NOAA ESRL's Potential Contributions to Solving the Nation's Energy-Climate Crisis through Renewable Energy Development

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Executive Summary

The interlinked crises of energy, climate, and the economy pose a daunting challenge to the United States and the world. The long-term solutions to this three-part problem must include the development of carbon-free energy sources that are sustainable and economically viable. Renewable energy sources (that include wind, solar, biomass/biofuels, geothermal, and ocean waves and currents) are the most rapidly growing energy sectors within the U.S., and they hold the promise of soon becoming a significant portion of the total U.S. energy supply. However, almost all of these renewable energy sources depend on atmospheric and oceanic information. To accelerate the integration of renewable-energy sources into the U.S. energy system, better atmospheric and oceanic observations, models, forecasts, and analysis tools are needed. By accelerating the deployment and distribution of renewable energy in the United States, we would advance the nation's energy security and reduce CO_2 emissions; this in turn would help mitigate climate change. Investments that substantially enhance NOAA's observation networks and predictive models would pay for themselves many times over in the near and long term. For example, improvements in short-term forecasts of parameters such as wind speed and solar radiation would help electric grid operators know how much spinning-reserve power is needed to meet demand; studies have shown that this would save billions of dollars annually, increase grid stability, and reduce CO_2 emissions.

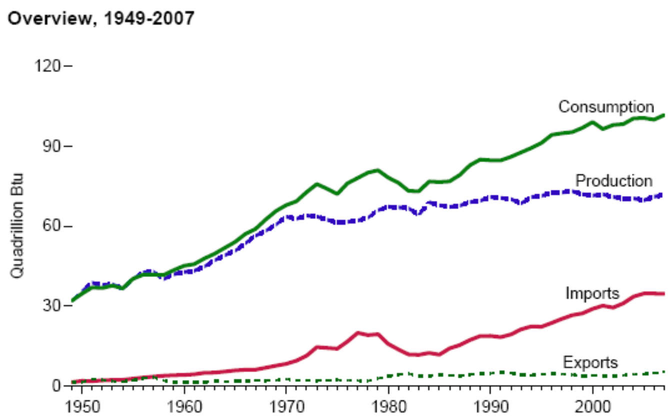
The requirements for expanding renewable energy within the U.S. also include better long-term atmospheric and oceanic information. NOAA's climate models need to be enhanced to improve our understanding of how renewable-energy deployments will affect weather and climate; and likewise to increase our understanding of how climate change will impact renewable-energy resources, including studies about the ways that wind, solar, oceanic, and hydropower resources will change as the climate evolves. NOAA's climate modeling capabilities also need to be harnessed to support DOE and industry estimates of long-term energy demand.

NOAA ESRL is strengthening its relationships with its partners on these projects, e.g., National Renewable Energy Labs, DOE, NCAR, University of Colorado, Colorado School of Mines, Colorado State University, as well as private companies. Through increased communication and collaboration, NOAA can provide more useful products and services to private-sector renewable-energy enterprises.

The United States would demonstrate critically needed leadership by developing new, sustainable energy technologies to meet growing demands for electricity while sharply reducing greenhouse-gas emissions. NOAA is uniquely qualified to support this effort. The observations, enhanced models and improved forecasts needed to support renewable energy would also serve many other applications, such as aviation-safety forecasts, air quality, and water management. Meeting the nation's energy demands, maintaining a strong economy, and reducing emissions of greenhouse gases are inextricable goals. Multiple federal agencies are charged with meeting these goals, but NOAA's mission and expertise are compelling and essential. NOAA's responsibility for nationwide observing networks, predicting weather, and understanding climate, "to meet our nation's economic, social, and environmental needs" is the nexus of the energy-economy-climate challenge. If NOAA does not meet the evolving needs of the renewable-energy sector, other governmental agencies will be forced to develop meteorological observation networks and forecast capabilities that fall within the scope of NOAA's mission.

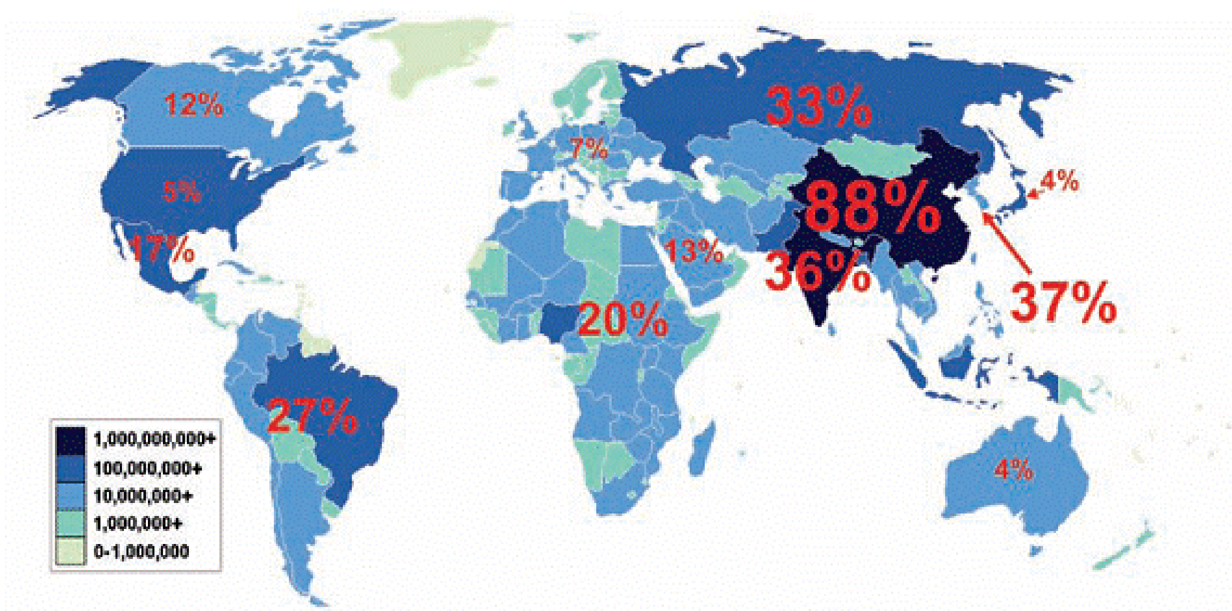
The Challenges of Climate Change and Energy Sustainability

The United States and the world face an energy revolution. Demand for energy in the United States and worldwide is burgeoning. U.S. energy consumption is projected to rise by 19% between 2006 and 2030[2], and U.S. electricity consumption is projected to rise by 29% between 2006 and 2030. World marketed energy consumption is projected to increase by 50% from 2005 to 2030[3]. Much greater increases in global consumption are projected by mid-century. Meanwhile, "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level. Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations."[4]



U.S. energy consumption and production. Source: *Energy Information Administration, Annual Energy Review (2007).*

The massive challenges of meeting global energy demands and reducing carbon dioxide are inextricably intertwined. Unprecedented amounts of carbon-free energy must be produced to meet U.S. projections and international energy demands.



Population vs. projected 10-year growth in total energy demand (% increase compared to 2006 value in each country) per capita. Industrial superpowers will compete with developing nations for access to energy resources. *Source: U.S. Census Bureau, International Data Base; U.S. Energy Information Administration, International Energy Outlook 2006. Figure courtesy of Mr. Fred Palmer.*

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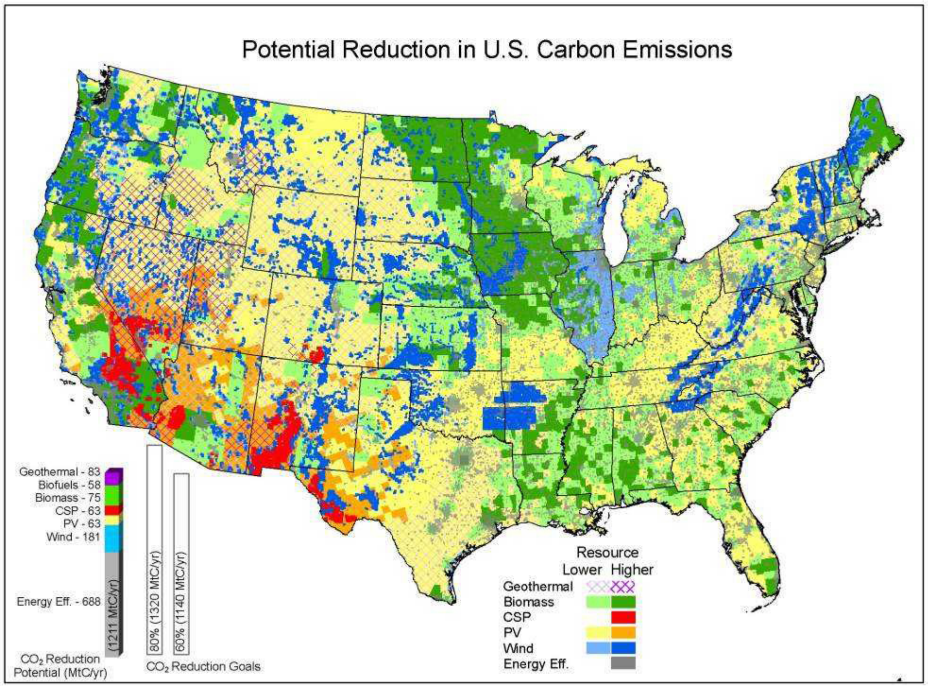
[2] U.S. Energy Information Administration (2008), Annual Energy Outlook 2008.

[3] Ibid

[4] IPCC, 2007: Summary for Policymakers

Burning fossil fuels for transportation or generating electricity produces atmospheric emissions of carbon dioxide. Carbon-free renewable energy sources, like wind and solar, are key to simultaneously meeting the growing demands for energy and cutting atmospheric emissions carbon dioxide.



Optimized renewables. U.S. map indicating the potential contributions from energy efficiency and renewable energy by 2030. CSP and wind are based on deployment scenarios; other renewables indicate resource locations. *Graphic courtesy of the American Solar Energy Society, "Tackling Climate Change in the U.S." (2007).*

Meteorological Impacts on the Future U.S. Energy System

Today, the United States spends more than one trillion dollars annually on its energy consumption.[5] Within the U.S. energy system, energy demand can be divided into four principal categories: the electrical grid, transportation, industrial uses, and residential and commercial heating. This energy comes principally from coal, natural gas, oil, and nuclear plants, with a small contribution (~6%) from renewable sources (mostly hydropower). The demand side of today's system has some weather dependency (air conditioning in the summer and heating in the winter). Besides impacts from hurricanes and major winter storms, current energy production is almost entirely independent of atmospheric and oceanic conditions, with the exception of the effects of precipitation on hydropower and the small quantities of biomass and biofuels.

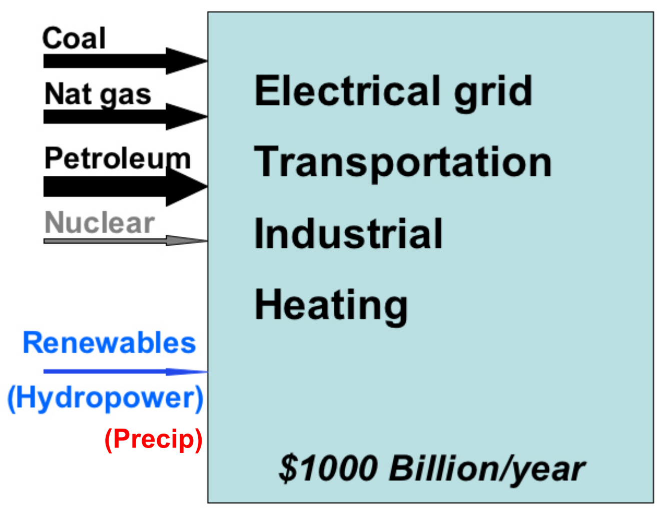
By 2030, the U.S. energy system will have changed dramatically. Fossil fuels will have decreased in importance, either through the implementation of climate-oriented policies, or simply because the rate at which we can extract fossil fuels will have decreased, while extraction costs will have risen commensurately. In contrast, as the costs of renewable energy continue their well-established long-term decline, the market share of renewable energy will have increased significantly. Already DOE has published its report "20% wind by 2030," and is considering possibilities wherein the United States could achieve 80% of its electrical power from renewable sources by 2050.

The striking difference between today's U.S. energy system and that shown for circa 2030 is the much greater dependence of renewable energy production, and the dependence of this production

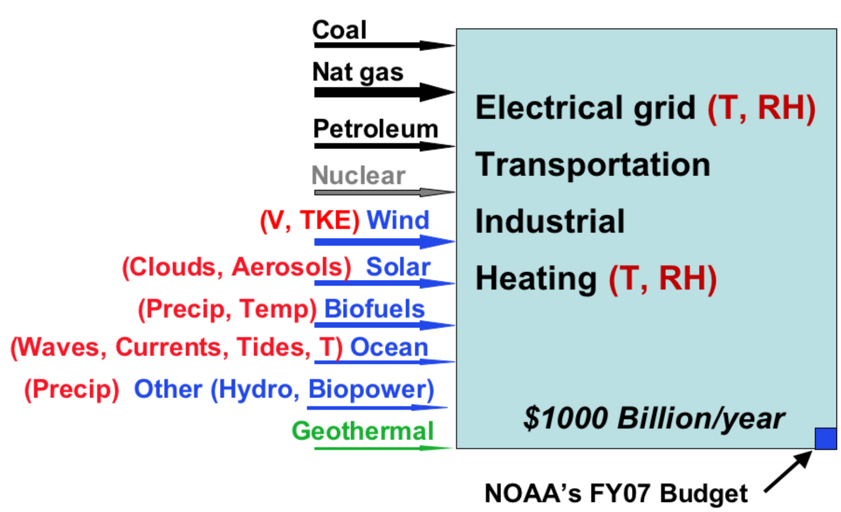
[5] State Energy Price and Expenditure Estimates, DOE/EIA-0376 (2005)

on processes in the atmosphere and ocean. The development of large numbers of wind and solar energy farms depends on a better understanding of the spatial and temporal distribution of wind and solar resources. The integration of wind and solar energy into the electrical grid and demands for transmission and storage would require very accurate wind and cloud forecasts. Likewise, the generation of energy from ocean resources requires an accurate mapping and prediction of waves and currents, while the production of biofuels depends on seasonal drought and temperature forecasts. On longer time scales, inter-annual and decadal climate variability will affect each of these renewable resources. Unlike the present situation, in the future, NOAA's observations, models, and forecasts should be woven into the fabric of the energy system, and could play a key role in how it is designed and operated.

In this new energy system, NOAA would make profound contributions by managing the renewable resource availability portfolio, thereby supporting production of a stable and abundant supply of energy to our nation with reduced emissions of carbon dioxide. It is important to note the relative size of NOAA's budget to the U.S. energy enterprise. With an annual budget (FY 2007) of $4 billion, NOAA's entire budget is less than only 0.4% of the present energy consumption expenditures. Even at levels of 10%, 20% or 30% renewable-energy generation, NOAA's products and services would be a vital component of a system many times larger than NOAA.



Current energy and forecasts: Current fossil-fuel and nuclear sources of electricity do not depend on meteorological factors or forecasts.



Future energy and forecasts: The energy mix of 2030 will include more renewable-energy sources (e.g., hydroelectric, wind, solar, biofuels, waves, currents and hydroelectric), will depend on meteorological factors and can be optimized by improved forecasts. T=temperature, RH=relative humidity. Arrow thickness represents relative contribution to the energy mix.

Current Shortfalls of Meteorological Forecasting for Renewable Energy

Numerical Weather Prediction (NWP) models have not been optimized to address the needs of the wind-energy community. First, little is known of the skill of operational and research models at predicting winds in the wind turbine layer (20 m to 200 m) simply because there are few high-quality measurements available in this layer. This challenge is compounded by the fact that wind energy increases as the cube of the wind speed, so that small errors in forecast speed can result in very large errors in forecast energy production. Second, even the spatial scales addressed by most NWP models may not be adequate for wind-energy forecasting needs. Accurate prediction of winds depends on small-scale variations in terrain and other surface-roughness elements, so that a horizontal spatial resolution of less than 1 km is desirable. Unfortunately, mesoscale models rely on parameterizations valid for horizontal grid spacings as small as several km, and should not be run at resolutions finer than 1 km because these models' parameterizations are not valid at those scales. Large-eddy simulation (LES) models that employ different turbulence closure methods have been designed for spatial scales less than 100 m. The simulation gap between mesoscale and eddy-resolving models should be bridged to provide local wind-variation forecasts for both wind-farm siting and adaptive operations. Although many wind turbines are sited in relatively flat terrain, a substantial number of wind turbines are sited in complex terrain with steep slopes, where different approaches may be required. Development, testing, and validation of existing approaches tailored specifically to wind-energy applications, such as forecast ensembles and improved forward models for wind observations in the 20 m to 200 m above ground level range to use in data assimilation would be fruitful. These specific developments for forecasting capability would benefit from rapid update cycles and assimilation of turbulence measurements, among others.

A related problem, data assimilation of current observations to accurately initialize NWP models, is equally complex as the models themselves. Forecasts of local near-surface winds and clouds, like those for thunderstorms, are dependent on accuracy of detailed initial conditions from local to regional scale. More effective assimilation of wind observations (wind towers, a proposed nationally deployed network of wind profilers, and turbulence observations) and cloud observations (satellite, surface, radar) are essential, especially with assimilation cycles at high temporal frequency (at least hourly).

NWP model development and enhancement, as well as post-processing procedures specifically aimed to meet the weather-forecast needs of the renewable energy industry will be necessary. (See some specifics below.) Improvement of NWP at all scales — global, regional, and local — is needed. Inclusion of uncertainty in the forecasts using ensemble techniques for probabilistic prediction is also needed.

For solar energy, there are few ground-based observations with which to evaluate current and future solar potential. This gap has traditionally been filled with modeled values covering a large portion of the United States and compared to the few existing observations. These modeled results are typically for long-time averages, months to years, and do not contain specific information on spatial-temporal cross correlation that could be useful in optimal resource utilization. They are also dependent on marginally quantified clouds and aerosols. Even fewer measurements of the *direct* solar beam, which are particularly useful for concentrating solar power, are available. Developers of models that are being used by NREL to provide direct solar beam assessment place a 20% uncertainty on the results on short time scales and about 7% uncertainty on annual averages. Additional ground-based measurements will improve our ability to infer direct and scattered solar radiation at the surface from satellite data. Improvements in NWP model prediction of clouds, which are the major attenuators of direct solar radiation, is essential for the siting and operation of concentrating solar power systems. Better chemistry models will improve understanding of the aerosol burden, which has a secondary, but non-negligible effect on solar concentrators. Cloud forecasts are themselves dependent on improved forecasts of aerosols (for cloud condensation nuclei) and chemical constituents. Improved surface wind forecasts could be useful for modeling the mineral dust load in arid regions of the southwestern U.S. that could impact the performance of solar power systems.

Economic Benefits of Improvements in Forecasts

Although it is intuitively apparent that better meteorological information will allow the future U.S. energy system to run more efficiently, it is difficult to quantify the monetary value of this information. The system is still evolving, and all of the necessary studies have not yet been done. However, very recently detailed studies show the economic impact of meteorological information on some sub-components of the future energy system.

One is a study made by General Electric (GE) on the impact of wind forecasting on electricity production in Texas.[6] Historically, wind forecasts have not been used by electrical grid operators, because the amount of wind energy on the grid was small, and because the wind forecasts were not considered to be reliable. Because of this, extra fossil-fuel-burning electrical generation units are required to be on-line, in case the wind generation should suddenly disappear because of variable meteorological conditions. These “excess” fossil-fuel plants are kept operating at a fraction of their full capacity, until and if they are needed. However, when operating at less than full capacity, the efficiency rates of these fossil fuel plants drop significantly (up to 30% for a combined-cycle gas plant), which increases electricity costs and carbon dioxide emissions.

Texas has the most wind energy production of all the states: 5,000 MW at full capacity. The GE study investigated the impact of using “next day” (18 h to 42 h) State-of-the-Art (SOA)[7] and perfect forecasts on the value of wind-energy production, as well as on their impacts on carbon-dioxide emissions reductions, for wind energy production capacities equal to the present 5K MW, as well as for 10K and 15K MW.

The GE study demonstrates that using a State-of-the-Art forecast greatly increases the value of wind energy — by more than 50%. Expressing this result as a savings per MWh of wind energy produced (~$16/MWh averaged for all wind capacity scenarios) allows for the Texas results to be extrapolated to the United States as a whole, assuming that 20% of electricity (~800 TWh) is produced by wind in 2030. The value of wind energy production with the State-of-the-Art forecasts would increase by $13B/year over the value using no forecast, while the value of improving from a SOA forecast to a perfect forecast is $2.4B/year.

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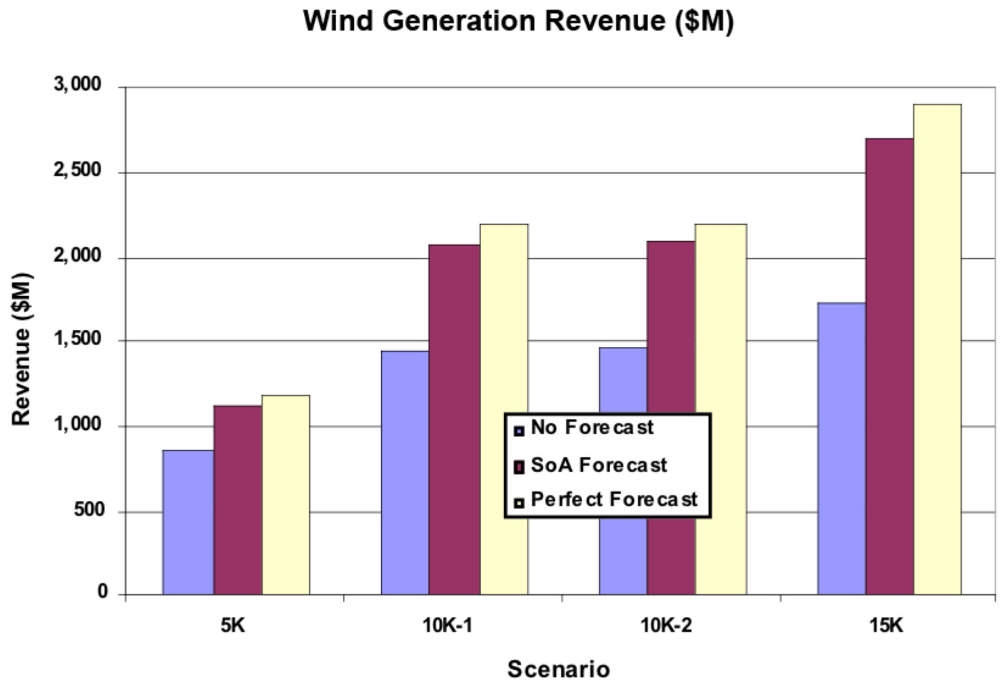
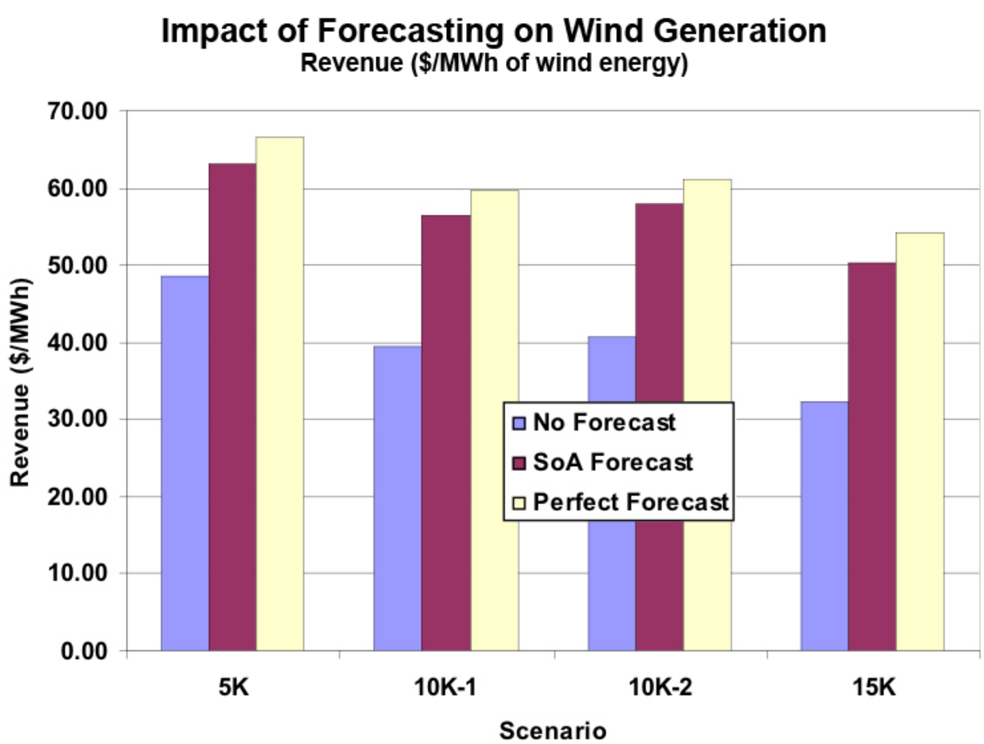
[6] General Electric. Final Report: Analysis of Wind Generation Impact on ERCOT Ancillary Services Requirements. Prepared for: Electric Reliability Council of Texas, March 28, 2008.

[7] In the GE study, “actual” winds were generated by a mesoscale weather model. State-of-the-Art forecasts were generated by statistically degrading these “actual” winds, using the observed skill of a mesoscale model that the authors had used previously to predict winds in California.



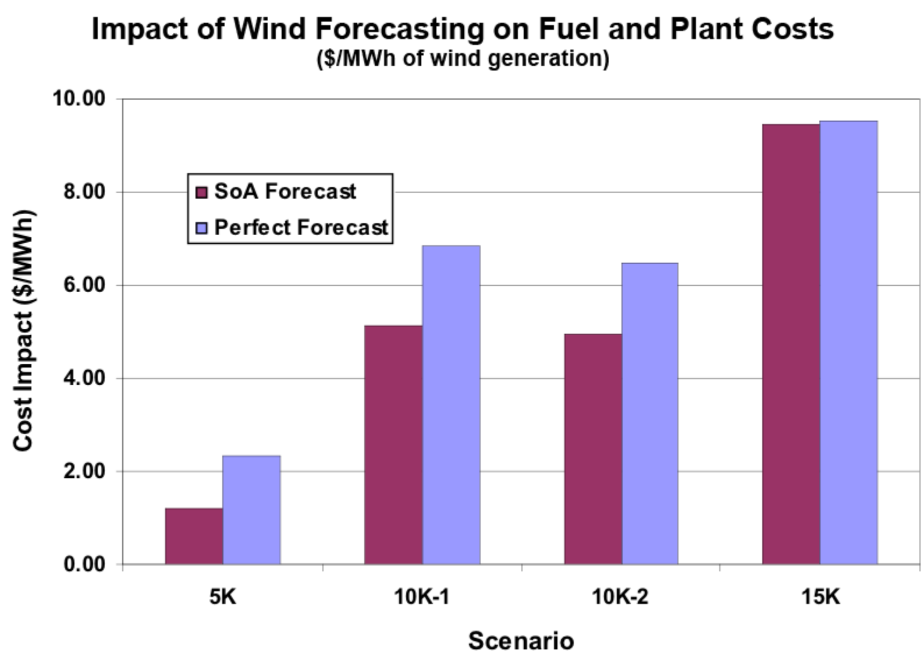
The impact of wind forecasting on electricity production in a study by General Electric for ERCOT. On the x-axis are shown several scenarios of different wind energy production capacities that range from the present 5K MW to 15,000 MW of wind capacity (~17% penetration). There are two 10,000 MW scenarios, one (1) in the Texas Panhandle and the other (2) in South Texas near the Gulf of Mexico.



Wind financials. If 20% of U.S. electricity production is by wind in 2030 (800 TWh), then appplying the revenue value of a State-of-the-Art forecast in the GE Texas study (~$16/MWh) to the nation as a whole, implies an annual savings of $13 billion/year ($16/MWh x 800TWh). The value of improving from a State-of-the-Art forecast to a perfect forecast is about $2.4 billion/year. *Source: "Impact of Wind Forecasting." Presentation by Gary Jordon, at the Utility Wind Integration Group Fall Technical Meeting, Oct. 1-3, 2008, Denver, CO.*

The value of wind forecasting can also be analyzed from the perspective of the reduction in fuel and plant costs achieved by running fewer inefficient fossil-fuel plants. Again assuming that the results from Texas can be extrapolated to the nation as a whole, a value of ~$5/MWh for a SoA forecast implies a savings of $4 billion/year, while the incremental value of improving from a SoA to a perfect forecast is $800 million/year. Clearly the dollar value of wind forecasts, either in terms of the increased value of wind energy, or the savings in fuel and plant costs, is enormous, and would greatly help the expansion of wind energy. The value of SoA wind forecasts is also significant for carbon dioxide emissions. The GE study found that CO_2 emissions would decrease by 13% with the SoA forecast, while NOx and SO_2, two important components of air pollution, would decrease by 11% and 6%, respectively.

Although the GE study investigated only the value of "next day" forecasts, improved wind forecasts will allow for better matching of supply and demand on multiple timescales. Definitive studies have yet to be done, but many in the industry expect that short-term (0-h to 12-h) forecasts will have an even larger impact than the "next-day" forecasts. In addition, accurate wind forecasts will contribute to greater grid stability, reducing the likelihood of brownouts or blackouts.



Wind financials II. If 20% of U.S. electricity production is by wind in 2030 (800 TWh), then applying the fuel and plant savings from a State-of-the-Art forecast from the GE Texas study (~5/MWh) to the nation as a whole is about $4 billion/year ($5/MWh x 800TWh). The value of improving from a State-of-the-Art forecast to a perfect forecast is about $800 million/year. *Source: "Impact of Wind Forecasting." Presentation by Gary Jordon, at the Utility Wind Integration Group Fall Technical Meeting, Oct. 1-3, 2008, Denver, CO.*

Improved forecasts will enable better matching of supply and demand on multiple timescales, which is the key to efficient grid operation, e.g., ensuring that supply meets demand, reducing the amount of reserve power, and reducing the production of excess energy. Generally, generating units with shorter production lead times have higher production costs (higher spot fuel prices). A particularly dramatic example of this occurred on February 26, 2008, when an abrupt loss of 1,200 MW of wind energy caught the Electric Reliability Council of Texas off guard and caused wholesale power prices to soar from $30 per MWH to $105 per MWH in West Texas.

Specific Opportunities for NOAA ESRL's Research to Advance Renewable Energy

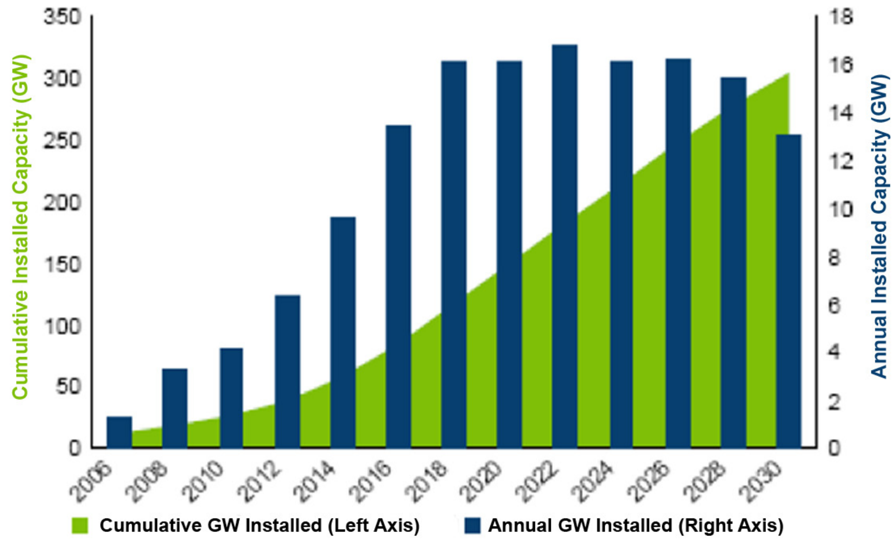
NOAA's responsibilities, capabilities, and expertise with measurement systems (including assessment of current instruments for certain measurements and tasks, as well as design of new instruments when needed); nationwide observing networks; and environmental prediction, model development and data assimilation should be enhanced and modernized. A comprehensive explication of the specific contributions to support renewable energy by various components of NOAA is beyond the scope of this paper. When discussing the specific research advances that will support renewable energy, this text focuses on the expertise at the NOAA Earth System Research Laboratory.

Wind Energy

Although at present, wind energy contributes only 1% of U.S. electricity (21,000 MW installed), wind power can play a major role in meeting America's increasing demand for electricity, according to a groundbreaking technical report.[8] This report from the DOE proposes that 20% of U.S. electricity demand be provided by wind energy by 2030. Using more domestic wind power will diversify the nation's energy portfolio — adding wind-generated electricity at stable prices not subject to market volatility — and strengthen national energy security through reduced reliance on foreign sources of fossil fuels. Obtaining 20% of US electrical needs by 2030, the report says, would lead to the creation of 500,000 jobs in this country and provide other economic benefits as well.

The DOE 20% Wind Scenario would alter U.S. electricity generation as shown in the figure below. In this scenario, wind would supply enough energy to displace about 50% of electric-utility natural-gas consumption by 2030. This amounts to an 11% reduction in natural-gas use across all industries. Also, coal consumption would fall by 18%. Only with improved forecasts of wind energy generation can reduction of carbon-based energy generation be achieved.

[8] 20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply, prepared by the U.S. Department of Energy with contributions from the National Renewable Energy Laboratory, the American Wind Energy Association, Black & Veatch and others from the energy sector.



Wind strategy. To implement the 20% wind scenario, new wind-power installations would increase to more than 16,000 MW per year by 2018 and continue at that rate through 2030, as shown. Wind-plant costs and performance are projected to improve modestly in the next two decades, but no technological breakthroughs are needed.

Applied research and development are needed in several areas if the 20% Wind Scenario is to be achieved. These include siting of wind farms, optimal configuration of the individual wind turbines within wind farms, wind forecasting, and environmental impacts of wind generation, both locally and globally. These are discussed in more detail in the following sections, along with how NOAA is positioned to contribute to this work. There are certain important research and development themes that occur repeatedly in this discussion. Of particular note is the need for improvement of fundamental understanding of wind structures and turbulence at wind-turbine heights of 20 m to 200 m above ground. Routine observations of wind and temperature in this layer are almost entirely lacking at present.

Develop 1-km National Weather Models with Hourly Updating as a Backbone to Renewable Energy Guidance Infrastructure

- A much improved, frequently updated weather model assimilating the latest meteorological observations would provide a backbone for renewable energy guidance for both near-surface winds and solar energy. Such a system would improve initial conditions for the private sector from which they would provide still-higher resolution model predictions and tailored products.
- This system would incorporate improved observations from NOAA-deployed national observing systems (e.g., wind, cloud, moisture).
- Improved high-resolution high-frequency forecasts would also improve forecasts of strong wind events for which managers must shut down wind farms to avoid turbine damage.

Establish Wind-Energy Testbeds

- Suites of instruments specially suited for measuring the atmospheric boundary layer and low-level wind field would be deployed at a small number of sites across the U.S. that are located in areas of high wind resource (e.g., West Texas, the upper Midwest, California, etc.). Data from these testbeds would be collected for at least several years.
- Observations from the testbeds would be used to assess the performance of current and new

mesoscale models.
- New measurement technologies and strategies, e.g., remote sensing systems such as multiple-LIDAR deployments, would be evaluated.

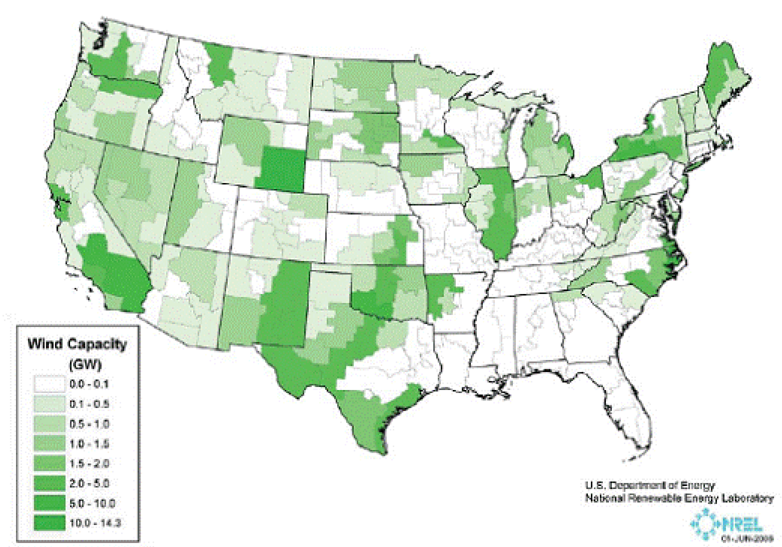
Understand Meteorological Physical Processes to Maximize Wind Energy

Observations from the Wind-Energy Testbeds would be used to:
- Improve our fundamental understanding of meteorological phenomena that have proved critical to wind-energy operations.
    - Low-level jets
    - Stable boundary layers
    - Surface roughness properties, including complex terrain
    - Turbulence induced by internal shear layers at rotor heights (i.e., shear not tied to surface roughness)
    - Severe wind events

- Develop new model physical parameterization schemes for low-level winds and turbulence
- Develop wind forecasting technologies such as new forward models to effectively assimilate wind and turbulence measurements at wind-turbine heights into mesoscale forecast models.

Micrositing, Array Effects and Turbine Dynamics

- Construct improved models for the wake of a large array of wind turbines
- Advance planetary boundary layer research and development applicable to strongly inhomogeneous terrain
- Acquire large scale data sets of higher quality and broader range of conditions than those now available; 50 m to 200 m above ground; for spatial and temporal resolution needed to characterize and understand detailed turbine-atmosphere interactions
- Develop accurate models for isolated turbine inflow characterization
- Develop models to characterize ingestion of wakes (including turbulence) from upwind turbines
- Characterize extreme and anomalous inflow events (which expend turbine fatigue life, cause component failures, and even threaten catastrophic machine failure)



Model scenario of approximate wind locations for 20% penetration of wind into electric grid (for producing energy). *Graphic courtesy of American Solar Energy Society (2007) "Tackling Climate Change in the U.S."*

Wind: Impacts of Wind Energy on Climate and the Impact of Changing Climate on Wind Energy Resources

There is considerable uncertainty about physical feedback between wind plants and boundary-layer dynamics, and uncertainty about how those feedbacks interact with or affect climate change. At the same time, there are very few observations that could be used to measure the impact of existing wind plants on boundary-layer dynamics.[9] NOAA could provide services such as the following:

- Understand and quantify variability on synoptic to decadal time scales and historic trends of wind resources
  - This would help with siting future wind plants and reduce risk associated with investments in wind energy
- Develop a long-term measurement program to identify changes in wind resources
- Improve understanding of the impact of wind plants on local climate, e.g., precipitation, evapotranspiration, and changes in number of frost-free days near wind plants
- Develop models that incorporate wind plants into mesoscale simulations
- Develop observational data sets to quantify the interactions between wind plants and planetary boundary layer properties
- Deploy existing remote sensors at and surrounding currently operating wind plants

Solar Energy

A conservative estimate of the penetration of solar energy into the U.S. energy supply by 2030 projects ~7% from Concentrated Solar Power (CSP, in the amount of 80,000 MW, from today's installed capacity of 419 MW) and ~17% from photovoltaics (PV, in the amount of 200,000 MW, from today's installed capacity of 824 MW) using only currently existing technology.[10] And as in the case of the wind-energy industry, many good jobs will be created in this country by developing solar energy. For example, the construction of a 280 MW CSP plant in Arizona would create 1,500 construction jobs over two years, and 85 permanent jobs.

Parabolic trough solar collectors at the recently dedicated 1 MW Saguaro power plant outside Tuscon concentrate sunlight onto a receiver tube along the trough's focal line. Solar energy heats a working fluid in the receiver tube, which vaporizes a secondary fluid to power a turbine. A next-generation version of this collector is being installed at a 64-MW plant in Nevada. *Graphic courtesy of the American Solar Society, "Tackling Climate Change in the U.S." (2007).*

[9] US DOE Workshop Report: Research Needs for Resource Characterization; NREL Tech. Report 500-43521 June 2008.

[10] ASES Tackling Climate Change in the U.S. (2007)

Solar: Data Needed for Siting CSP Farms and for Forecast Validation

CSP uses direct solar radiation (as opposed to total radiation, which is the sum of direct plus diffuse radiation), for which there are few historic and even fewer current observations; hourly satellite and model estimates can and do have extreme errors. NOAA has world-class expertise in direct solar-measuring capability and could complete the following tasks:

- Acquire an enhanced solar observational database to help evaluate current and future solar resources for spatial and temporal variability, which will help optimize a modernized electrical grid
    - o Revive the Integrated Surface Irradiance Study network, eight sites located at NWS offices currently shut down for lack of operating funds; they could be quickly made operational, since the equipment is still at the sites
    - o Secure commitment for the continuation of Surface Radiation Budget (eight additional highest research-quality U.S. sites) funding past 2009, currently fully operational for climate and renewable energy applications
    - o Utilize data from a 10-year, 25-site network run by Colorado State University and the U.S. Department of Agriculture
    - o Acquire data at the additional Surface Energy Balance Network (SEBN) sites proposed in the United States
        - Extend SEBN mission to include renewable energy, resulting in further observing sites to fill the optimal observing density and distribution for renewable energy.
    - o Enhance ability to infer direct solar radiation at the surface from satellite data using these ground-based measurements as validation datasets
    - o Compare U.S. solar-radiation measurements with those of Europe, where solar energy commands a large market. Europe's national networks support the commercial solar-energy sector, while also supporting routine weather forecasting and climate monitoring. The U.S. network is a poor cousin in comparison.

"CSP could provide nearly 7,000 GW of capacity, or about six times the current total U.S. electric capacity."
– Western Governors' Association study. Excluded land with solar resource of less than 6.75 KWh/m2/day and applied other environmental and land-use exclusions. Eliminated land having slope of more than 1%. When distance to present-day transmission lines was factored in, the authors identified 200 GW of optimal locations.

In a carbon-constrained world, with carbon value of $35/ton of CO_2 and 30% investment tax credit, the authors found that 80 GW of CSP could be economically deployed by 2030. Assumes 6 hours thermal storage and capacity factor of 43%.
– ASES Tackling Climate Change in the U.S. (2007)

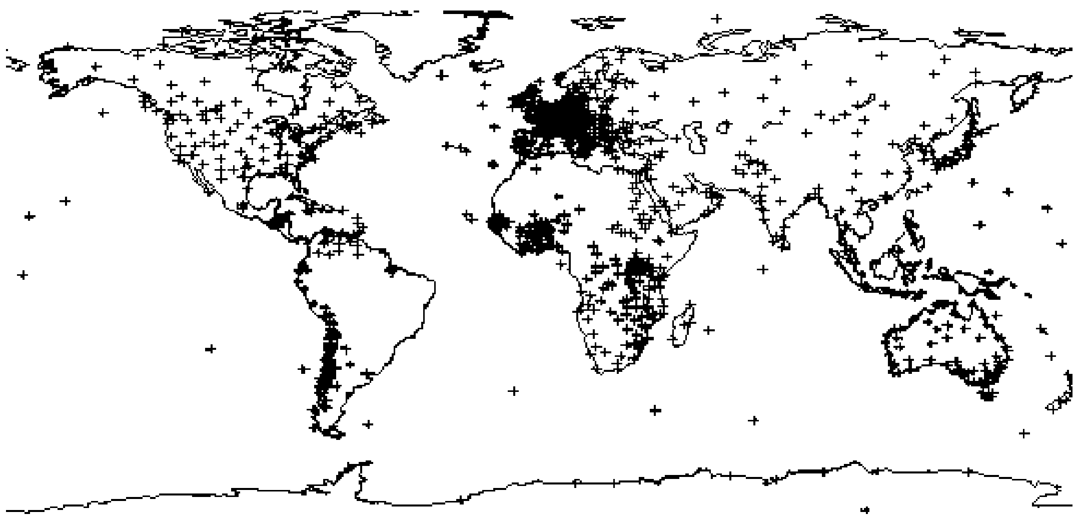
Solar: Forecast Needs for Optimizing Solar Energy

NOAA could provide services including the following:

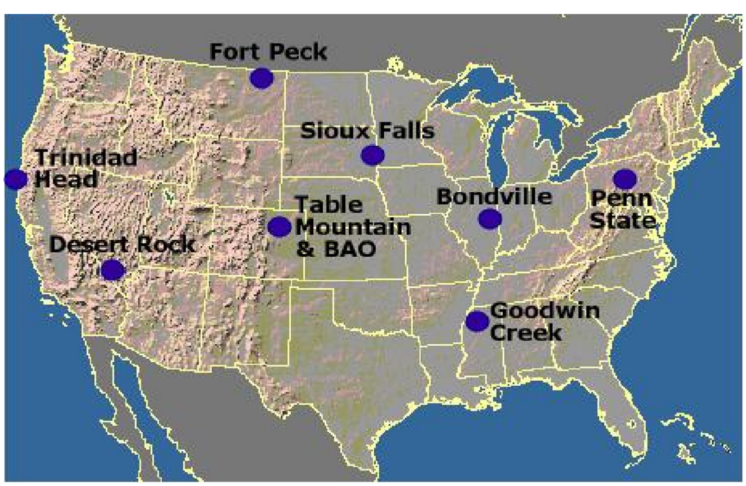
- Improve cloud forecast in models
    - o Improve assimilation for satellite, surface-based (ceilometer-equipped METAR sites), radar-based cloud/hydrometeor observations
    - o Complement improved cloud observations with dense, relatively inexpensive GPS-based measurements of integrated water vapor
- Improve fundamental understanding of clouds

- o Forecasts of direct solar radiation at the surface will require forecasts of optical depth of hydrometeors and other particulates, e.g., smoke, dust, other human made particle pollutants, and cirrus formed naturally and by contrail spreading, and forecasts of direct attenuation of the solar beam caused by absorption by water vapor
- o Introduce coupled (inline) air chemistry, aerosol, improved microphysics, and radiation processes into NWP models for hydrometeor and aerosol prediction for application to prediction of direct solar radiation.

- Develop and validate surface solar radiation forecast products (direct and total)
- Extract the direct radiation value from current operational model output, then validate (for diagnostic and prognostic purposes)
  - o Share this product with the public, including private companies that serve specific regions, once data are validated as being useful
  - o Improve model cloud forecasts and forecasts of other attenuators of solar radiation (aerosols and water vapor)
    - Assimilate current aerosol and albedo data into forecast models
    - Improve total column aerosol data
    - Improve assimilation of satellite cloud information in models
    - Improve cloud prediction, especially for high-level cirrus and low-level clouds and fog



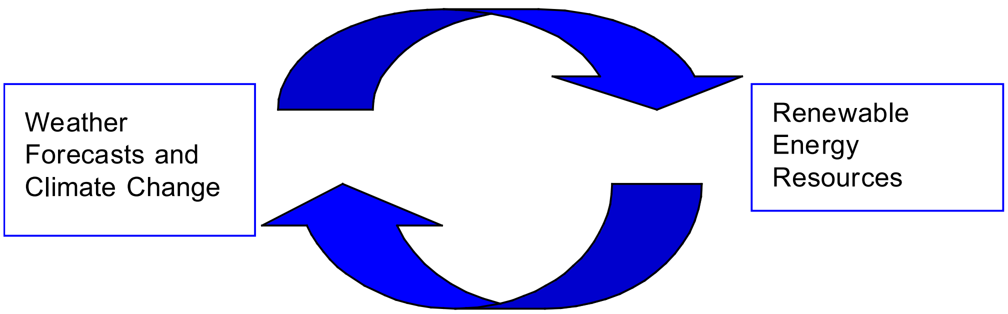
Surface solar radiation sites between 1964 and 1993. By 1993 most U.S. sites were inactive. Reviving these U.S. sites quickly would be very helpful for supporting solar energy development.



NOAA solar network sites supported as of 2008. The new Surface Radiation Budget network started in 1995 with three sites.

Solar: Climate Effects Related to Solar Energy

- Quantify and understand historic trends and variability of solar resources
  - o This will help with siting future solar farms and reduce risk associated with investments in solar energy
- Improve understanding of impact of CSP farms on local climate, e.g., changes in sensible and latent heat flux, formation of clouds, and changes in precipitation
  - o Develop models that treat solar farms and incorporate them in mesoscale simulations
  - o Develop observational data sets to quantify the interactions between solar plants and clouds
- Develop a long-term measurement program to identify changes in solar resources



A coupled energy-climate model would advance understanding of climate and renewable energy resources.

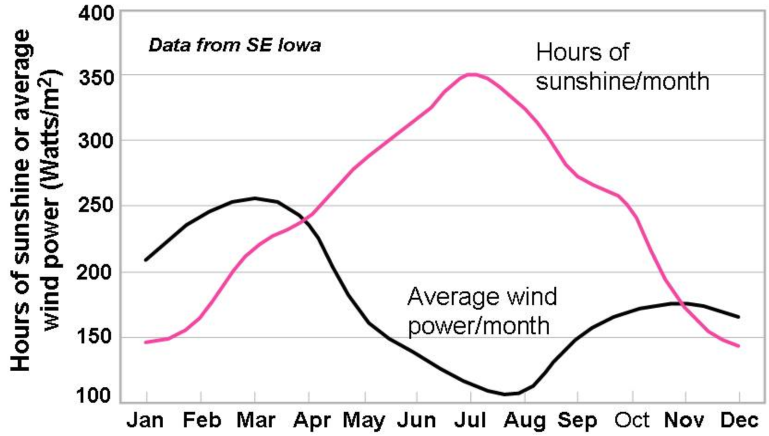
Co-Variability and Complementarity of Sun and Wind

Solar energy can provide electricity during the day, and concentrated solar power (CSP) with six hours of thermal storage extends this source of electricity even after the sun goes down. In many parts of the country, a low-level jet appears or strengthens during the evening, so that in many locations, more wind energy is available during the nighttime hours than during the day. This is shown in the figures below.

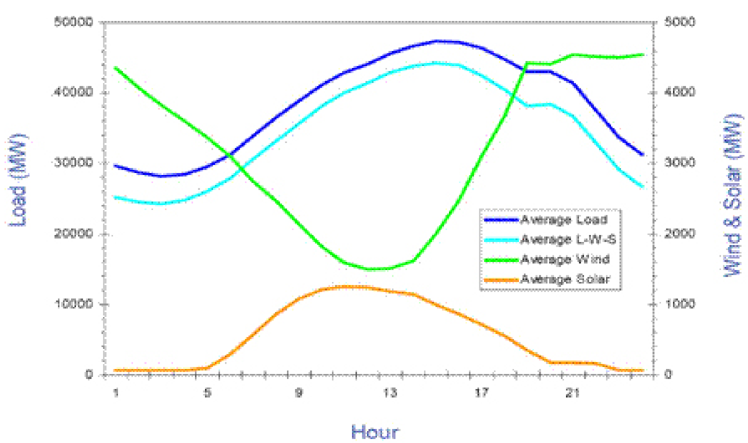
NOAA could assume a leading role in the assessment of spatial co-variability of wind and solar power potential within each projected network, as well as between these grids. One could exploit both the existing observational database as well as reanalysis data to get at least first order estimates of local, regional, and national probability distributions of each field in the historical record. NOAA could provide valuable observations and analysis of these resources to help understand the spatial and temporal co-variability of solar and wind energy, to facilitate their integration into the U.S. electrical grid. For example, it is often stated that by spreading wind energy plants over a broad geographical area that the problem of wind intermittency will be reduced. However, weather systems that control the wind speed often span many states. Over how large of a region, then, should these plants be distributed? Also, can one quantify the advantage of using a combination of wind and solar plants, under the assumption that wind and sunshine tend not to be correlated, so that if wind turbines are not turning, that the sun will be shining on solar energy devices? And how does the spatial co-variability of wind and sunshine vary from season to season, and does it also vary depending on climatic state, e.g., El Niño or La Nina years?

Annual Solar and Wind Energy are Complementary

Hours of sunshine are highest in the summer, when the average wind power is lowest, in SE Iowa. Across the months of the year, wind and solar energy complement each other.



Diurnal Solar and Wind Energy are Complementary



Solar power is greater during the day (which, of course, is to be expected), and wind power is greater in the night, in SE Iowa. Across the hours of the day, wind and solar energy complement each other.

Biomass and Biofuels

Biomass is plant matter such as trees, grasses, wood, agricultural crops or wastes, municipal wastes, or other biological material. It can be used as a solid fuel, or converted into liquid or gaseous forms, for the production of electric power, heat, chemicals, or fuels. Biomass can help mitigate climate change by offsetting fossil-fuel use in heat and power generation and by providing a feedstock for liquid-fuels production. In addition, biomass has the potential to sequester carbon in the soil (using agronomic and silvicultural practices to promote soil carbon accumulation) and to capture and sequester carbon during the processing of biomass. Biomass has the potential for net negative carbon dioxide emissions. For a detailed discussion of the various processes, please see the ASES Report.[11]

In 2007, the U.S. biomass capacity was 10.5 GWe. In 2004, biomass generation was 68 TWh, at a cost of 8-10¢/kWh. The DOE projects 160 TWh from biomass (net electricity exported to grid from integrated 60 billion gal/yr biorefinery industry) by 2030, at a cost of 4-6¢/kWh.

[11] ASES Tackling Climate Change in the U.S. (2007), pg. 113-118

Energy crops such as the switchgrass shown here can fuel base load biomass power plants and help revitalize rural economies. *Photo courtesty of Warren Gretz, NREL PIX 08369; American Solar Energy Society (2007) "Tackling Climate Change in the U.S."*

Algae can be grown in municipal waste treatment ponds. Algae can produce large amounts of oil for transportation fuel.

Biofuels are made from biomass. The use of biofuels instead of fossil fuels shifts the flow of carbon into the atmosphere from vehicles from carbon stored in the ground in a long geological time scale to a carbon source that is rapidly (at least annually) recycled between the atmosphere and the biosphere. Burning biofuels does emit carbon, but it provides a new pathway for recycling carbon on a rapid time scale, which prevents net atmospheric accumulation of carbon dioxide. The efficacy of carbon recycling depends on the source of the biomass and the technologies used in its conversion.

The DOE has considered the possibility of flooding a large portion (~ 20 million acres) of Arizona in order to grow algae to produce oil (biofuel). This scale of land-use change warrants close monitoring for impacts on weather and climate.[12]

[12] "A Look Back at the U.S. Department of Energy's Aquatic Species Program—Biodiesel from Algae," Prepared for: U.S. Department of Energy's Office of Fuels Development," July 1998. http://govdocs.aquake.org/cgi/reprint/2004/915/9150010.pdf

Current ethanol production is primarily from the starch in kernels of field corn, but researchers are developing technology to produce ethanol from the fibrous material (cellulose and hemicellulose) in the corn stalks and husks as well as other agricultural and forestry residues. *Photo courtesy of Warren Gretz, NREL.*

Algae vs. Other Sources of oil for fuel

Oil yields	liters/ha-yr	barrels/ha-yr
Soybeans	400	2.5
Sunflower	800	5
Canola	1,600	10
Jathropha	2,000	12
Palm Oil	6,000	36
Microalgae	60,000-240,000*	360 -1500*

Microalgae produce large amounts of oil: This graph shows the volume of oil produced by various biomass sources.

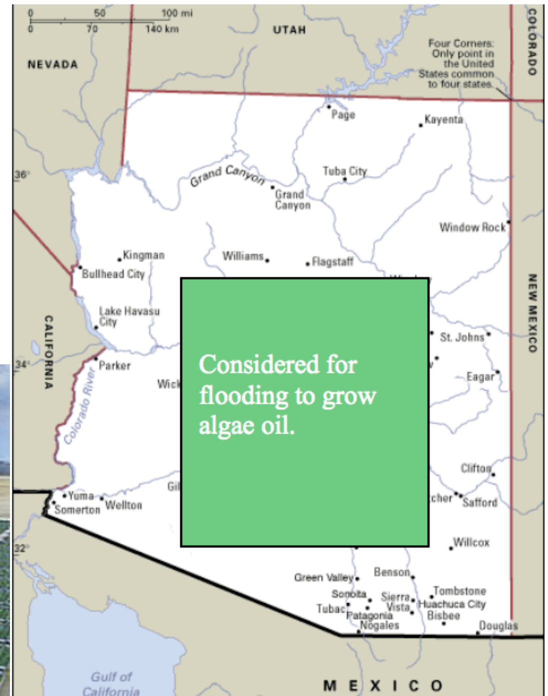
Biomass and Biofuels: Meteorological Contributions

The National Integrated Drought Information System (NIDIS), a multi-agency effort of federal, state and local partners, led by NOAA, provides a clearinghouse for drought mitigation and response innovations, and coordination of drought plans among states and communities that share a common river basin. NOAA could support biopower in the following ways:

- Improve forecasts of precipitation and drought, which would help crop producers manage their crops as effectively as possible, e.g., through irrigation scheduling

- Monitor the impacts of land-use changes on weather and climate
    - For instance, some have proposed flooding a large portion of the southwest U.S. to grow algae for the production of oil; such a proposal warrants monitoring of weather and climate, including the North American Monsoon.

The green box represents the approximate percentage (20 million of the 72 million acres) of Arizona that would be flooded to grow algae for the production of oil, according to a scenario considered by the DOE.



Algae ponds offer the possibility of large amounts of fuel. They could span large areas and affect weather and climate. NOAA could monitor larger scale weather and climate impacts of such deployments of biofuel production.

Visualization Tools for Users

NOAA has developed many sophisticated visualization tools to support weather forecasting. Probably the most well known of these is the Advanced Weather Interactive Processing System (AWIPS), which is used at National Weather Service field offices. AWIPS is an integrated suite of automated data-processing equipment that supports complex analysis, interactive processing, display of all meteorological and hydrological data, and all satellite and radar data, and enables the forecaster to prepare and issue more accurate and timely forecasts and warnings. These tools allow any properly geo-referenced dataset to be displayed and integrated with all other similarly referenced data. A hallmark of the AWIPS system is its ability to operate in a real-time environment where timeliness is measured in seconds.

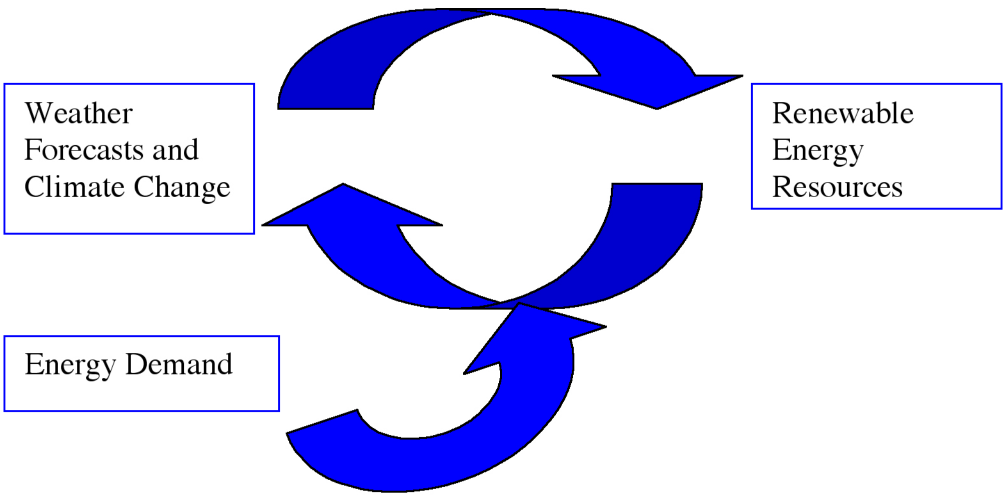
These tools could be applied effectively to focus on energy-related issues such as more accurate wind, sun, and temperature forecasts or to generate reliable probabilities of certain wind, solar, temperature, or precipitation thresholds being met.

Energy Demand

NOAA's incorporation of energy demand into a coupled energy-climate model would provide climate projections that could improve DOE and long-term industry estimates of energy demand. Improved seasonal climate (temperature) predictions would also help in anticipating energy

demand.
Improved temperature forecasts, for instance, can improve the accuracy of electricity demand forecasts. Improved demand forecasts lead to lower electricity production costs. The money saved is from avoiding incremental costs resulting from inaccurate forecasts. For instance, electrical production units with shorter production lead times generally have higher production costs. If a load forecast is too low, long lead-time units will not have been brought on line, and the more expensive short lead-time units will be forced into production to supply the unanticipated demand. Conversely, if the load forecast is too high, long-lead-time units may be running unnecessarily, which wastes money (and emits excess CO_2).

U.S. electricity generators already save $166 million annually using 24-hour temperature forecasts to improve the mix of generating units that are available to meet electricity demand.[13] The same study determined that a 1°C improvement in temperature forecast saves $59 million annually. As the U.S. electric grid is modernized and grid managers strive to attain a better match between supply and demand, such savings will likely increase: Improved weather forecasts that yield improved energy demand forecasts will become even more valuable. A critical part of this improvement will be the provision of better estimates of forecast uncertainty.



NOAA’s Mission in Relation to Renewable Energy

Meeting the nation’s energy demands, maintaining a strong economy, and reducing emissions of greenhouse gases are inextricable goals. Multiple federal agencies are charged, to one degree or another, with meeting these goals. NOAA’s mission and expertise are essential to this end. NOAA’s responsibility for nationwide observing networks, predicting weather, and understanding climate, “to meet our nation’s economic, social, and environmental needs” is the nexus of the energy-economy-climate challenge.

The NOAA five-year research plan[14] articulates NOAA’s obligation to provide the scientific advancements needed to expedite widespread renewable-energy use:

[13] Teisberg, et al. (2005)
[14] Research in NOAA: A Five Year Plan, Fiscal Years 2008-2012, pg. 1.(emphasis added)

"Over the next several decades, population growth and changing demographics, energy security, climate change, advances in technology, and the use of natural resources will drive society's demands for information and services. ... The growing need for energy security will lead to ***increasing consideration of alternative energy sources*** and imaginative application of fossil fuels. …Widespread advances in technology offer new opportunities for improving the quality and effectiveness of research but also will challenge society as it adjusts to increasingly rapid change... ***NOAA is the single federal agency with operational responsibility to protect and preserve ocean, coastal, and Great Lakes resources and to provide critical and accurate weather, climate, and ecosystem forecasts that support national safety and commerce. As social and economic systems evolve and become more complex, the tools and information needed to promote growth, to preserve and improve human and environmental health, to develop and maintain a viable national infrastructure, and to provide security for present and future generations must advance as well.*** It is through research that society gains the understanding to make informed decisions in an increasingly complex world. …This plan aligns NOAA's research along a path toward a broader understanding of the global ecosystem as a whole to address the dynamic array of social, economic, and environmental needs we face today and will face in the future."

Complementary Federal Missions

The Department of Energy's overarching mission is to advance the national, economic, and energy security of the United States; to promote scientific and technological innovation in support of that mission; and to ensure the environmental cleanup of the national nuclear weapons complex.

The Environmental Protection Agency's mission is to protect human health and the environment.

The Federal Energy Regulatory Commission's mission is to regulate and oversee energy industries in the economic, environmental, and safety interests of the American public.

The Department of the Interior's mission is to protect and provide access to our nation's natural and cultural heritage. One of its goals is to manage resources to manage resources to promote responsible use and sustain a dynamic economy.

Among other energy-related agencies within the DoI is the **U.S. Geological Survey,** whose mission is to serve the nation by providing reliable scientific information to describe and understand the Earth; minimize loss of life and property from natural disasters; manage water, biological, energy, and mineral resources; and enhance and protect our quality of life.

NOAA's mission is to predict and understand changes in Earth's environment and conserve and manage coastal and marine resources to meet our nation's economic, social and environmental needs.

The NOAA five-year research plan cites national and international planning documents that identify a spectrum of societal needs for environmental information, including those of the U.S. Integrated Earth Observation System (US/IEOS). To meet these needs, the plan explains, NOAA will have to "manage more intensive data streams, develop improved approaches to using them, and build the modeling capabilities to integrate data from different parts of the Earth system." Examples of the US/IEOS societal benefit areas include improvements to weather forecasting; protection and monitoring of oceans; understanding, assessing, predicting, mitigating, and adapting to climate variability and change; and monitoring and managing of energy resources.

The five-year research plan explains that ***"The economic viability of alternative energy sources, like hydroelectric, wind, solar power, or biofuels will depend upon increasingly accurate,***

location-specific weather and climate information. Adverse and/or complementary effects of these energy choices need to be addressed. For example, the impact on air quality of switching to biofuels needs to be evaluated."

NOAA's scientifically rigorous research is essential to informing decisions of policy makers. Many public policies and official statements emphasize this point. For example, section 633 of the Energy Independence and Security Act (2007) mandates that NOAA prepare a report on the potential impacts of marine and hydrokinetic energy systems on marine ecosystems. NOAA's research is at the heart of providing indispensable information in making decisions that are often complicated and controversial.

The Energy Independence and Security Act of 2007 emphasizes the wisdom, urgency and efficacy of rapidly developing better sources of renewable energy. The act notes that this pursuit protects consumers, assists the economy and moves the United States toward greater energy independence and security.

"The nation realizes that "environmental" issues are social issues by their very nature, as human relations, e.g., the economy, safety, security, and culture, are embedded within the processes and structures that comprise ecosystems. NOAA's role is to study environmental phenomena at the intersection of multiple disciplines and convey the knowledge gained to decision makers across the nation and beyond."
(Research in NOAA: A Five Year Plan, Fiscal Years 2008-2012, pg. 5.)

DOE/NREL has opened discussions with NOAA about how NOAA can support renewable energy development. A Letter of Intent was signed by the directors of NREL and NOAA ESRL in July 2008 detailing specific research activities to pursue in support of renewable energy development.

If NOAA does not meet the evolving needs of the renewable-energy sector, other governmental agencies will be forced to develop meteorological observation networks and forecast capabilities that fall within the scope of NOAA's mission.

Highly efficient sources of decarbonized energy can drive our economy and mitigate climate change. Much of the critical research and data needed to realize this vision can be accomplished nowhere more effectively than at NOAA.

NOAA's Mission Goals and How Renewable Energy Relates to Each Goal

Ecosystems Mission Goal: ***Protect, Restore, and Manage the Use of Coastal and Ocean Resources through an Ecosystem Approach to Management***

Ocean acidification is one of many impacts of climate change. About one-quarter of carbon dioxide emitted to the atmosphere is absorbed by the ocean. The ocean's efficiency as a carbon sink has decreased ~16% in the last 50 years.[15] Now, the oceans are 30% more acidic than they were two centuries ago, which has led to a 16% decrease in carbonate ion needed for the growth of corals and calcareous plankton.

[15] Canadell et al., 2007, PNAS.

The only way to decrease acidification of the ocean is to decrease emissions of carbon dioxide. To the extent that renewable energy sources are carbon-free, as wind and solar energy are, they provide a means to decrease ocean acidification. Pursing this objective is imperative under NOAA's ecosystem goal. See Appendix A for "outcomes" and "performance objectives" of each mission goal; those in blue are supported by healthy oceans, which require a reduction and eventually a reversal of ocean acidification.

Climate Mission Goal: ***Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond***

The projections of climate change attributed to human-caused greenhouse-gas emissions and changes in land use are increasingly well understood.[16] "Stakeholders and customers for climate research range from decision makers, resource managers, and policy makers dealing with global, regional, and local issues in most sectors: energy, transportation, industry, land use, water, agriculture, commerce, environmental organizations, the general public, other federal agencies, and other researchers both internal and external to the federal government."[17] The NOAA research plan articulates the need to **"enhance NOAA's decision support tools to provide climate services for national socioeconomic benefits …** NOAA's Regional Decision Support program addresses an increased demand for traditional climate services, such as data and forecast dissemination and customer support, as well as identifying and satisfying new requirements for decision support in sectors such as water, fire, emergency preparedness, health, transportation, **energy**, … These research activities build bridges between producers and users of climate information, allowing decision makers to participate in the creation of new knowledge, processes, tools, and products to improve planning, risk management, resource allocation, impacts assessment and mitigation, early warning, and operational response in sectors sensitive to climate variability and change."[18]

Carbon-free renewable energy sources, such as wind and solar energy, provide means to mitigate climate change. Development of a coupled energy-climate model that incorporates the effects of changing climate on energy demand and renewable-energy sources (e.g., changes in clouds, which affect solar radiation available for producing electricity), as well as the effects of large arrays of renewable-energy production equipment on climate, support the NOAA climate goal. See Appendix A for "outcomes" and "performance objectives" of each mission goal, and specifically those in blue. As noted above, biomass can help mitigate climate change by offsetting the use of fossil fuels in heat and power generation and by providing a feedstock for liquid fuels production. In addition, when combined with carbon capture and sequestration during the processing of biomass, this energy source actually provides the opportunity to create a *net reduction* in atmospheric carbon dioxide concentration.

Weather and Water Mission Goal: ***Serve Society's Needs for Weather and Water Information***

"NOAA research focuses on technological developments in the major components of prediction: observational science, quality control, analysis, and ingestion of the observational data (e.g., data assimilation), improved numerical modeling, and user products and other services. Beyond reducing errors, a new emphasis will be on the description of uncertainty at all stages in

[16] IPCC, 2007.
[17] Research in NOAA: A Five Year Plan, Fiscal Years 2008-2012, pg. 28. (emphasis added)
[18] Research in NOAA: A Five Year Plan, Fiscal Years 2008-2012, pg. 35. (emphasis added)

the forecast process. Observations drive improved understanding of important processes. NOAA will integrate multi-purpose observing systems, especially those involving radars, satellites, and profilers, and obtain better observations of environmental parameters. The new observations will be digested by advanced data-assimilation methods, reducing the error in the ensuing forecasts. Numerical modeling, including ensemble techniques, will focus on reducing and representing all forecast uncertainty for use in existing and new forecasts and warnings. Altogether, **these improvements will lead to enhancements in NOAA's flagship weather and water forecast products to better serve the needs of the user community. NOAA research will continually evaluate new observing, data assimilation, and numerical simulation systems for application to improved NOAA services."**[19]

Improved forecasts of precipitation and drought that support the optimal production of biofuels have the concomitant benefit of assisting water managers, e.g., those who would benefit from such improvements when making decisions about releasing water from a reservoir.

An alternative proposing research by NOAA to support renewable energy was submitted to the PPBES in Spring, 2008 for FY11-15 in the Weather and Water Goal, ST&I Program. See Appendix B for a copy of this alternative.

Commerce and Transportation Mission Goal: ***Support the Nation's Commerce with Information for Safe, Efficient, and Environmentally Sound Transportation***

The optimal production of crops for biofuel will depend on accurate weather forecasts, e.g., temperature and precipitation. Biofuels have the potential to provide an alternative, renewable means of powering engines of automobiles, shipping trucks, and marine shipping vehicles. The current (and enlarging) use of NOAA weather guidance by the aviation industry (other transportation industries, to a smaller extent) is an excellent example of how national management and a multi-dimensional private sector might coordinate in a future renewable energy consortium.

NOAA's Coordination with Other Parties in the Field of Renewable Energy

NOAA ESRL has launched a new, monthly seminar series, "Sustainable Energy and Atmospheric Sciences," hosted by NOAA ESRL and NREL (National Renewable Energy Laboratory). The seminar series is designed to enhance communication and collaboration among scientists at NREL, NOAA ESRL, and others in the community working on renewable-energy issues. This series brings together those who can combine their knowledge and expertise to solve the problems that have until now slowed the integration of renewable energy sources into the U.S. electric grid. Scientists at the University of Colorado, School of Mines, Colorado State University, the National Center for Atmospheric Research, and private industry are encouraged to participate. The first seminar was held on October 30 and was a great success. People from private industry, universities and the public were enthusiastically engaged throughout the presentations and panel discussion. Many have requested copies of presentation slides and asked to meet with NOAA to discuss their research and possible collaborations, including Xcel Energy. For presentation slides and a film of the event, see: http://www.esrl.noaa.gov/research/events/seas.

[19] Research in NOAA: A Five Year Plan, Fiscal Years 2008-2012, pg. 38. (emphasis added)

The Private Sector and Opportunities that Improved Forecasts will Provide to This Sector

Private companies run weather forecast models, but do not have the resources to attack problems related to data assimilation and improvement of model physics. Data assimilation systems are expensive and complex, owing to the cost of acquiring and managing data and the computer systems and skilled people power necessary to run and monitor advanced data assimilation systems. Improvements in model physics would inevitably involve costly field-measurement campaigns, but private-sector meteorologists would benefit from the improved physics in the models they do run. Improvements in NOAA/National Centers for Environmental Prediction operational models providing higher-resolution with high-frequency updating from global to national scale would provide a backbone for renewable energy guidance. All of the physics and data assimilation improvements would also make the operational NCEP models more accurate, and models run by the private sector would use these coarser-resolution models for initialization and boundary conditions, again improving the quality of everyone's products.

NOAA is committed to working with private industry to serve the needs of the nation most effectively. To this end, NOAA ESRL procured the following information from 3TIER, a renewable energy forecasting and assessment company that uses its knowledge about weather, climate and their impacts on wind, hydro and solar energy to help its clients make better decisions about their renewable energy investments. The following comments[20] were provided by 3TIER (www.3tiergroup.com) when NOAA asked how we could most effectively collaborate with private industry working on renewable energy. In addition to research in general on improving weather and climate forecasting at all time and space scales, some specific areas that would be helpful for improving forecasting for the renewable energy industry are the following:

Near-term or actionable items

- Improve real-time access to reanalysis and reforecast updates, reliability of those updates, and reduced lag from real-time for some products
- Advance research on week-two forecasts targeted for wind and solar resources
- Pursue reciprocity with the European Union over access to European Center for Medium-Range Weather Forecasts (ECMWF) analysis and forecast products (given that NCEP products are free and accessible); European companies are able to out-compete U.S. companies for wind-energy-sector contracts in the United States, in part by incorporating ECMWF forecast or analysis products that are perceived as superior to NCEP equivalents

Longer-range items

- Research targeting simulation and analysis of boundary-layer processes — not only wind (speed and direction) but also humidity and incoming solar radiation
- Incorporation of wind- and solar-related modeling advances into Weather Research and Forecasting (WRF) model and other community models
- Verification (for NWP and reanalysis) that specifically targets wind fields used in the wind-energy industry (50 m to 150 m above ground)
- A more dense irradiance-monitoring network would also be useful for validation of raw model output of downward solar flux at the surface

[20] Appendix C of the paper contains additional feedback from 3TIER.

The University Community

NOAA ESRL has been working with the Colorado Renewable Energy Collaboratory (www.coloradocollaboratory.org/), which is a research partnership among the National Renewable Energy Laboratory and Colorado's premier research universities — University of Colorado, Colorado State University, and Colorado School of Mines. The Collaboratory works with public agencies, private enterprise, nonprofit institutions and all of Colorado's universities and colleges to:

- Increase the production and use of energy from renewable resources like wind energy, solar energy, and biofuels
- Support economic growth in Colorado and the nation with renewable energy industries
- Build a renewable energy economy in rural Colorado and rural America
- Establish Colorado as America's leading center of renewable energy research and production
- Educate our nation's finest energy researchers, technicians and work force

The Collaboratory receives up to $2 million per year from the State of Colorado for use as matching funds to attract research grants and contracts from federal and private sources. NOAA ESRL has been working with the Collaboratory's nascent Center for Research and Education in Wind (CREW). NOAA ESRL has participated in multiple meetings of CREW with private industry to demonstrate what the members of CREW, including NOAA ESRL, can contribute to the development of renewable energy. In April, NOAA ESRL signed a letter of support for the NSF IGERT proposal that CREW submitted to NSF for a graduate training program, and in October, all four ESRL division directors signed a letter of commitment to the CREW NSF IGERT proposal.

NOAA ESRL's efforts have led to NOAA's being given the title and status of "CREW partner," which allows ESRL to seek research funding in conjunction with the Collaboratory. Whereas CU-Boulder, Colorado School of Mines, NREL, and CSU are officially the four "CREW institutions," NOAA has been deemed a "CREW partner." Any CREW institution can respond to CREW RFPs, and NOAA can respond to such RFPs if it partners with at least one CREW institution. Further details of this working relationship are being formalized in an MOU with the CREW's lead institution, the University of Colorado.

Additional Applications/Benefits

The observations, enhanced models and improved forecasts described above will be useful for many other applications, including:

- Hazardous weather (severe weather, flash floods, fire) prediction
- Transportation forecasts, especially aviation
- Recreational forecasts
- Air-quality forecasting, forecasting for Homeland-Security and DOD operations.

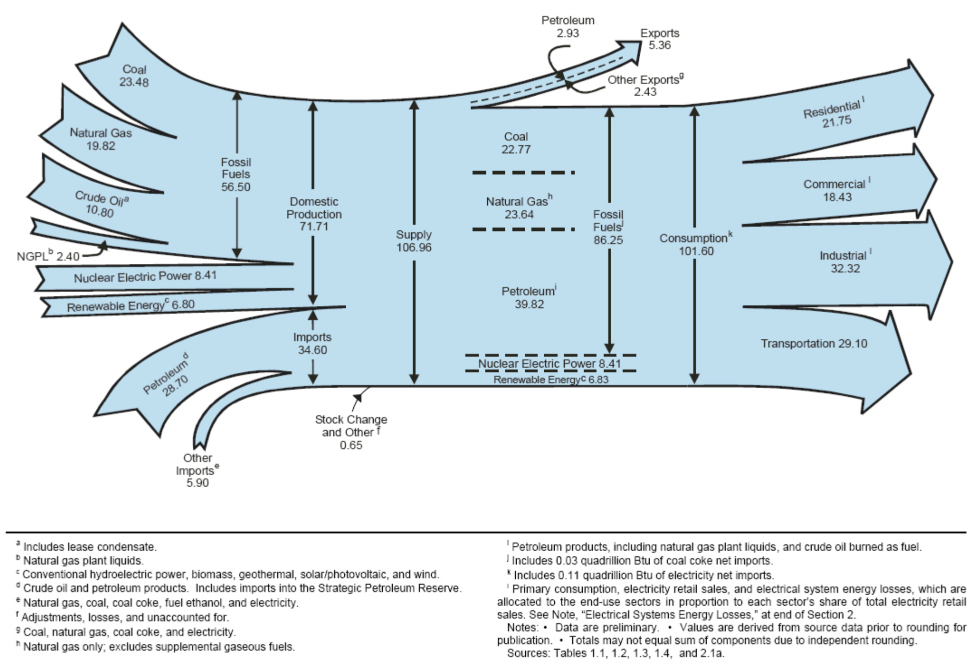
The U.S. Smart Grid of the Future

The foregoing information, describing how NOAA can support the development of renewable energy, stands on its own. However, as the U.S. electric grid is modernized and becomes the intelligent, flexible, and two-way-communicating Smart Grid in the coming years, the enhanced observations and forecasts detailed in the paper will become even more valuable. The full implications of the Smart Grid, regarding how meteorology affects the operation of the electric grid, are still evolving. Nevertheless, it is clear that more users will be impacted by meteorology, e.g., home users of electricity will make decisions based, at least in part, on weather forecasts. This section describes the future Smart Grid.

The proposed U.S. Smart Grid is supposed to replace the ill-designed, antiquated current U.S. electrical grid. Understanding the nation's outdated utility-grid system will make it easier to grasp the future, Smart Grid system.

As the Pulitzer-Prize-winning New York Times columnist Thomas Friedman explains, the current electric-utility-grid system in the United States today was developed with the primary "obligation to serve load." Local and state governments, and the resultant regulatory boards, grant monopolies to utilities (i.e., power companies) to provide electricity or natural gas to regional customers. The utilities, then, must provide power at a reasonable price, power that is reliable, and power that is ubiquitous. The utilities have met their obligations.[21]

But today's grid system is a patchwork. A well-thought-out design was never created and implemented. Today's 3,200 U.S. electric-utility companies and their power lines have by now joined one of three regional grids.

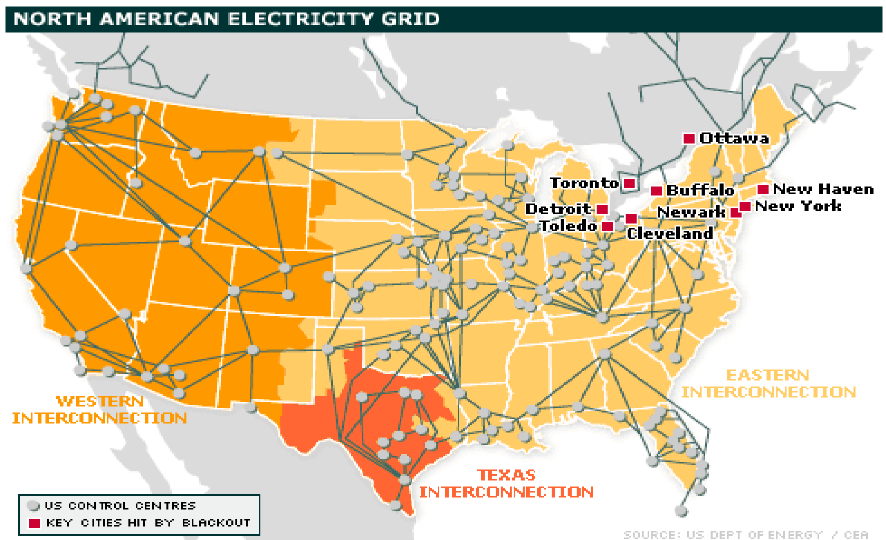


U.S. energy diagram. Energy Information Administration, Annual Energy Review (2007).

[21] Much of this discussion of the U.S. current and future (Smart) grid comes from Friedman, T.L. (2008) Hot, Flat, and Crowded. (Farrar, Straus, and Giroux.; New York.)

This hodgepodge of regional grids suffers several limitations. First, there is insufficient integration within and among the regional grids, making it difficult to send electricity from one part of a region to another, not to mention inter-regional transmission. Another limitation is that communication and electricity flow in only one direction: from utility to customer.

A third limitation of the current grid is the price one pays for electricity each month is constant and does not reflect the time of day it was used, the source of the electricity, or the demand when the energy was bought.[22]



Bottlenecked grid. America operates about 157,000 miles of high-voltage electric transmission lines. While electricity demand increased by about 25% since 1990, construction of transmission facilities decreased about 30%. The result is grid congestion. Transmission and distribution losses are related to how heavily the system is loaded. U.S.-wide transmission and distribution losses were about 5% in 1970, and grew to 9.5% in 2001, due to heavier utilization and more frequent congestion. Congested transmission paths, or "bottlenecks," now affect many parts of the grid across the country.

The mandate for cheap electricity has dominated concerns about carbon dioxide emissions. And the requirements to provide reliable, ubiquitous energy encouraged utilities to build more than their supply capacity so that they always had an ample "reserve margin," which could always meet peak demand.

Given the rates at which developing countries' energy demands are sky-rocketing, along with their carbon dioxide emissions, and the prediction that global oil production will peak soon, it is imperative to get smart about energy production now.

NOAA expertise contributing to improved forecast models could reduce the reserve requirement by reducing uncertainty in anticipated renewable energy supply.

The Department of Energy describes the U.S. Smart Grid of 2030[23] as a 21st century U.S. electric system connecting ev-

[22] An exception is the state of California, which introduced an electricity pricing structure in the mid-1970s that charges people more for electricity at the hours of peak usage. In California, the per capita electricity usage has grown very little in the last 30 years, while the per capita usage in the rest of the United States, which lacks a pricing structure that charges more for electricity during peaks hours, has increased significantly.

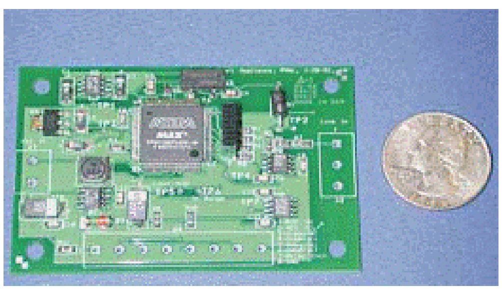
[23] Grid 2030: A National Vision for Electricity's Second 100 Years (2003), United States Department of Energy, Office of Electric Transmission and Distribution.

eryone to abundant, affordable, clean, efficient, and reliable electric power any time, anywhere. These advancements will be achieved by modernizing the electric grid with information-age technologies, such as microprocessors, communications, advanced computing and information technologies. The Smart Grid will dramatically increase the efficiency of electricity usage and rely heavily on carbon-free renewable energy. Briefly, here is how it will work.

In each person's home will be a Smart Black Box (SBB), a home's individual energy dashboard. The SSB integrates the controls and interoperability of all the electrical items and appliances in the home, e.g., phones, computers, internet access, heating, cooling, washer-dryer, televisions, music stations, and plug-in electric hybrid cars and their storage batteries.

"Working together, a willing coalition of industry, universities, nongovernmental organizations, and Federal and state government agencies can help make Grid 2030 [the Smart Grid] a reality."
— http://www.oe.energy.gov/DocumentsandMedia/Electric_Vision_Document.pdf

In each device is a microchip that can inform the utility directly or through the SSB the energy level at which it is operating, receiving instructions from the homeowner or utility about when it should operate and at what power level, and tell the utility when it wants to purchase or sell electricity. This two-way communication facilitates flattening of load peaks and raising of load valleys, thereby reducing the need for wasteful spinning reserves.



Grid-Friendly Appliance Controller. Pacific Northwest National Laboratory has developed a device, based on the gate array chip, commonly found in cell phones, that monitors line frequency, detects dips, and provides the means to trip a load in a graceful manner. Installed in refrigerators, air conditioners, water heaters and various other household appliances, this device would monitor the power grid and turn appliances off for a few seconds to a few minutes in response to power grid overload. By triggering appliances to turn on and off at different times, this device could help control power oscillations that occur in different parts of the grid. Grid Friendly™ appliances reduce some of the load on the system to balance supply and demand.

On average, electrical generating facilities are used about 55% of the time. As a result, customers' efforts to consume less electricity during peak periods can improve electric-system efficiency and economics. Mechanisms to reduce peak demand include time-of-use pricing, load management devices such as "smart" thermostats, load-shifting technologies such as energy storage, and peak-eliminating techniques such as distributed generation. Precise near-surface wind energy and solar energy forecasts will allow use of effective regional and local transmission and storage management, and thermally activated heating, cooling, and humidity-control devices.[24]

Heating and air-conditioners, refrigerators, lighting, car batteries, etc. can be programmed to operate at lower levels when the grid's demand for electricity is highest and the price is proportionately high. Appliances can conversely be programmed to run at higher levels during the night, when the grid's demand for electricity is lowest and the price is relatively low. Plug-in electric hybrid cars can charge and store energy at night.

[24] "Grid 2030."

A key component of the Smart Grid is its significant dependence on renewable energy, such as wind and solar, which have been considered too variable to be economically feasible. In any given location, the wind is not always blowing and the sun is not always shining. But the intelligence, flexibility and two-way communication of the Smart Grid allow renewable energies to be fully integrated and useful for providing electricity to the nation. When the clouds obscure the sun or the wind stops blowing, the Smart Grid sends this information to users' Smart Black Boxes, which could be programmed to respond to the decrease in energy supply. The flatter a utility's load profile is, the more a utility can effectively and profitably use sources of renewable energy instead of fossil-fuel powered sources. The efficiency of the Smart Grid will rely on accurate forecasts of meteorological parameters such as wind and sun (clouds and aerosols). The more accurate the forecasts, the more efficient the operation of the Smart Grid can be.

Plug-in electric hybrid cars, also called "Rolling Energy Storage Units," will help utilities meet peak demand and keep their load profiles relatively flat by allowing owners to sell to utility companies electricity generated by wind or sun and stored in their car batteries.

Another component of the Smart Grid is that electricity users will increasingly rely on meteorology-based forecasts of short-term, future electricity prices to make decisions on when to purchase electricity. For example, a manufacturing company may choose to alter its production schedules to reduce energy costs; car owners may decide not to sell energy stored in the car battery back onto the grid until they know the forecast for tomorrow's electricity price will be high.

"So now there is a direct correlation between how smart your grid is, how much energy efficiency it can generate, and how much renewable power it can use."
— Thomas Friedman, *Hot, Flat and Crowded*

Batteries of plug-in electric hybrid vehicles will provide electricity to utility companies to meet peak demand and keep load profiles flat. Electricity can be produced by wind turbines, solar panels or biofuels, and then sold to utilities.

Conclusions

The global atmospheric concentration of carbon dioxide has increased from a pre-industrial value of about 280 ppm to 385 ppm in 2007. The atmospheric concentration of carbon dioxide in 2007 exceeds by far the natural range over the last 650,000 years (180 ppm to 300 ppm) as determined from ice cores.[25] While many experts believe that global atmospheric carbon dioxide must be stabilized well below 450 ppm,[26] and Hansen et al.[27] report that it must be stabilized at or below 350 ppm, the fact is that the maximum safe atmospheric concentration of carbon dioxide is not known.

The longer society waits to begin serious efforts to reduce carbon dioxide emissions, the tougher it will be to stabilize them, and even harder to achieve more stringent stabilized concentration levels. The Earth system has built-in buffers that create a lag time between carbon dioxide emissions and their full impact on climate. A sound approach to risk-management is to begin immediately to curtail carbon dioxide emissions, as we continue to increase understanding of climate change.

Developing the science necessary for significantly greater deployment of renewable energy would increase the nation's energy security, support mitigation of climate change through reduced emissions of carbon dioxide, and strengthen the economy by the production of high quality jobs. NOAA looks forward to working with its partners, including NREL, DOE, NCAR, and other stakeholders, such as utility companies and grid operators, to serve the nation by ensuring sustainable, plentiful, and affordable supplies of energy.

NOAA has the expertise and mission to establish and maintain baseline atmospheric and oceanic observation networks to evaluate current and future renewable energy resources for spatial and temporal variability, thereby supporting optimal electrical grid system design and operation; improve operational forecast models, thereby enabling wind- and solar-farm operators to better anticipate energy-farm output and facilitate integration of renewable energy into the electric grid; and develop climate models that incorporate renewable energy factors.

NOAA could provide significant support for renewable energy if it were to develop a 1 km national weather model with hourly updating; develop a wind-energy testbed; improve forecast skill for mesoscale and local flows in NWP models; develop and deploy new instrumentation; acquire an enhanced solar observation database; improve ability to infer direct solar radiation from satellite data; improve cloud forecasts and fundamental understanding of clouds; develop data distribution and visualization tools, and develop a coupled-energy climate model.

NOAA's mission is at the heart of the energy-climate-economy challenge.

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[25] IPCC (2007) Working Group 1, Fourth Assessment Report.
[26] Nature, 6 December 2007, doi:10.1038/news.2007.361
[27] Hansen, J., et al. "Target Atmospheric CO_2: Where Should Humanity Aim? Cornell University Library" [physics.ao-ph], arXiv:0804.1126v2

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- *http://www.oe.energy.gov/smartgrid.htm*

Appendix A: NOAA's Mission Goals

Ecosystems Mission Goal: Protect, Restore, and Manage the Use of Coastal and Ocean Resources through an Ecosystem Approach to Management

Outcomes	Performance Objectives
Healthy and productive coastal and marine ecosystems that benefit society A well-informed public that acts as steward of coastal and marine ecosystems	Increase number of fish stocks managed at sustainable levels Increase number of protected species that reach stable or increasing population levels Increase number of regional coastal and marine ecosystems delineated with approved indicators of ecological health and socioeconomic benefits that are monitored and understood Increase number of invasive species populations eradicated, contained, or mitigated Increase number of habitat acres conserved or restored Increase portion of population that is knowledgeable of and acting as stewards for coastal and marine ecosystem issues Increase environmentally sound aquaculture production Increase number of coastal communities incorporating ecosystem and sustainable development principles into planning and management

Climate Mission Goal: Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

Outcome	Performance Objectives
A predictive understanding of the global climate system on time scales of weeks to decades with quantified uncertainties sufficient for making informed and reasoned decisions Climate-sensitive sectors and the climate-literate public effectively incorporating NOAA's climate products into their plans and decisions	Describe and understand the state of the climate system through integrated observations, monitoring, data stewardship Understand and predict climate variability and change in timeframes ranging from weeks to a century Improve the ability of society to plan and respond to climate variability and climate change

Weather and Water Mission Goal: Serve Society's Needs for Weather and Water Information

Outcome	Performance Objectives
Reduced loss of life, injury, and damage to the economy Better, quicker, and more valuable weather and water information to support improved decisions Increased customer satisfaction with weather and water information and services	Increase lead time and accuracy for weather and water warnings and forecasts Improve predictability of the onset, duration, and impact of hazardous and high-impact severe weather and water events Increase application and accessibility of weather and water information as the foundation for creating and leveraging public (i.e., Federal, state, local, tribal), private and academic partnerships Increase development, application, and transition of advanced science and technology to operations and services Increase coordination of weather and water information and services with integration of local, regional, and global observation systems Reduce uncertainty associated with weather and water decision tools and assessments Enhance environmental literacy and improve understanding, value, and use of weather and water information and services

Commerce and Transportation Mission Goal: Support the Nation's Commerce with Information for Safe, Efficient, and Environmentally Sound Transportation

Outcomes	Performance Objectives
Safe, secure, efficient, and seamless movement of goods and people in the U.S. transportation system Environmentally sound development and use of the U.S. transportation system	Enhance navigational safety and efficiency by improving information products and services Realize national economic, safety, and environmental benefits of improved, accurate positioning capabilities Reduce weather-related transportation crashes and delays Reduce human risk, environmental, and economic consequences resulting from natural or human-induced emergencies Increase total government procurements from NOAA-licensed commercial firms operating remote sensing systems

Appendix B: Renewable Energy Alternative Submitted in FY11-15 W&W/ST&I

WW-WWS – Weather and Climate Support for the Renewable Energy Industry		Attached Documents (submit with alternative)
Capability:	• WW-WWS-WCL Weather-Climate	
Applicable Mission Requirement(s):	• WW-WWS - Provide NOAA operational units (such as NWS) with new science applications and technology tools to enable more skillful and timely forecasts and warnings • WW-WWS – Perform research to develop and transfer knowledge and information about atmospheric processes responsible for high-impact weather (including severe storms, , hurricanes, floods…) to enable forecasters to provide improved critical products and services.	
Description:	To address the expanded requirements on NOAA that result from our nation's increased use of renewable energy, NOAA/ESRL proposes to create a new program that will deliver the additional information needed by energy developers and providers. The new activities, which initially emphasize wind energy but also include assessments of NOAA support for the other types of renewable resources, are described in the following three tasks: Task 1: Development of a Wind Energy Test Bed Site and Analysis of Observations ($900K).	

At present, a strong requirement exists for new datasets that adequately describe the atmospheric boundary layer structure for wind energy development. The reasons for this includes the fact that most long-term, high temporal resolution measurements come from surface meteorological stations that are not representative of winds in the layer from 25-200 m, where most wind turbines reside. In contrast, operational wind profiler and WSR-88D scanning radar data do not extend low enough to the ground and are of too coarse vertical resolution to be useful. As a result, locating new wind energy farms is fraught with uncertainty regarding the economic viability of the wind resource, and lack of knowledge as to whether the local wind-shear and turbulence profiles will cause fatigue and even premature failure of wind-turbine hardware.

One solution to the need for better meteorological observational data sets is to develop Wind Energy Testbed sites**.** The goal of the Wind Energy Testbeds is to accelerate the development of wind energy through use of new technologies from the atmospheric and wind energy research communities. These include deployment of advanced tools (new observational systems as well as weather, turbulence, and turbine prediction models) in a test bed setting where they are continuously refined, demonstrated, and evaluated. The Test bed sites would provide the long-term measurements necessary to 1) characterize the turbulence intensity and wind shear profiles that affect the reliability and longevity of wind turbines, 2) evaluate and improve low-level wind simulations in microscale, mesoscale and climate models, and 3) evaluate instruments that might commonly be deployed at potential wind energy sites.

We propose to create a testbed site in the vicinity of a presently existing large wind energy farm. Atmospheric measurements would be taken immediately upstream, within and downstream of the wind farm. Remote sensing instrument systems will be deployed that are capable of making high vertical resolution measurements of the mean wind and turbulence within the boundary layer, but especially in the lowest 250 m. Long-term continuous measurements will be taken, over at least a two-year period. The test bed would then be moved to a new site that has added complexity in the local terrain features, and measurements will be taken for an additional two years. These long-term measurements will be supplemented by shorter period intensive field campaigns during which we will deploy and evaluate supplemental instrumentation that is still in the development phase, and/or instrumentation requiring constant monitoring.

<u>Task 2</u>: Numerical Weather Prediction Model Evaluation and Improvement ($600K)

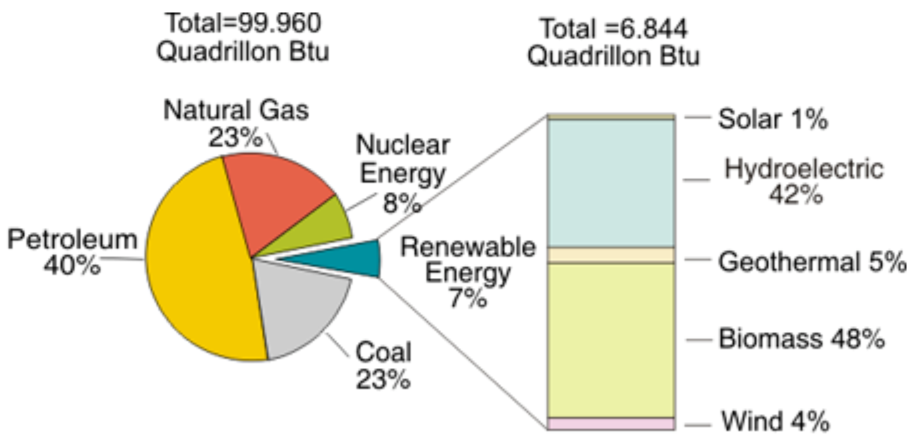
Concurrent with the observational program described in Task 1, research microscale and mesoscale weather prediction models will be run, and model output data from NOAA's operational models will be collected and archived. Because of the dependence of wind power on the cube (third power) of the wind speed, the requirement for precise model predictions of wind speed is more critical for wind energy than for most other model applications. Task 2 is to assess the accuracy of model predictions of wind speed, shear, and turbulence at the heights of turbine rotors, including the ability of the models to properly represent the spatial variability of the resource, since such models are routinely used for siting decisions. As described previously, comprehensive data sets of the wind flow above the surface are not routinely available for such assessments, so a model-validation dataset is a critical need for the wind energy community. This task will be integrated into the data acquisition in Task 1 as both an ongoing assessment during data gathering and as a key aspect of the analysis phases. Identification of where model improvements are most needed and the development of improved representation of critical physical processes in the models are important objectives of this task.

<u>Task 3:</u> Evaluation of the capability of climate models to accurately predict wind, solar, and ocean energy resources ($500K)

Uncertainty as to how renewable energy resources will change in future climates is an increasingly important factor in assessing the economic value of a potential renewable energy project. We propose to use IPCC and other climate model simulations to provide answers to the following questions: What is the present skill of climate models at simulating geographical variability of wind and solar resources? How do these resources change in simulations of the future? What are the physical mechanisms responsible for these changes? Can the natural climatic variability of renewable energy resources be separated from that attributed to anthropogenic forcing? Can an ocean wave model be realistically driven with climate model winds to assess changes in wave energy potential? Task 3 will be to evaluate the ability of the current generation of global climate models to simulate season to season, year to year, and region to region changes in energy resources, using the data gathered for Task 1 along with other available climate datasets. This important information will be needed to properly weigh the results of climate model output in the decision making process for future energy development strategies. For example, if the climate models were to predict that the LLJ of the Great Plains will have weaker winds in a future warm-climate scenario, but the model proved to have little skill in representing changes in LLJ speed over the period of evaluation, decision makers may not want to take this prediction as seriously as if the model exhibited considerable skill.

Background:

86% of current energy usage within the U.S. comes from the burning of fossil fuels, and these fuels are the nation's largest source of greenhouse gas emissions, with electrical power generation accounting for 40% of all emissions (DOE Energy Information Administration). In addition, the cost of all fossil fuels (oil, gas, and coal) has been increasing exponentially over the past decade, and these increases show no signs of stopping, to the detriment of the national economy. Oil, and to an increasing extent natural gas as well, are increasingly being imported from foreign sources that are politically unstable and therefore unreliable. This importation also increases the national foreign deficit.



Note: Sum of components may not equal 100 percent due to independent rounding.
Source: EIA, *Renewable Energy Consumption and Electricity Preliminary 2006 Statistics (2007).*

A solution to these problems is the increased development of renewable energy, including wind, solar, oceanic (primarily wave and tidal), and hydropower. The move to renewable energy is underway. Although at absolute levels the amount of energy provided by renewable resources is still small, the growth rates are large. For example, at present wind energy only provides approximately 1% of U.S. electricity generation, but it is expanding at a rate of over 45% per year (in 2007 over 30% of total installed new electrical generation capacity came from wind), and is envisioned to produce as much as 20% of the nation's power generation by 2030 (DOE Energy Information Administration).

The increasing use of renewable energy presents special problems or needs, the solutions to which are at the core of NOAA's mission and expertise. The needs include:

- assessment of present wind, solar, and oceanic energy resources, through observations and numerical weather/ocean prediction models, for purposes including development and siting;
- short-term forecasting of wind, clouds, precipitation and ocean waves that determine renewable energy production potential, allowing for a more rational and economical balancing of other electrical generation sources (coal and natural gas), thereby improving the electrical grid stability and reducing the chances for brownouts or blackouts;
- understanding how wind, solar, oceanic, and hydropower resources will change as the climate continues to evolve, and of how these changes will impact the economic feasibility of renewable energy systems; and
- understanding how the local micro-climate may change as a result of the deployment of massive arrays of renewable energy devices, especially large arrays of wind turbines.

	Because many wind farms are located on leased agricultural land, changes in the local micro-climate from arrays of wind turbines is of great interest, as these changes could alter the productivity of the land, for example by changing the number of frost-free days in a growing season. • This alternative describes a new effort within NOAA focused on supporting the growing renewable energy sector with an enhanced research, modeling and forecasting capability. It spans both weather and climate impacts on the energy sector. It is represented in the NOAA Strategic and 5-Year Research Plan under the following mission coal outcomes: ▪ Climate-sensitive sectors and the climate literate public effectively incorporating NOAA's climate products into their plans and decisions ▪ Better, quicker, and more valuable weather and water information to support improved decisions; in the AGM through the High-Impact Weather ("NOAA's overall strategy to address the service gaps that exist in the delivery of weather and water information, forecasts, and warnings, which are a growing foundation of many decisions by individuals, industry,..") and Climate ("communicating climate impact information tailored to specific regional needs") theme; and is relevant to the Service Improvement W&W strategy.
Partnerships:	This effort will be part of the Science, Technology and Infusion Program (WWS) and administered through OAR/ESRL. It will partner with the Environmental Modeling Program (EMP) through coordination with NWS/NCEP. Eventual links with the Climate Research and Modeling (CRM), Coasts Estuaries and Oceans (CEO), and Local Forecasts and Warnings (LFW) Program are expected as well. It will partner with the National Wind Technology Center (NWTC) of the DOE's National Renewable Energy Laboratory (NREL), and will benefit from the close physical proximity of NREL with ESRL. It will also collaborate with the Colorado Renewable Energy Collaboratory, a research partnership between the University of Colorado, Colorado State University, the Colorado School of Mines, and NREL.
Priority:	(leave blank)
Performance Measure(s):	• WW-WWS Systems Deployed • WW-WWS Number Major Field Programs Completed • WW-WWS Number of New Algorithms Delivered • WW-WWS Infusion of Technology into Operations
Impact on Performance Measures:	• A number of meteorological systems will be deployed as part of a Wind Energy Test Bed in coordination with NREL'S NWTC. • Continuous test bed field programs will be conducted every year from FY11-FY15 to generate the required boundary layer data sets • Decision support algorithms and associated weather model and climate model outputs tailored to the wind energy industry will be developed. • Data products and decision support tools relevant to the wind energy industry will be transferred to an operational context
Impacted Mission Support Program(s):	• Mission Support: Acquisition and Grants (MS-ACG) • Mission Support: Administrative Services (MS-ADM) • Mission Support: Environmental Modeling (MS-EMP) • Mission Support: Facilities (MS-FCY)

Resources	**FY11**	**FY12**	**FY13**	**FY14**	**FY15**	**TC**
Funding (current program in $K))	0	0	0	0	0	
Funding (Δ above current program)	2000	2000	2000	2000	2000	TBD
FTE (current program Federal FTE)	0	0	0	0	0	
FTE (Δ above current program)	1	1	1	1	1	TBD
Milestones						
Test bed 1(X) &2(x) – Deploy/operate/analyze data (current program)						
Test bed 1(X) &2(x) – Deploy/operate/analyze data (Δ above current program)	X	X	X/x	x	x	TBD
Run weather model tests/analyze results (current program)						
Run weather model tests/analyze results (Δ above current program)		X	X	X	X	TBD

Run climate model tests/analyze results (current program)						
Run climate model tests/analyze results (Δ above current program)	X	X	X	X	X	TBD
Outputs	**FY11**	**FY12**	**FY13**	**FY14**	**FY15**	
Test bed 1 draft report 1 (current program)						
Test bed 1 draft report (Δ above current program)			X			
Test bed 2 draft report (current program)						
Test bed 2 draft report (Δ above current program)					X	

Appendix C: Report from 3TIER

The following comments were provided by 3TIER (www.3tiergroup.com) when NOAA asked how we could most effectively collaborate with private industry working on renewable energy.

In addition to research in general on improving weather and climate forecasting at all time- and space-scales, some specific areas that would be helpful for improving forecasting for the renewable-energy industry are the following:

Near-term or actionable items

- Improved real-time access to reanalysis and reforecast updates, reliability of those updates, and reduced lag from real-time for some products.
    - The current ESRL/NCEP reforecasts posted on the ftp site (ftp://ftp.cdc.noaa.gov/pub/Datasets.other/refcst/ensdata/), for example, are appear to be missing or late in posting 1-3 days per month;
    - But to be used for commercial purposes should have an even better reporting rate.
    - Another example – the North America Regional Reanalysis (NARR) data appear to have about a 4-day lag from real-time, which is also insufficient for many operational purposes.
    - The Rapid Update Cycle (RUC) in comparison has a workably short lag, but its utility is limited by the lack of a retrospective dataset that is consistent with the real-time product.
- Further research on week 2 forecasts targeted for wind and solar resource outlooks
- Pursue reciprocity with the European Union over access to ECMWF analysis and forecast products (given that NCEP products are free and accessible). European companies are able to out-compete US companies for wind energy sector contracts *in the US* in part by incorporating ECMWF forecast or analysis products that are perceived as being superior to NCEP equivalents.

Longer range items

- Research targeting simulation and analysis of boundary layer processes – not only wind (speed and direction) but also fields like humidity and incoming solar radiation (relevant to solar energy industry).
- Incorporation of wind and solar related modeling advances into Weather Research and Forecastsing (WRF) model and other community models.
- Verification (for NWP & reanalysis) that specifically targets wind fields used in the wind energy industry (50-150 m above ground level)
    - Perhaps NOAA could support an ongoing measurement/verification effort, or expand existing activities, particularly in geographic areas identified by wind speed / transmission mapping as high quality wind energy resources.
    - A more dense irradience monitoring network would also be useful for validation of raw model output of downward solar flux at the surface.
- Reanalysis / reforecast: as new reanalysis efforts and reforecast efforts move forward, maintain communication with private sector groups in addition to other applications sector groups (as recommended in the recent NOAA ESRL 5-year review) to ensure that output

fields include those which support follow-on analysis and applications. A sample list of fields that can be used as a minimum set to initialize mesoscale NWP used in retrospective wind and solar energy forecasting studies includes:

-- *at standard pressure levels* (1000, 850, 700, 500, 400, 300, 250, 200, 150, and 100 hPa) plus 925 and 50 hPa (desirable):

  - U- and V- wind components
  - Geopotential height
  - Temperature
  - Relative Humidity

-- *near surface*:

  - Sea-level pressure
  - 10-m U- and V- wind components
  - 2-m Temperature
  - 2-m Relative Humidity

- Maintain regular workshop/meeting opportunities for interaction between NOAA forecasting and analysis participants and private sector personnel. At present, the Climate Diagnostics and Prediction workshop (CDPW, Fall) and Climate Prediction Applications and Science workshop (CPASW, Spring) are perhaps the two primary such opportunities; but it may be worth having a workshop targeting alternative energy directly – ie, research-to-applications or research-to-operations workshop with an alternative energy theme.
- One of the NOAA CPO programs (perhaps SARP or TRACS, which are applications-focused) could include an emphasis area encourage agency-academia-private sector applications research in the area of alternative energy.
- Wind energy forecast demands are for hour ahead, day ahead, week ahead and month ahead at this point. It is unclear yet what lead times will be most important for solar energy applications. Perhaps the most poorly understood area of predictability is at the month-ahead and season-ahead lead time for wind and solar energy. Although ENSO has been shown to offer minor predictability, research in this area could be beneficial if it could lead to a better sense of what predictors are best for wind speed and solar irradiance at different lead times, in different regions and even different seasons.

Q. What research related to wind energy can be handled by the private sector?

A. The private sector goes beyond forecasts of natural variables like wind speed to provide forecasts of energy and power at the turbine, project and/or regional levels of aggregation.

- NOAA should focus primarily on analysis and forecasting of Earth system variables rather than quantities (such as energy production) derived from and/or describing the interaction of those variables with energy production and resource management (e.g., water) systems.
- Analysis and forecasting of such systems is a primary area in which the private sector can add value to NOAA weather and climate monitoring and prediction efforts.

Q. Is your group doing any research on co-variability of wind (and solar) energy supply (and demand) on a national scale. If not, would that be of use? (clarification: the question is more on spatial co-variability (and extreme events) rather than local co-variability. Sort of how (un-)likely is it that the national, say, wind energy output drops below 50% of capacity (or goes above 200%), or something like that).

A. At present, we are not conducting research at synoptic, regional or continental scales on the spatial co-variability of alternative energy production. Regional energy production in some sectors (such as hydro) has been and is of interest to financial industry groups, such as energy traders, and this may become true in other alternative energy sectors. Regional and larger-scale wind or solar variations may come to support tradable indices of different types of energy at these scales, but much more attention is being paid at present to co-varability across renewable energy sources at a local scale, with the hope that co-variability-based synergies exist to facilitate the integration of wind and solar with less intermittent energy resources. Note: to the extent that this kind of analysis is practically linked to particular local or regional energy production installations (solar, wind & hydro), this kind of research may also be best undertaken by the private sector (albeit using more general tools & datasets developed via publically-supported research).