii. Land cover change (Optical remote sensing from space borne platforms – Landsat, MODIS, VIIRS etc.) iii. CH_4 flux (MOPITT, AIRS, TES, Envisat)	i. Vegetation characterization – type, condition, density, etc (Optical remote sensing from space borne platforms – Landsat, MODIS, AVHRR, VIIRS etc.) ii. Land cover change – long term changes and near term disturbances.	i. Vegetation characterization – type, condition, density, etc (Optical remote sensing from space borne platforms – Landsat, MODIS, VIIRS etc.) ii. Land cover change (Optical remote sensing from space borne platforms – Landsat,

In situ	Local[1]	Regional[2]	Continental/ Oceanic	Global
airborne platforms, *in situ* measurements) 3. Carbon content of biomass (lab analyses by species and inventories) 4. Vegetation inventory (field sampling) iv. Atmospheric exchange (Tower measurements of eddy-covariance CO_2 and CH_4 fluxes; automated soil-surface chambers; airborne concentration profilers) v. Soil erosion (Sampling) vi. Stream POC and DOC (Sampling and laboratory analysis)	2. Foliar chemistry (airborne hyperspectral instrument, e.g. AVIRIS) 3. Canopy height and structure (airborne lidar or radar [AIRSAR, LVIS]; space borne MISR) iv. Soil moisture (AIRSAR, UHF/VHF radar (IIP), Hydros)	Vegetation inventory (Field sampling, remote sensing Landsat, MODIS) iv. Soil survey (Field inventory, remote sensing Landsat, hyperspectral) v. Soil moisture (SSM/I, Envisat, Hydros) vi. Fire occurrence, intenisty, burnt area (Landsat, MODIS) 1. Vegetation impacts (MISER, AVIRIS, lidar, radar AIRSAR) 2. Carbon emissions (Field experiments) vii. Carbon in wood products (from inventories)	(Optical remote sensing from space borne platforms – Landsat, MODIS, VIIRS etc.) iii. CH_4 flux (MOPITT, AIRS, TES, Envisat) iv. Soil moisture (SSM/I, Envisat, Hydros (ESSP alternate))	MODIS, VIIRS etc.) iii. Total atmospheric carbon (OCO)
. Emissions by biomass burning (direct measurements) ii. Removal by harvest (direct measurement; inventory)	i. Changes in atmospheric carbon near the ground (eddy correlation measurements from towers or ground based instruments; airborne instrumentation.) ii. Land cover change (airborne or space borne instrumentation with ground resolution no greater than 15-30m.)	i. Land cover change (Airborne or space borne instrumentation with ground resolution no greater than 15-30m.)		

[1]Up to 1 km2
[2]Up to thousands of km^2: Information reportable at political (county/borough, state/province, country) and natural region (ecosystem) levels

Table 2: Measurement Parameters (Observables) and Scales of Interest for Biomass/ Biofuels and Carbon Sequestration

Current Portfolio

Current research activities associated with terrestrial sequestration are found across a number of federal agencies. For a detailed discussion on technologies and current research activities, see:

http://www.climatetechnology.gov/library/2003/tech-options/tech-options-5-4.pdf, http://www.climatetechnology.gov/library/2003/tech-options/tech-options-3-2-3-1.pdf, or http://www.climatetechnology.gov/library/2003/tech-options/tech-options-3-2-3-2.pdf

In summary, the current portfolio includes the following:

- The EPA, with assistance from USDA/Forest Service, prepares national inventories of emissions and sequestration from managed lands. These inventories capture changes in the characteristics and activities related to land uses, and are subject to on-going improvements and verification procedures.
- The USDA Forest Service Forest Inventory and Analysis Program and the Natural Resources Conservation Services National Resources Inventory provide baseline information to assess the management, structure, and condition of U.S. forests, croplands, pastures, and grasslands. This information is then converted to state, regional, and national carbon inventories. Hierarchical, integrated monitoring systems are being designed in pilot studies such as the Delaware River Basin interagency research initiative (USDA 2004).
- Prototype soil carbon analysis systems have been developed and are undergoing preliminary field-testing.
- Satellite and low-altitude remote sensing systems have been developed that can quantify agricultural land features at spatial resolution of approximately 0.5 square meters.
- Prototype versions of Web-based tools are being developed for estimating carbon budgets for regions.
- Multidisciplinary studies are increasing the accuracy of carbon sequestration estimates related to land management and full accounting for land/atmosphere carbon exchange.
- The Agriflux and Ameriflux programs will improve the understanding of carbon pools and fluxes in large-scale, long-term monitoring areas. The flux measurements will provide quantitative data for calibrating and validating remote sensing and for making other estimates of carbon sequestration.

  The Agriflux network is being developed by the USDA to measure the effects of environmental conditions and agricultural management decisions on carbon exchange between the land and the atmosphere. Studies will identify crop management practices to optimize crop yield, crop quality, and carbon sequestration and other environmental conditions. Research will lead to new ways for prediction and early detection of drought in agricultural systems based on weekly and monthly climate forecasts.

  Ameriflux towers are taking long-term measurements of CO2 and water vapor fluxes in 15 sites throughout the world, including the U.S. Data gathered from these measurement sites are important to understand interactions between the atmospheric and terrestrial systems. The AmeriFlux network is apart of an international scientific program of flux measurement networks (e.g., AmeriFlux, FLUXNET-Canada, CarboEurope, and AsiaFlux) that seeks to better understand the role of the terrestrial biosphere carbon cycle. See: ORNL 2003.

- Other research activities focusing on imaging and remote sensing methods include LIDAR and RADAR, used for 3-dimensional imaging of the forest structure.
- Isotopes are being used to assess sequestration potential by monitoring fluxes and pools of carbon in natural ecosystems.
- Tillage and land conservative studies offer test-beds for ground-based and remote sensing methods, as well as verification of rules of thumb for emission factors.

Research and development on *in situ* and remote sensing technologies and laser-based diagnostics are underway in the U.S. At U.S. National Laboratories, for example, these diagnostics include microbial indicators; Fourier Transform Infrared (FTIR) Spectroscopy, Laser Induced Breakdown Spectroscopy (LIBS), Light Detection and Ranging (LIDAR), and a variety of satellite programs:

- Laser Induced Breakdown Spectroscopy (LIBS) is a robust chemical analysis technique that has found application in a range of areas where rapid, remote and semi-quantitative analysis of chemical composition is needed. Light is used to ionize a small portion of the analyte and the spectral emission (characteristic of the electronic energy levels) from the species in the resulting plasma is collected to determine the chemical constituents. Most often the light comes from a laser since high photon fluxes can be obtained readily with this type of light source. By focusing the light from the laser to a small spot, highly localized chemical analysis can be performed.
- LIght Detection And Ranging (LIDAR) uses the same principle as RADAR. The LIDAR instrument transmits light out to a target. The transmitted light interacts with and is changed by the target. Some of this light is reflected/ scattered back to the instrument where it is analyzed. The change in the properties of the light enables some property of the target to be determined. The time for the light to travel out to the target and back to the LIDAR is used to determine the distance to the target.
- Fourier Transform Infrared Spectroscopy (FTIR) technology can measure more than 100 of the 189 Hazardous Air Pollutants (HAPs) listed in Title III of the Clean Air Act Amendments of 1990 (CAAA). The FTIR can measure multiple compounds simultaneously, thus providing an advantage over current measurement methods, which measure only one or several HAPs; FTIR methods can provide a distinct cost advantage since they can be used to replace several traditional methods.

4. Major Gaps and Challenges

Development of an integrated measurement and monitoring system is in its early stages of development and will require evaluation of measurement priorities and data quality needs. As such, there are numerous opportunities for consideration in future portfolio planning. Some specific goals are identified below.

Merging Data: One goal is to develop a system that merges data from across the spectrum of measurement and monitoring systems, with information from one layer helping to calibrate, constrain, and verify information in other layers. Data fusion and integration technologies would enable the integration of information from numerous sources, such as satellite observations, real-time surface indicators, and reported emissions inventories. This data integration may require additional technology capacity in the area of data handling and processing, and, in some cases, it may depend on the development of innovative sensors, platforms, computational models and systems, and their integration into decision support resources. Cross-verification of these data elements requires coordination with national and international standards-setting bodies to develop protocols for interoperability of datasets. Data systems are also required for integrating and comparing data among hierarchical layers of the system and for application of the measurement and monitoring technologies. Some measurements would need to be averaged or processed to reflect the variability in emissions rates or volumes, as well as spatial and temporal variability.

Developing Spatial-Scale and Measurement-Layer Platforms: Another goal is to develop and use platforms for all spatial scales and measurement layers, for example, from new types of global sensors on satellite platforms and from new airborne platforms (e.g., remotely operated or autonomous). Greenhouse gas emission sources and geologic sequestration may require portable platforms for sensors and autonomous units that measure, analyze, and report emissions, while ocean sequestration would likely require development and deployment of autonomous submersible systems with appropriate sensors and reporting capabilities.

Developing Decision Support Tools: A final goal is to develop decision support tools to incorporate the data and information created from the measurement and monitoring systems (e.g., change in emissions, regional or continental information, fate of sequestered gases), along with model sensitivities and model predictions generated by CCSP activities into interactive tools for decision makers. These tools would provide the basis for "what-if" scenario assessments of alternate emission reductions technologies (e.g., sequestration, emission control, differential technology implementation time schedules in key countries of the developing world, etc.)

Future Research Directions

Research topics identified for consideration in future research and development portfolio planning are categorized as follows:

- National implementation of a hierarchical system to quantify stocks, emissions, and sinks from the plot scale to the national scale.
- Development of imaging and volume measurement sensors for land use/cover and biomass estimates.
- Development of low-cost, practical methods to measure net carbon gain by ecosystems, and to conduct life cycle analysis of wood products.
- Isotope markers to determine the source and movement of greenhouse gases in geological, terrestrial, and oceanic systems.

- New measurement technologies that support novel sequestration concepts, such as enhanced mechanisms for CO_2 capture from free air, new sequestration products resulting from genome sequencing studies, and modification of natural biogeochemical processes.

5. Future Earth Observation Systems that May Fill Gaps

An integrated measurement and monitoring system architecture can help establish a systems approach to delivering the information needed to plan, implement, and assess greenhouse gas reduction actions (see Figure 2). This architecture would provide a measurement and monitoring framework that contributes to integrated system solutions for greenhouse gas reduction actions and would help in identifying more cost effective solutions. It would enable the benchmarking of planned improvements against current capabilities.

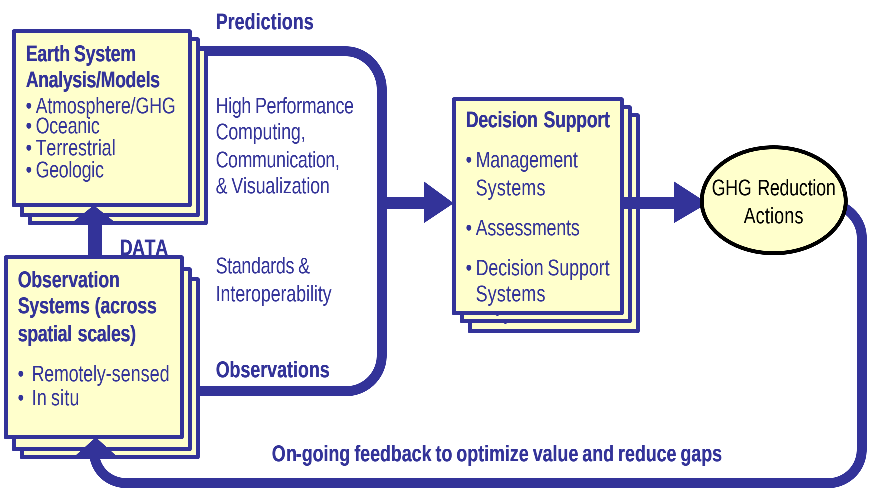

Figure 2: Integrating System Architectural Linking Measurement and Monitoring Observation Systems to Greenhouse Gas Reduction Actions

An integrated measurement and monitoring capability would have the ability to integrate across spatial and temporal scales and at many levels, ranging from carbon measurements in soils, to emissions from vehicles, from large point sources to diffused area sources, from landfills to geographic regions. This capability is graphically depicted in Figure 3. The integrated system builds on existing and planned observing and monitoring technologies of the CCSP and includes new technologies emerging from the CCTP research and development portfolio.

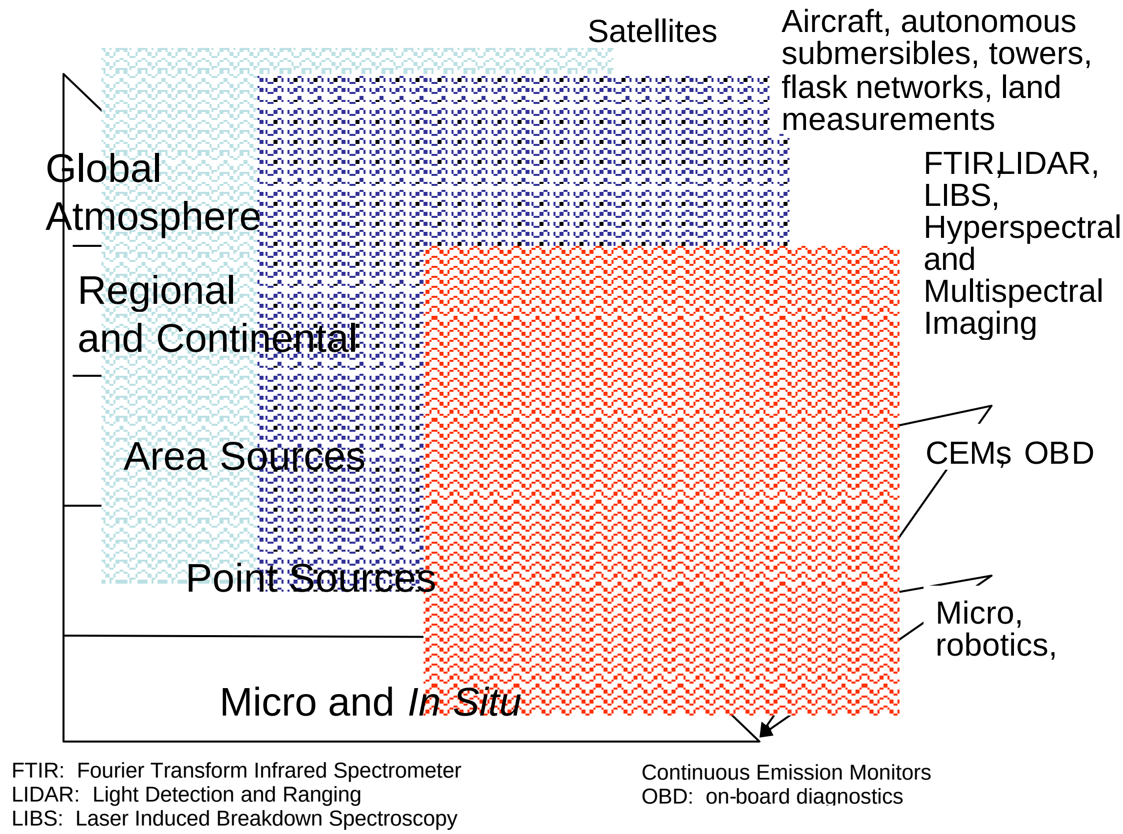

Figure 3: Hierarchical Layers of Spatial Observation Technologies and Capabilities

Advanced measurement and monitoring technologies offer the potential to collect and merge global and regional data from sensors deployed on satellite and aircraft platforms with other data from ground networks, point-source sensors, and other *in situ* configurations. An integrated system provides the benefits of compatibility, efficiency, and reliability while minimizing the total cost of measurement and monitoring.

Technology Strategy
The strategy for developing an integrated system is to focus on the most important measurement needs and apply the integrated concept design to ongoing technology opportunities as they arise. In the near- term, development of observation systems at various scales would be needed. In the longer-term, merging these spatial systems into an integrated approach would be needed.

Current Portfolio
The current Federal research and development portfolio has been targeted on a number of developments. For a detailed analysis of the current research, see:
http://www.climatetechnology.gov/library/2003/tech-options/tech-options-5-1.pdf

Some examples of the current research and development activities include:

- **Global:** Satellites such as NASA's Earth Observation System research satellites and NOAA's operational weather and climate satellites, as well as NOAA's distributed ground network, which includes the Mauna Loa Observatory, are currently operational and support data gathering relevant to CCSP and CCTP.
- **Continental:** Ongoing research involves estimating net CO_2 emissions for the North American continent using different approaches: inversion analysis based on CO_2 monitoring equipment as currently arrayed, remote sensing coupled with ecosystem modeling, and compilation of land inventory information. European researchers have embarked on a similar track by combining meteorological transport models with time-dependent emission inventories provided by member states of the European Union.
- **Regional:** Advanced technologies, such as satellites, are monitoring and/or verifying countries' anthropogenic and natural emissions. NOAA is building an atmospheric carbon monitoring system under the CCSP using small aircraft and tall communications towers that will be capable of determining emissions and uptake on a 1000 km scale. As part of the Climate Change Science Program (CCSP) and the North American Carbon Program (NACP), NOAA is building a Carbon Cycle Atmospheric Observing System mainly across the U.S. in order to reduce the uncertainty in the North American carbon sink. In order to measure carbon fluxes on a 1000 km scale over land, vertical profiling is necessary. From about 24 sites, small aircraft will, on a weekly basis, carry automatic flask sampling systems. These systems will collect 12 samples for analysis of carbon gases and isotopic carbon ratios at predetermined altitudes from the surface to about 8 km. In conjunction, tall communications towers (~ 500 m) will sample carbon and other greenhouse gases continuously from about 12 U.S. sites. This technique will be capable of determining regional carbon sources and sinks and may have applications in the Climate Change Technology Program for monitoring the effectiveness of, for example, sequestration activities.
- **Local (micro or individual):** A number of techniques are currently used to directly or indirectly estimate emissions from individual sites and/or source sectors, such as mass balance techniques, eddy covariance methods (e.g., at the AmeriFlux sites, where source identification is being done using isotope signatures), application of emissions factors derived from experimentation, forestry survey methods, and continuous emissions monitors in the utility sector.

6. Interagency and International Partnerships

Within the U.S., most of the energy systems are privately held. While the government retains responsibility for the roads and air traffic system in the transportation sector, the vast majority of the vehicles and systems that actually consume energy are privately held. Similarly, most of the U.S. built infrastructure is privately held. Commercial companies provide energy to their customers in the forms of fuel oil, natural gas, and electricity, and commercial entities own and operate the energy distribution networks, such as the natural gas pipelines and the electric grid.

Many of these commercial activities rely upon government Earth observations and environmental information for their planning and operations. For example, weather forecasts are critical for air travel, building management, planning and operations of renewable energy generation facilities such as hydro-, wind, and solar power generation systems. In addition to these government-provided observations, the commercial and competitive nature of the energy sector provides a rich environment for private observation systems and value-added data management, modeling, and decision support systems.

Partnership for Solar Energy Resource Assessment
DOE/NREL and NASA have an established partnership to assess and improve solar resource mapping. Plans are being made for a task to be performed under the International Energy Agency involving DOE/NREL, NASA and 7 foreign nations (Germany, France, Spain, Italy, Portugal, Canada, Japan). The task is planned to assess existing solar resource maps and to establish a criterion for the assessment of future predictions of solar resource on several different time scales. For predictions, NASA and NOAA will collaborate.

Partnership with Utility Companies
Utility companies need to better predict demand loads. These are crucially dependent upon forecasts of weather and other parameters. Improved weather parameters will help to improve load forecasts and better anticipate peak demands. A partnership between NASA, NOAA and Electric Power Research Institute (EPRI) was initiated to accomplish such a task. NASA/NOAA will collaborate to provide recent past and forecast data in formats and with parameters important to the load forecasting problems.

7. Conclusions

The growing worldwide demand for abundant, affordable, reliable, and secure energy requires a well developed energy strategy that includes research on new technologies for alternative fuels, including hydrogen, the advancement of carbon capture and sequestration technologies, and the promotion of energy efficiency and renewable energy sources. A well integrated portfolio of research and observations on the efficacy of these new technologies will enhance energy security and reliability while helping to meet the growing demand for fuels and power that is forecasted to occur at the rate of three- to five-fold over the next century.

Observations of the effectiveness of implemented energy optimization and greenhouse gas-reduction technologies will require an integrated architecture of measurement and monitoring systems. Current systems of ground-based and remote sensing technologies must be enhanced and integrated across spatial scales to deliver the information needed to plan, implement, and assess ongoing greenhouse gas reduction actions.

Partnerships between government and commercial sectors can be enormously beneficial for creating value-added data management, modeling, and decision support systems that help optimize energy production, use, and distribution. An effective energy strategy requires that sustained future investments be made in observations systems that can provide the information needed to assess the health of growing economies that depend on a strong and reliable energy sector. Only then can the world's growing population realize a rising standard of living that includes increased longevity within a safe and wholesome environment.

References

1. The IPCC's *Special Report on Emission Scenarios* reports long-term energy demand for 40 different future energy scenarios. These scenarios suggest that by 2100, primary energy demand may be as much as 6.5 times higher than it is today.

2. Balcomb, J. D. and A. Curtner, 2000: Designing sustainable buildings: MCDM-23, a tool for making the right decisions. Proc. Solar 2000, solar powers life, share the energy, Madison, WI, Amer. Solar Energy Soc.

3. Environmental Building News, 2001: Buildings and the environment: the numbers. Brattleboro, VT, May, 1-10.

4. Report of the National Energy Policy Development Group, May 2001.

5. U.S. Climate Change Technology Program Research and Current Activities Introduction, URL http://www.climatetechnology.gov/library/2003/currentactivities/intro.htm accessed Aug. 5, 2004.

6. About the U.S. Climate Change Technology Program, URL http://www.climatetechnology.gov/about/index.htm accessed Aug. 5, 2004.

7. S. Abraham, "The Bush Administration's Approach to Climate Change," *Science* 305, 616-617 (2004)