Data Sources and Methodologies

Wind

Wind Maps – Data Sources

Arizona, California, Nevada and Utah – Wind Energy Resource Atlas of the United States, Pacific Northwest Laboratory (PNL), 1987.

Colorado – Brower and Company for Colorado Office of Energy Conservation, 1995.

New Mexico – Brower and Company for New Mexico Department of Energy, Minerals and Natural Resources, 1997.

Idaho, Montana, Oregon, Washington, Wyoming – TrueWind Solutions High-Resolution Wind Mapping Project for Northwest SEED, 2002.

Wind Generation Potential Estimates

Wind resource maps for the eleven Western states are currently available in varying degrees of accuracy and resolution. These estimates were developed using the most recent figures available for each state (sources given above).

Idaho, Montana, Oregon, Washington and Wyoming

The wind data were generated by TrueWind Solutions using their MesoMap wind mapping system. This system combines a numerical weather model and a microscale wind flow model to produce a high-resolution wind resource map that accounts for complex flows, such as channeling, sea breezes, downslope winds, and other effects. These high-resolution data were fully validated by NREL.

Land Use Exclusions

The exclusion criteria were developed in coordination with NWSeed and NREL. Although NREL is still in discussions with the Department of Energy, and has not finalized their definitions of exclusion zones, these guidelines represent their current thinking. The areas 100% excluded fall under three general categories:

1. Landforms – land with a slope of greater than 20%
2. Environmentally sensitive areas
   a. All National Park Service lands
   b. All Fish and Wildlife lands
   c. All Forest Service or BLM lands with a "special" designation, such as National Recreation Area or National Wilderness Area
3. Land use exclusions
   a. All bodies of water
   b. Wetlands
   c. Urban areas

Other land use exclusions were not applied because development will depend on conditions in individual project areas.

Colorado and New Mexico

These maps were developed by Brower and Company, in collaboration with consulting meteorologist Richard L. Simon, using GIS-based regression models. The 1987 US Wind Atlas was the starting point for the CO map; modifications in the wind resource estimates were made to account for the effects of local terrain exposure and roughness as well as new wind data that had become available, particularly in mountainous areas. The NM map was developed independently of the 1987 US Wind Atlas using data from nearly 70 towers located throughout the state. The maps have not been independently validated. No attempt was made to reconcile the two maps at the borders. In addition, the CO map was based on wind power, whereas the NM map was based on wind speed and subsequently converted. For these reasons there is a noticeable discontinuity at the border between the two maps. New maps for both states, will be produced by TrueWind Solutions and are scheduled for completion in early 2003.

Land Use Exclusions were the same as above.

Arizona, California, Nevada and Utah

The analysis for Arizona, Nevada, California and Utah relied on tabular data produced by PNL in 1991 and 1992. The 1992 report provides the most accurate calculations for windy land area by state, with varying definitions of exclusions presented. However, it did not provide a breakdown of windy land area by wind class. In order to provide this level of detail, the total windy land area in the 1992 report was interpolated down to wind classes, based on the percentages for each category represented in the 1991 report. Prior to 1995, when Brower produced the map of Colorado, no GIS compliant data had been created to accurately model wind resources in the Western United States. The maps contained in the 1987 Atlas presented a coarse wind resource assessment by assigning a single wind power class to each 25km^2 grid cell. The power class assigned to the cell represents the maximum wind power class likely to occur on well-exposed areas within that grid cell. To account for the variation in terrain, each grid cell was assigned a terrain exposure factor varying from 5% (representing exposed ridgecrests) to 95% (flat open plains).

Land Use Exclusions

Since GIS compliant data were not available at the time the 1991 and 1992 data were created, exclusions were based on manually tabulated data. First, all federal and state environmentally sensitive lands were 100% excluded from development. These lands included parks, monuments, US Forest Service lands, wilderness areas and wildlife refuges. The available windy land area was further reduced by exclusions based on the primary land use of each region. Percentages were determined for eight land use types:

1. Forest – 50% excluded
2. Agriculture – 30% excluded
3. Range – 10% excluded
4. Mixed Agriculture and Range – 20% excluded
5. Barren – 10% excluded
6. Wetland – 100% excluded
7. Urban – 100% excluded
8. Water – 100% excluded

Because of the change in exclusion methodologies, the 2002 Wind Area figures reflect more of a gross potential than these 1992 numbers. This difference in emphasis accounts for much of the contrast between the 1992 and 2002 Wind Area figures land area for the individual states.

Sources:

"An Assessment of the Available Windy Land Area and Wind Energy Potential in the Contiguous United States," 1991, Pacific Northwest Laboratory (PNL), by Dennis Elliott, Larry Wendell and Gene Gower.

"Gridded State Maps of Wind Electric Potential," 1992, by Marc Schwartz, Dennis Elliott and Gene Gower, presented at Windpower 1992.

Solar

Solar Maps – Data Sources

National Renewable Energy Laboratory, 2002

George, R., and E. Maxwell, 1999: "High-Resolution Maps of Solar Collector Performance Using Climatological Solar Radiation Model," Proceedings of the 1999 Annual Conference, American Solar Energy Society, Portland, ME.

Maxwell, E., R. George and S. Wilcox: "A Climatological Solar Radiation Model," Proceedings of the 1998 Annual Conference, American Solar Energy Society, Albuquerque, NM.

Marion, W. and S. Wilcox, 1994: "Solar Radiation Data Manual for Flat-plate and Concentrating Collectors." NREL/TP-463-5607, National Renewable Energy Laboratory, 1617 Cole Boulevard, Golden, CO 80401.

Details: This map provides annual average daily total solar resource information on grid cells of approximately 40 km by 40 km in size. The insolation values represent the resource available to a flat plate collector, such as a photovoltaic panel, oriented due south at an angle from horizontal equal to the latitude of the collector location. This is typical practice for PV system installation, although other orientations are also used.

The map was developed with data derived from the Climatological Solar Radiation (CSR) model. The CSR model was developed by the National Renewable Energy Laboratory for the US Department of Energy. Specific information about this model can be found in Maxwell, George and Wilcox (1998) and George and Maxwell (1999). This model uses information on cloud cover, atmospheric water vapor and trace gases, and the amount of aerosols in the atmosphere, to calculate the monthly average daily total insolation (sun and sky) falling on a horizontal surface. The cloud cover data used as input to the CSR model are an 8-year histogram (1985–1992) of monthly average cloud fraction provided for grid cells of approximately 40 km x 40 km in size. Thus, the spatial resolution of the CSR model output is defined by this database. The data are obtained from the National Climatic Data Center in Asheville, North Carolina, and were developed from the US Air Force Real Time Nephanalysis (RTNEPH) program. Atmospheric water vapor, trace gases, and aerosols are derived from a variety of sources, as summarized in the references. The procedures for converting the modeled global horizontal insolation into the insolation received by a flat plate collector at latitude tilt are described in Marion and Wilcox (1994).

Where possible, existing ground measurement stations are used to validate the model. Nevertheless, there is uncertainty associated with the meteorological input to the model, since some of the input parameters are not available at a 40 km resolution. As a result, it is believed that the modeled values are accurate to approximately 10% of a true measured value within the grid cell. Due to terrain effects and other microclimate influences, the local cloud cover can vary significantly even within a single grid cell. Furthermore, the uncertainty of the modeled estimates increases with distance from reliable measurement sources and with the complexity of the terrain.

After acquisition from NREL, GreenInfo Network smoothed the data by interpolating a grid using the centroids of the 40 km cells as data points using a inverse distance weighted function. The annual average of the daily solar radiation were used, as described above. The raster resolution of the interpolated grid was 3 km. These data were then smoothed using an averaging filter to simplify data and improve map legibility.

Solar Generation Potential Estimates

These estimates represent a possible scenario of the energy that could be generated from distributed solar photovoltaic installations, as opposed to centralized power stations, based on simple assumptions limiting their maximum deployment:

1. Solar power producing systems can be installed on rooftops and open spaces representing 0.5% of the total area of each state.
2. Solar panels will occupy 30% of the area set aside for solar equipment, with the balance taken up by support structures, access paths and other equipment.

3. Solar energy can be converted to electricity at an average system efficiency of 10%. Although crystalline silicon photovoltaic modules have demonstrated efficiencies as high as 22.7% under laboratory conditions, commercially viable systems average much lower, particularly when total system efficiencies are considered. In addition, heat can have a major impact on panel efficiencies in a real world setting, typically leading to a derating of 10% or more in sunny environments. Reliance on other forms of solar electrical production, using concentrating photovoltaic collectors or solar thermal systems, would introduce a very different set of assumptions and results.

The results represent theoretical potentials, moderated by these simple constraints, and do not take economic realities into account. Market conditions, local environmental considerations, and future developments in solar technologies and other energy sources will ultimately determine the economic viability of solar penetration at these levels.

Geothermal

Geothermal Maps – Data Sources

Southern Methodist University Geothermal Lab, 2001
http://www2.smu.edu/geothermal/georesou/resource.htm

Details: The data used to produce the geothermal maps are derived from a model that incorporates heat flow, thermal gradient, sediment thickness, hot springs and previous maps by the DOE and EGI-UURI. The well locations on the map are taken from the Western US Geothermal database and represent those records with an uncorrected heat flow gradient greater than 150 mW/m^2 at the deepest interval sampled. This was suggested by scientists at SMU as an approximate cut-off for sites with a gradient suitable for electricity production. It should be noted that several factors determine the suitability of an area for geothermal electricity production and that site-specific tests would be needed before developing the resource potential.

The values in the composite model used are unit-less; they do not represent actual heat flow. The actual data were received from SMU as a text file and were converted to an ArcView shapefile of points for the Western US. These points were interpolated using an inverse distance weighted method at a cell size of 3 km. The data values were divided into 30 equal intervals and were assigned colors. These data were then draped onto a hillshade of terrain for the region at 1 km resolution.

Geothermal Generation Potential Estimates

These figures were taken from the Geothermal Electric Submodule of the Renewable Fuels Module of the National Energy Modeling System (NEMS). Details on the model are available at:
http://tonto.eia.doe.gov/FTPROOT/modeldoc/m069(2002).pdf

The estimates given on page 13 include geothermal resources which would produce electricity at less than $60 per MWh.

Biomass

Biomass Maps – Data Sources

Landfill Gas: Landfill Methane Outreach Program (LMOP) database (2001)
http://www.epa.gov/lmop/projects/projects.htm

Crop residues: USDA Published Estimates Database (PEDB) (2000–2001)
http://www.nass.usda.gov:81/ipedb/ for corn, wheat and barley

Forest Residue: USDA Forest Service's Forest Inventory and Analysis Database (FIADB) (1996)
http://www.fia.fs.fed.us/

Animal Waste: USDA Published Estimates Database (PEDB) (2000–2001).
http://www.nass.usda.gov:81/ipedb/ for dairy cattle, beef cattle, swine and sheep

Biomass Generation Potential Estimates

Landfill Gas

Landfill gas resources were estimated by aggregating the MW capacities of both existing landfill gas recovery systems and potential future systems, as estimated by EPA in their Landfill Methane Outreach Program database (2001).

For some of the landfills identified in the EPA database no capacity estimates are specified. For these landfills, EPA does provide estimates for total waste material buried in the landfill (in tons). In order to estimate likely system capacities, a regression of the natural logarithm of generation capacity was fitted on tons of buried waste at existing and potential sites where both capacity and buried tons are documented.

$$\ln(MW) \sim tons$$

where:

- MW is the generation capacity of the landfill.
- $tons$ is the number of tons of garbage contained in the landfill.

This log linear regression has an R^2 value of approximately 0.3. The regression yields the following equation for electric capacity in MW:

$$MW = e^{((6.40 \text{x} 10^{-8})tons + 0.383)}$$

This formula was used to estimate generation capacity where only tonnage values are available. 29% of the landfill capacity estimates were calculated using this formula. Where multiple projects exist at one landfill, estimates were adjusted so that the sum of estimated project generation capacities does not exceed the total estimated capacity for the landfill. Annual expected production was calculated by multiplying the capacity (MW) by 8760 hrs/yr. The conversion from heat energy to electrical energy is assumed to be 25% efficient. When calculating annual heat energy, an energy transfer factor of 13,600 kWh/BTUs was used which incorporates the assumed efficiency.

Crop Residues

The principal grains – corn, wheat, and barley – are the major source of potentially usable crop residues in the West. Crop residue resources were calculated using data acquired from the USDA Published Estimates Database (2000–2001). Annual expected generation due to crop residues was calculated using:

$$\frac{bushels \text{ x } lb\_per\_bushels \text{ x } residue\_fraction \text{ x } energy\_density \text{ x } residue\_factor \text{ x } moisture\_factor}{2000 \text{ x } energy\_transfer\_factor \text{ x } 1000} = MWh$$

where:

- $bushels$ is bushels of grain harvested (USDA data)
- lb_per_bushel is the weight of an average bushel. The assumed weight per bushel of each grain follows:
  – barley 48 lb/bushel
  – corn 56 lb/bushel
  – wheat 60 lb/bushel
- $residue\_fraction$ is the assumed fraction of residue that can be taken from fields after harvest without negatively affecting soil quality. A residue fraction of 0.30 was used for all grains.
- $energy\_density$ is the energy contained in 1 ton of residue. Each ton of residue is assumed to contain $15.0 \text{x} 10^6$ BTUs [Kerstetter and Lyons, 2001]

- *residue_factor* is used to determine the amount of available residue based on the grain harvest. The residue factors used for each grain follow:
  – barley 1.50
  – corn 1.00
  – winter wheat 1.70
  – durum wheat, spring wheat 1.30
- *moisture_factor* is used to adjust the weight of the residue to a dry weight. The moisture factors used for each grain follow:
  – barley 0.90
  – corn 1.00
  – winter wheat 0.87
  – durum wheat, spring wheat 0.87
- *energy_transfer_factor* is a conversion factor used to convert between electrical energy and heat energy. Assuming a 25% efficient boiler, the energy transfer factor is 13,600 kWh/BTU.

Forest Waste

Forest waste resources are based on an aggregation of forest waste and mill waste annual energy capacity data from the USDA Forest Service's Forest Inventory and Analysis Database (1996). Urban waste (municipal solid waste) is not included. The conversion from heat energy to electrical energy is assumed to be 25% efficient. When calculating annual heat energy, an energy transfer factor of 13,600 kWh/BTUs was used which incorporates the assumed efficiency.

Animal Waste

Animal waste resources were estimated by combining county totals of dairy cattle, beef cattle, swine and sheep. Estimated county totals were acquired from the USDA Published Estimates Database (2000–2001). Annual expected generation due to animal waste was calculated using:

$$\frac{365 \text{x} \, animals \, \text{x} \, volatile\_solids \, \text{x} \, volume \, \text{x} \, energy\_per\_volume \, \text{x} \, (1 - handling\_loss) \, \text{x} \, digester\_efficiency}{1000 \, \text{x} \, energy\_transfer\_factor} = MWh$$

where:

- *animals* is the number of animals.
- *volatile_solids* is the weight in lbs of volatile solids produced by a typical animal each day. Volatile solids assumed for each animal follow:
  – beef cattle 6.00 lb/animal/day
  – dairy cattle 11.20 lb/animal/day
  – swine 1.20 lb/animal/day
  – sheep 0.92 lb/animal/day
- *volume* is the volume in ft^3 of gas generated from each lb of volatile solids. Volumes for each animal follow:
  – beef cattle: 9.76 ft^3/lb
  – dairy cattle, sheep 14.00 ft^3/lb
  – swine 8.00 ft^3/lb
- *energy_per_volume* is the energy in BTU's contained in each ft^3 of gas. Energy per volume of each animal follows:
  – beef cattle, dairy cattle, sheep 600 BTU/ft^3
  – swine 650 BTU/ft^3

- *handling_loss* is the expected waste management handling loss. Expected waste management handling losses for each animal follow:
  – beef cattle, sheep 0.25
  – dairy cattle 0.10
  – swine 0.20
- *digester_efficiency*. Expected digester efficiencies for each animal follow:
  – beef cattle, swine 0.50
  – dairy cattle, sheep 0.35
- *energy_transfer_factor* is a conversion factor used to convert between heat energy and electrical energy. Assuming an internal combustion engine efficiency of 25%, the energy transfer factor is 13,600 kWh/BTU.
- 365 days equals one year. This is used to convert daily generation to annual expected generation.

Electricity Generation (p. 16):

Data source: Energy Information Administration, Electric Power Annual 2000, Volume I – Net Generation of Industry by state and resource for year 1999

Renewable Energy Facilities (p. 18):

Installed Capacity and Location Data source: REPiS: The Renewable Electric Plant Information System, 2001; American Wind Energy Association, 2002

The REPiS database records information on the status, capacity and fuel types of renewable energy facilities producing electricity with some information on the geographic location of the facilities. The location of most of the records can be derived from the city or name or the zip code. Only operating plants at the time of the release of the data were included in the mapping. Because the American Wind Energy Association data were more current, (for wind facilities) we used this for capacity and location for records that did not appear in the REPiS database.

In locating the facilities to map within a GIS, we used the most accurate geographic reference feature available for that record. For example, if the zip code was available for the plant we used that to link to the GIS, then city names, then county names. Within the GIS, cities were represented as points and counties and zip codes as polygons. For the polygon features, we used the centroid of the shape as the location of the plant. More than one facility may be represented by the icon on the map because we had to aggregate all records with same geographic locator. Out of 1,768 records for all facilities, 314 did not have either zip codes, counties or cities and could not be located using the GIS. Some of the records that did have a record for zip code, city or county name could not be located because of various reasons, often a missing zip code in the GIS data or a different spelling. These were not significant for any fuel or geography except for the city–solar combination. Out of 387 cities in the REPiS database with an operation solar facility, 85 were not matched. This was likely due to misspellings, unincorporated cities that may not appear in the GIS data, or use of local place names that would not be in the GIS data. This affects only the location map and not the installed capacity totals as these were compiled directly from the REPiS data.

Renewable Energy Policies (p. 19)

Data source: Database of State Incentives for Renewable Energy (DSIRE), updated June 2002, www.dsireusa.org

The West at Night (p. 20)

Data source: National Geophysical Data Center 2000

This image of the Lights of North America was downloaded from www.nationalatlas.gov. Transmission lines are shown courtesy of Platts, POWERmap, powermap.platts.com ©2002 Platts, A Division of The McGraw-Hill Companies.

Load Growth (p. 21)

Data source: *A Conceptual Plan for Electricity Transmission in the West, a Report to the Western Governors' Association,* August 2001, Figure 7, page 23

Transmission Constraints (p. 22)

Data source: *A Conceptual Plan for Electricity Transmission in the West, a Report to the Western Governors' Association,* August 2001, Figure 6, page 22; POWERmap, powermap.platts.com ©2002 Platts, A Division of The McGraw-Hill Companies

Land Use Considerations (p. 23)

Data source: National Atlas of the United States, USGS 1999; Bureau of Land Management 1999, Arizona Land Resource Information System, Colorado Department of Transportation 2001, Idaho Gap Analysis Project 1999, Montana Natural Heritage Program 2002, Nevada Gap Analysis Project 1996, New Mexico Gap Analysis Project 1996, Oregon State Service Center 1993, Utah Gap Analysis Project 1995, Wyoming Gap Analysis Project 1996

Environmental Impacts of Fossil Fuels (p. 24)

Data source: EPA Acid Rain Program (Title IV) Emissions Scorecard, 2000

Details: The annual values for SO_2, NO_X and CO_2 for the eleven Western states were selected from the full data set. The corresponding GIS data of plant locations was downloaded from the Clean Air Mapping and Analysis Program Web site (www.epa.gov/airmarkets/cmap/index.html) and was used to tie the emissions data to the plant location. These point locations of plants were buffered 10 miles to give them an areal extent necessary for the 3D visualization. Using ArcView 3D analyst, we created the images by scaling the height of the bars (centered on plant locations) to the emissions in 2000. SO_2 and NO_X were scaled proportionally by multiplying the emissions (tons) by 5 to derive the height of the bars. Because CO_2 emissions are so much higher (in terms of tons), a different scaling factor was applied. The amount of CO_2 emitted was divided by 40 to derive the height of the bars.