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DEPARTMENT OF BUSINESS, ECONOMIC DEVELOPMENT & TOURISM

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Bill No. SB 2526

Statement of
ABBEY S. MAYER
Director, Office of Planning
Department of Business, Economic Development, and Tourism
before the
COMMITTEE ON ENERGY AND ENVIRONMENTAL PROTECTION
AND
COMMITTEE ON WATER, LAND, AND OCEAN RESOURCES
Tuesday, March 9, 2010
9:30 AM
State Capitol, Conference Room 325

Date 3/8
Time 931
Cat AF AS AX B
Type 1 2 WI

in consideration of
SB 2526 SD1
RELATING TO WIND ENERGY FACILITIES

Chairs Morita and Ito, Vice Chairs Coffman and Har, and Members of the Committees on Energy and Environmental Protection and Water, Land, and Ocean Resources.

The Office of Planning opposes SB 2526, SD 1 which would amend Sec. 205-4.5 (a) HRS, to establish a minimum setback of one thousand feet between a wind energy facility utilizing wind turbine generators with the capacity to generate one megawatt or more from the nearest existing off-site residential dwelling unit.

We oppose this measure because the distance buffer between wind turbines and residential units should be determined as part of the planning process on a case-by-case basis by the respective county governments.

Thank you for the opportunity to testify.

DEPARTMENT OF PLANNING AND PERMITTING
CITY AND COUNTY OF HONOLULU
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MUFI HANNEMANN
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DAVID K. TANOUE
DIRECTOR

ROBERT M. SUMITOMO
DEPUTY DIRECTOR

March 9, 2010

Bill No. SB 2526

Date 3/8

Time 1149

Cat AF AS AX B

Type 1 2 WI

The Honorable Hermina M. Morita, Chair
and Members of the Committee on Energy & Environmental Protection
The Honorable Ken Ito, Chair
and Members of the Committee on Water, Land & Ocean Resources
State House of Representatives
State Capitol
Honolulu, Hawaii 96813

Dear Chairs Morita, Ito and Members:

Subject: Senate Bill No. 2526, SD1
Relating to Wind Energy Facilities

The Department of Planning and Permitting (DPP) **opposes** Senate Bill No. 2526, SD1 which seeks to establish a 1,000-foot setback from any offsite residential dwelling for wind energy facilities on agricultural land.

This bill still does not explain why a minimum 1,000-foot setback is a reasonable or appropriate distance. We agree that potential impacts from wind energy facilities need to be properly mitigated. However, we believe that each wind energy project must be reviewed on a case-by-case basis since there is a multitude of factors which must be considered. Such factors include but are not limited to: the size of the project site, existing and surrounding land uses, topography, soil conditions, and access. As such, caution must be exercised when establishing a statewide standard such as a minimum setback because it may unnecessarily hamper a company's efforts to find a suitable site. Furthermore, it will delay the progress of developing wind energy facilities as alternative energy sources because it reduces the number of potential sites on which such facilities can be properly located. The DPP still believes that the counties are more effective in regulating such uses.

We respectfully request that Senate Bill No. 2526, SD1 be filed. Thank you for the opportunity to testify.

Sincerely yours,

A. David K. Tanoue, Director
Department of Planning and Permitting

DKT: jmf
sb2526sd1-kd.doc

HAWAII RENEWABLE ENERGY ALLIANCE
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Herbert M. (Monty) Richards
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TESTIMONY OF WARREN BOLLMEIER ON BEHALF OF THE HAWAII RENEWABLE ENERGY ALLIANCE BEFORE THE HOUSE COMMITTEES ON ENERGY AND ENVIRONMENTAL PROTECTION, AND WATER, LAND AND OCEAN RESOURCES

SB 2526 SD1, RELATING TO WIND ENERGY FACILITIES

March 9, 2010

Chairs Morita and Ito, Vice-Chairs Coffman and Har, and members of the Committees, I am Warren Bollmeier, testifying on behalf of the Hawaii Renewable Energy Alliance (HREA). HREA is an industry-based, nonprofit corporation in Hawaii established in 1995. Our mission is to support, through education and advocacy, the use of renewables for a sustainable, energy-efficient, environmentally-friendly, economically-sound future for Hawaii. One of our goals is to support appropriate policy changes in state and local government, the Public Utilities Commission and the electric utilities to encourage increased use of renewables in Hawaii.

The purpose of SB 2526 SD 1is to provide for a setback when wind energy facilities are being used in agricultural districts. HREA does not take a position on this measure at this time and provides the following comments for consideration by the committee:

Bill No. SB2526

Date 3/8

Time 1157

Cat AF AS AX (E)

Type (1) 2 WI

1. Wind Turbines[1], windfarms and Siting Requirements. Wind project developers must address a number of issues during the permitting process, some of which are related to "setback requirements." In general, setback requirements prescribe that a structure, should it fall over, should not extend beyond the project's property line. For example, the total height of a 1 MW class wind turbine on its tower with one of its blades extended in the vertical position would be on the order of 300 feet and on the order of 400 feet for a 2 to 2.5 MW class wind turbine. Thus, a 1,000 foot setback, as proposed in this measure, is 2 to 3 times the distance than is necessary to address safety concerns. In addition, the project must meet local zoning ordinances which typically include specification of maximum allowable noise levels during daytime and night time requirements. Today's advanced large wind turbines (1 MW and larger), when properly sited, can meet typical noise requirements.

2. County Jurisdiction. Developers must obtain permits from the Counties for siting wind turbines on agricultural land. All of the issues above, and many more, would have to be addressed by the developer in order to obtain a Conditional Use Permit for his project.

3. Recommendations. Given the above, we do not believe this bill is needed, as all stakeholders would have the right to express their concerns during the county permitting process for wind projects. Therefore, we respectfully request that the Committee hold this bill.

Thank you for this opportunity to testify.

[1] Wind turbine is the "industry term of art" for the machines that capture the wind and convert that energy into electricity or mechanical power. Older terms not generally in use include windmills, wind turbine generators and wind energy conversion systems.

Cyndi Apana

From: mailinglist@capitol.hawaii.gov
Sent: Monday, March 08, 2010 1:33 PM
To: EEPtestimony
Cc: tvandeveer76@hotmail.com
Subject: Testimony for SB2526 on 3/9/2010 9:30:00 AM

Bill No. SB2526

Date 3/8

Time 1337

Cat AF AS AX B

Type 1 2 WI

Testimony for EEP/WLO 3/9/2010 9:30:00 AM SB2526

Conference room: 325
Testifier position: oppose
Testifier will be present: No
Submitted by: Timothy Vandeveer
Organization: Individual
Address: 59-080 Kam. Hwy. Unit #B Haleiwa, HI
Phone: 388-0660
E-mail: tvandeveer76@hotmail.com
Submitted on: 3/8/2010

Comments:
I oppose SB 2526 as the buffer zone is not sufficient enough to eliminate issues connected with this technology. These issues include; audible and visual impacts, industrial encroachment on residential neighborhoods, and potential health and safety issues.
A more acceptable distance of one half to one full mile should be considered as this may; increase public acceptance of large wind tower and turbines in other suitable sites, increase the margin of safety for residents living in close proximity to large 1 megawatt turbines and towers, lower adverse affects on health and wellness issues that may be detrimental to humans
Thank you for your consideration on this matter.

Cyndi Apana

From: mailinglist@capitol.hawaii.gov
Sent: Monday, March 08, 2010 12:20 PM
To: EEPtestimony
Cc: kent@trisland.com
Subject: Testimony for SB2526 on 3/9/2010 9:30:00 AM
Attachments: The Congressional Research Service Report.pdf; Public Health Affects- Minnesota Dept. of Health.pdf

Bill No. SB2526

Date 3/8

Time 1352

Cat-AF AS AX B

Type 1 2 WI

Testimony for EEP/WLO 3/9/2010 9:30:00 AM SB2526

Conference room: 325
Testifier position: support
Testifier will be present: Yes
Submitted by: Kent Fonoimoana
Organization: Kahuku Community Association
Address: 56-423 Pahelehala Loop Kahuku, Hawaii
Phone: 808-294-9991
E-mail: kent@trisland.com
Submitted on: 3/8/2010

Comments:
As a member of Kahuku Community Association, I respectfully convey our conditional support for the intention of this measure. However, we ask that the recommended 1000' buffer zone be extended to 2640' or one half mile from the nearest offsite residential dwelling. Our community is solidly against the installation of 420' tall tower/turbines within 2640' of our community boundary. The Kahuku agricultural park abuts our community and O'ahu Wind Power Partners has plans to install ten (10) turbines in the ag park. We adamantly object to four of the ten proposed sites. We know our quality of life will be severely impacted should these four units be installed is such close proximity to our community. There is ample information available to suggest that placing these machines in close proximity to humans can be detrimental. Please refer to The Congressional Research Service Report prepared for Congress by Jeffrey Logan and Stan Mark Kaplan, Specialists in Energy Policy, Resources, Science, and Industry Division. Please read Public Health Impacts of Wind Turbines Prepared by: Minnesota Department of Health, Environmental Health Division.
There are many countries or organizations who recommend a greater distance than the 1000' setback that the developers advocate. Some of these are:
1-National Research Council; USA Past ½ mile or so 2-France National Academy of Medicine 1.5 KM .93 mile 3-Burton, Sharpe, Jenkins, Bossanyi
(Authors) Wind Energy Handbook. Wiley & sons LTD. 1991 10 rotor Diameters = 2,665 feet 4-Holland 1 KM .62 mile 5-UK Noise Association 1 mile 6-Scotland ½ mile
7-RETEXO-RISP: German Turbine developer 2KM 1.24 miles 8-Germany 1600 meters or 1.6 KM 1 mile 9-Riverside County, CA 2 miles 10-Town of Wilton, WI 1 mile 11-Professor Terry Matilsky; Rutgers 1350 meters/4429 feet .838 miles 12-Dr. Amanda Harry 1.5 miles 13-Dr. Nina Pierpont (Physician) 1.5 - 3 miles 14-Dr. Richard Bolton (Physicist) 1 mile 15-Dr. Gordon Whitehead (Audiologist) 1.5 miles 1.5 miles 16-Barbara Frey & Peter Hadden 2 km 1.25 miles
*Source: http://windwisefairhaven.com/
** Germany, which has more wind turbines than any country in the world, has a 1.6 km or 1 mile

Order Code RL34546

CRS Report for Congress

Wind Power in the United States: Technology, Economic, and Policy Issues

June 20, 2008

Jeffrey Logan and Stan Mark Kaplan
Specialists in Energy Policy
Resources, Science, and Industry Division

Prepared for Members and Committees of Congress

Congressional Research Service

Wind Power in the United States: Technology, Economic, and Policy Issues

Summary

Rising energy prices and concern over greenhouse gas emissions have focused congressional attention on energy alternatives, including wind power. Although wind power currently provides only about 1% of U.S. electricity needs, it is growing more rapidly than any other energy source. In 2007, over 5,000 megawatts of new wind generating capacity were installed in the United States, second only to new natural gas-fired generating capacity. Wind power has become "mainstream" in many regions of the country, and is no longer considered an "alternative" energy source.

Wind energy has become increasingly competitive with other power generation options. Wind technology has improved significantly over the past two decades. CRS analysis presented here shows that wind energy still depends on federal tax incentives to compete, but that key uncertainties like climate policy, fossil fuel prices, and technology progress could dominate future cost competitiveness.

A key challenge for wind energy is that electricity production depends on when winds blow rather than when consumers need power. Wind's variability can create added expenses and complexity in balancing supply and demand on the grid. Recent studies imply that these integration costs do not become significant (5-10% of wholesale prices) until wind turbines account for 15-30% of the capacity in a given control area. Another concern is that new transmission infrastructure will be required to send the wind-generated power to demand centers. Building new lines can be expensive and time-consuming, and there are debates over how construction costs should be allocated among end-users and which pricing methodologies are best.

Opposition to wind power arises for environmental, aesthetic, or aviation security reasons. New public-private partnerships have been established to address more comprehensively problems with avian (bird and bat) deaths resulting from wind farms. Some stakeholders oppose the construction of wind plants for visual reasons, especially in pristine or highly-valued areas. A debate over the potential for wind turbines to interfere with aviation radar emerged in 2006, but most experts believe any possible problems are economically and technically manageable.

Federal wind power policy has centered primarily on the production tax credit (PTC), a business incentive to operate wind facilities. The PTC is set to expire on December 31, 2008. Analysts and wind industry representatives argue that the on-again off-again nature of the PTC is inefficient and leads to higher costs for the industry. While there is often bipartisan support for the PTC in Congress, debate centers more fundamentally on how to offset its revenue losses. A federal renewable portfolio standard — which would mandate wind power levels — was rejected in the Senate in late 2007; its future is uncertain.

If wind is to supply up to 20% of the nation's power by 2030, as suggested by a recent U.S. Department of Energy report, additional federal policies will likely be required to overcome barriers, and ensure development of an efficient wind market.

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Wind Power in the United States: Technology, Economic and Policy Issues

Introduction

Rising energy prices and concern over greenhouse gas emissions have focused congressional attention on energy alternatives, including wind power. Although wind power currently provides only a small fraction of U.S. energy needs, it is growing more rapidly than any other electricity source. Wind energy already plays a significant role in several European nations, and countries like China and India are rapidly expanding their capacity both to manufacture wind turbines and to integrate wind power into their electricity grids.

This report describes utility-scale wind power issues in the United States. The report is divided into the following sections:

- Background on wind energy;
- Wind resources and technology;
- Industry composition and trends;
- Wind power economics; and
- Policy issues.

Three policy issues may be of particular concern to Congress:

- *Should the renewable energy production tax credit be extended past its currently scheduled expiration at the end of 2008, and, if so, how would it be funded?* The economic analysis suggests that the credit significantly improves the economics of wind power compared to fossil and nuclear generation.

- *Should the Congress pass legislation intended to facilitate the construction of new transmission capacity to serve wind farms?* As discussed below, sites for wind facilities are often remote from load centers and may require new, expensive transmission infrastructure. Texas and California have implemented state policies to encourage the development of new transmission lines to serve wind and other remote renewable energy sources. Legislation before the Congress would create a federal equivalent.

- *Should the Congress establish a national renewable portfolio standard (RPS)?* As discussed in the report, the economics of wind are competitive, but not always compelling, compared to fossil and nuclear energy options, and because wind power is dependent on the

> vagaries of the weather it is not as reliable as conventional sources. Some benefits of wind power cited by proponents, such as a long-term reduction in demand for fossil fuels, are not easily quantified. To jump-start wind power development past these hurdles, many states have instituted RPS programs that require power companies to meet minimum renewable generation goals. A national RPS requirement has been considered and, to date, rejected by Congress.

Other policy questions, such as federal funding for wind research and development, and siting and permitting requirements, are also outlined.

Background

The modern wind industry began in the early 1980s when the first utility-scale turbines were installed in California and Denmark.[1] Wind power then, as today, was driven by high energy prices, energy insecurity, and concern about environmental degradation. Early wind turbines, installed primarily at Altamont Pass outside of San Francisco in California, were primitive compared to today's machines, and suffered from poor reliability and high costs. Like most new technology, early wind turbines had to go through a process of "learning by doing," where shortcomings were discovered, components were redesigned, and new machines were installed in a continuing cycle.

Today's wind industry is notably different from that in the early 1980s. Wind turbines now are typically 100 times more powerful than early versions and employ sophisticated materials, electronics, and aerodynamics. Costs have declined, making wind more competitive with other power generation options. Large companies and investment banks now drive most wind power activity compared to the early days of collaborating scientists, inventors, and entrepreneurs.[2]

From the mid-1980s to the late 1990s the U.S. wind industry stagnated due to low energy prices and the technology's reputation for high cost and low reliability. But researchers continued to make improvements in the technology, driving down costs and improving reliability. New federal and state incentives encouraged developers to focus on the production of electricity at wind plants (also known as wind farms) and not just installing the equipment.[3] In 1999, the U.S. industry began a period of rapid expansion, slowed occasionally by expiring federal incentives.

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[1] T. Gray, *Proceedings of the Wind Energy and Birds/Bats Workshop: Understanding and Resolving Bird and Bat Impacts*, American Wind Energy Association and American Bird Conservancy, September 2004, p. 6.

[2] R. Wiser and M. Bolinger, *Annual Report on U.S. Wind Power Installation, Cost and Performance Trends: 2007*, U.S. Department of Energy (DOE), May 2008, p.14.

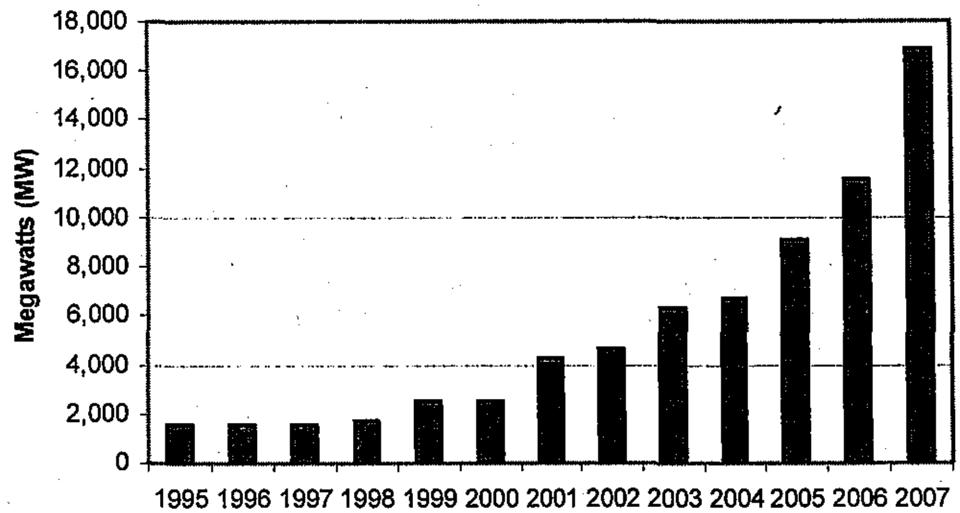
[3] Investment tax credits in the 1980s offered incentives for the installation of wind equipment. They did not reward wind project developers for actually generating electricity. From the 1990s through today, production tax credits have encouraged builders to maximize the output of wind electricity since they earn credits for each kilowatt-hour generated.

Strong growth continues to this day, but whether that growth will continue if federal tax incentives expire at the end of 2008, as currently scheduled, is unclear.

The Rise of Wind

Wind power is no longer an "alternative" source of energy in many regions of the country.[4] It is the fastest growing source of new power generation in the United States. Between 2004 and 2007, installed wind turbine generating capacity increased by 150% (see **Figure 1**), and power generation from wind turbines more than doubled.[5]

Figure 1. Cumulative Installed U.S. Wind Capacity



Source: U.S. Department of Energy, Wind Powering America Program, 2008.

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[4] This statement is supported by the economic analysis presented later in the report; by the fact that wind accounts for over 6% of total in-state electricity generation in Minnesota, Iowa, Colorado and South Dakota; and by the amount of proposed wind power projects under development (225,000 megawatts) in 2007 compared to all other power plants (212,000 megawatts) combined. See R. Wiser and M. Bolinger, *Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2007*, DOE, May 2008, pp. 7-10.

[5] Electric generating capacity, measured in watts, is an expression of instantaneous power output. Electricity generation is measured in watt-hours and is an expression of energy produced over time. For example, a 1,000 watt generator that operates all day would produce 24,000 watt-hours (24 kilowatt-hours) of energy. Prefixes kilo (thousand), mega (million), giga (billion), and tera (trillion) are often used with these units. Capacity references are from: Energy Efficiency and Renewable Energy, "Wind Powering America Program," DOE, January 2008. [http://www.eere.energy.gov/windandhydro/windpoweringamerica/wind_installed_capacity.asp]. Generation references are from: Energy Information Administration (EIA), *Supplement to the Electric Power Monthly March 2008*, Table ES.1.B, DOE, April 2008; and EIA, *Electric Power Monthly March 2005*, Table ES.1.B., DOE, April 2005.

Only the amount of new natural gas-fired generating capacity installed during this period exceeded that of wind.[6] In 2007 the U.S. wind power industry brought over 5,000 megawatts of new generating capacity on-line, the largest annual increase ever by any country.[7] The United States was not alone in strong growth for wind power in 2007: global installations rose by 27% to reach a total of 94,123 megawatts.[8] Only Germany, with 22,247 megawatts, has more wind power capacity than the United States.[9]

Wind power's growth is driven by a combination of the following:

- improvements in wind energy technology,
- high and volatile fossil fuel prices,
- the federal wind production tax credit (PTC) incentive,[10]
- state renewable portfolio standards (RPS),[11]
- difficulty siting and financing new coal-fired power plants given expectation of a future carbon constraint, and
- consumer preference for renewable energy.

However, wind power still accounts for only about 1% of the total electricity generated in the United States.[12] In some regions, a lack of transmission capacity is already beginning to constrain further growth in the wind power sector. And in states like Iowa, Texas, and Minnesota, where wind power has achieved a higher share of total electricity generation, there are concerns that additional wind power could lead to higher prices or threaten grid security. Finally, there is currently a shortage of wind turbine components and a backlog in scheduling transmission interconnection, leading to delays and rising costs.

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[6] New wind plants accounted for roughly 30% of total new power plant capacity installed in the United States in 2007. "Installed U.S. Wind Power Capacity Surged 45% in 2007," American Wind Energy Association, January 17, 2008.

[7] *Global Wind 2007 Report*, Global Wind Energy Council, 2008, p.64.

[8] *Global Wind 2007 Report*, Global Wind Energy Council, 2008, p. 6.

[9] *Global Wind 2007 Report*, Global Wind Energy Council, 2008, pp.8-10.

[10] The PTC is an incentive for business developers of wind farms and other renewable energy projects that produce electricity. It is discussed in the Policy Issues section later in this report. Also see CRS Report RL34162, *Renewable Energy: Background and Issues for the 110th Congress*, by Fred Sissine.

[11] Twenty-six states and the District of Columbia currently have mandatory RPS programs, requiring utilities to provide a minimum percentage of their electricity from approved renewable energy sources. Five others have non-binding goals. These numbers are reported by the Federal Energy Regulatory Commission (FERC) and can be accessed at [http://www.ferc.gov/market-oversight/mkt-electric/overview/elec-ovr-rps.pdf].

[12] Wind farms in the United States generated approximately 32 billion kilowatt-hours in 2007 compared to total power sector generation of 4,160 billion kilowatt-hours. Energy Information Administration (EIA), *Electric Power Monthly*, DOE, March 2008 Edition, Table ES1.B. The American Wind Energy Association forecasts that the U.S. wind industry will generate 48 billion kilowatt-hours of electricity in 2008.

Benefits and Drawbacks of Wind Power

There are frequently noted benefits and drawbacks to wind energy. **Text Box 1** and **Text Box 2** summarize selected problems and benefits, respectively, for wind power.

> **Text Box 1. Selected Problems Facing Wind Power**
>
> - Power output depends on when the wind blows, not when users need electricity.
> - New transmission infrastructure is often required.
> - Depends on inconsistent federal incentives.
> - Causes bird and bat deaths.
> - Considered unsightly by some.
> - Can interfere with radar in some cases.

Drawbacks. A key challenge for wind energy is that electricity production depends on when and how consistently winds blow rather than when consumers most need power. This variability can create added expenses and complexity in balancing supply and demand on the grid.[13] Several recent studies note that system integration costs do not become significant ($3 to $5 per megawatt-hour) until wind turbines account for 15-30% of the capacity in a control area.[14] These apparently modest cost estimates have yet to be confirmed within the context of the U.S. electricity system.

Another concern is that new transmission infrastructure may be required to send the wind-generated power to where it is needed. This can be an expensive and time-consuming effort. There are debates over how construction costs should be allocated among end users and which pricing methodologies are most economically efficient. Although transmission constraints face all new power generating options, wind power is especially handicapped because wind resources are often far from demand centers and do not usually use the full capacity of the transmission line due to the variable output. Texas is analyzing new transmission capacity to send wind-generator power from West Texas to the more populated northern and eastern sections of the state that could cost from $3 billion to over $6 billion.[15] On a national scale, the U.S. Department of Energy (DOE) states that the most cost-effective way to meet a 20% wind energy target by 2030 would be by constructing over 12,000 miles of new transmission lines at a cost of approximately $20 billion.[16] (See the section on Transmission Constraints for more on this issue.)

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[13] These issues are further discussed in the Wind Operation and Systems Integration Issues section of this report.

[14] This is about 5-10% of the price of typical wholesale electric power, according to CRS calculations. R. Wiser and M. Bolinger, *Annual Report on U.S. Wind Power Installation, Cost and Performance Trends: 2006*, U.S. DOE, May 2007, p. 20.

[15] "ERCOT Files Wind Transmission Options with Commission," Electric Reliability Council of Texas (ERCOT) Press Release, April 2, 2008.

[16] Energy Efficiency and Renewable Energy, *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply*, U.S. DOE, May 2008, p. 95.

Wind power is supported by federal and state incentives. In 2007, the Energy Information Administration (EIA) of DOE estimated that federal incentives for wind — primarily the PTC — totaled $724 million.[17] In 2008, incentives could exceed $1 billion if wind generation expands from 32 billion kilowatt-hours to 48 billion kilowatt-hours as estimated by the American Wind Energy Association (AWEA), a national trade association promoting wind. Costs to states using RPS policies are difficult to estimate because they are mandated requirements. Some believe that these are high costs to pay for a relatively small amount of energy. Others note that wind energy is an evolving technology and additional breakthroughs are possible. Many in the industry believe that the on-again, off-again nature of the federal PTC incentives harm rational development of the sector.[18]

Among some critics, wind power also results in unacceptable bird and bat deaths. To others, it is the visual impacts that wind turbines have on the landscape, or the noise that causes objection. Finally, increasingly tall wind turbines have interfered with military and airport radar. These issues are discussed in a later section of the report.

Benefits. Wind turbines have no direct emissions of air pollutants, including oxides of sulfur and nitrogen, mercury, particulates, and carbon dioxide.[19] They also offset the need to mine, process, and ship coal and uranium; drill and transport natural gas (and to a much lesser degree, oil); and construct or maintain hydroelectric dams. As noted previously, wind power contributed approximately 32 billion kilowatt-hours of electricity to the U.S. electricity grid in 2007; if that electricity had been generated using the average mix of power plants in the United States, an additional 19.5 million tons of carbon dioxide would have been released that year.[20]

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[17] EIA, *Federal Financial Interventions and Subsidies in Energy Markets 2007*, U.S. DOE, April 2008, Table ES5.

[18] M. Barradale, "Impact of Policy Uncertainty on Renewable Energy Investment: Wind Power and PTC," U.S. Association for Energy Economics Working Paper No. 08-003, January 2008.

[19] Wind power does have "lifecycle emissions" associated with the materials that go into turbine and transmission line construction, operation and maintenance activities, and decommissioning. A study by the International Energy Agency estimated lifecycle carbon dioxide emissions for wind power at 7-9 grams of CO_2 per kilowatt-hour. For comparison, coal- and natural gas-fired plants released 955 and 430 grams per kilowatt-hour, respectively. International Energy Agency, *Benign Energy?: The Environmental Implications of Renewables*, Table 3-1 and 3-2, 1998.

[20] CRS calculation based on EIA data for 2006 and estimates for 2007. EIA, *Electric Power Monthly*, U.S. DOE, April 15, 2008, Table ES1.B. For comparison, total U.S. electric power sector emissions of carbon dioxide in 2006 were over 2,500 million tonnes. EIA, *Electric Power Annual*, U.S. DOE, Table 5.1, October 2007.

Given rising prices for coal, natural gas, and nuclear fuel, power suppliers are drawn to the certainty that wind — while variable — is inexhaustible and has no fuel cost. By displacing coal-fired and gas-fired generation, wind power would reduce the demand for these fuels, perhaps moderating future prices and price volatility.

Text Box 2. Selected Benefits of Wind Power

- Operations do not produce carbon dioxide or other air pollutants.
- Reduces power market exposure to volatile fuel prices.
- Assists rural development by giving landowners income from wind leases.
- May provide more "green jobs" than other power generation options.
- Offers shorter construction lead time than some other options.
- Provides competitive electricity, especially at peak times.
- Does not require water for operations.

Wind plants can catalyze rural development because farmers and ranchers receive royalty payments from wind developers who lease their land; the vast majority remains available for crops or grazing. Farmers and ranchers typically receive from project developers $2,000-5,000 per year for each turbine on their land.[21] The land taken out of production for wind turbine pads, access roads, and ancillary equipment reduces income for corn farmers, for example, by about $165 per turbine.[22]

Wind energy provides an additional source of revenue for local governments in the form of property taxes on wind plant owners. Wind turbines — unlike fossil and nuclear power plants — do not require water for cooling, a potentially important issue in areas with scarce water resources. Also, the lead time for planning and constructing wind plants is shorter than that for nuclear and coal, assuming transmission access is not an issue.

Finally, wind power proponents argue that wind energy creates "green collar" manufacturing and field service jobs rather than traditional carbon-intensive employment.[23] A study by Navigant Consulting in February 2008 estimated that 76,000 U.S. jobs in the wind industry were at risk if the PTC is not renewed well

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[21] "Wind Power's Contribution to Electric Power Generation and Impact on Farms and Rural Communities," Government Accountability Office, GAO-04-756, September 2004, p. 1.

[22] According to the U.S. Department of Agriculture (USDA), projected revenue in 2008-09 for corn grown in the United States is $846 per acre. (See *World Agricultural Supply and Demand Estimates*, USDA, May 9, 2008, p. 12.) Total expenses per acre to produce this corn in 2006 were $410 (See "Commodity Costs and Returns: U.S. and Regional Cost and Return Data," USDA Economic Research Service, available at [http://www.ers.usda.gov/Data/CostsAndReturns/data/current/C-Corn.xls]. Expenses for 2008-09 have increased due to higher fuel and fertilizer costs. Assuming these expenses to be 25% higher in 2008-09 leads to $513 per acre, and net income of $333 per acre. According to NREL, about 0.5 acres of land is removed from production for each turbine, leading to a loss of corn production of about $165 dollars per turbine. (See "Power Technologies Energy Data Book: Wind Farm Area Calculator," NREL. Available at [http://www.nrel.gov/analysis/power_databook/calc_wind.php].)

[23] S. Greenhouse, "Millions of Jobs of a Different Collar," *New York Times*, March 26, 2008.

before its expiration in December 2008.[24] It is unclear how many U.S. jobs are at risk if traditional power plants are not built.

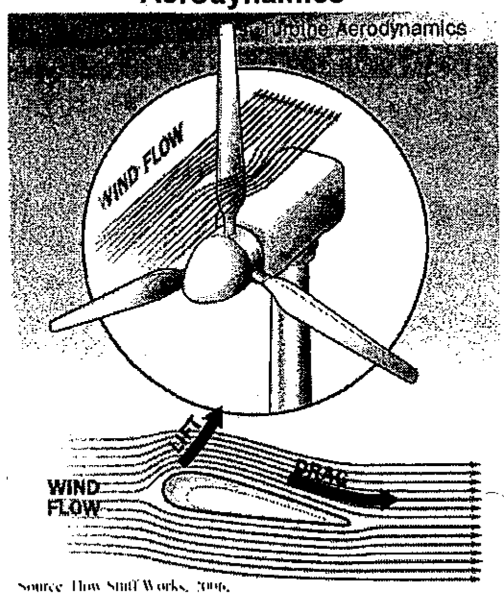
Wind Resources and Technology

This section begins with a description of how wind turbines work. It then provides information on wind resources in the United States, both on and offshore. Finally, the section outlines technology trends in the wind power sector.

Wind Power Fundamentals

Unequal solar heating of the Earth's atmosphere and oceans creates wind. Wind turbine blades, like airplane wings, produce lift when air passes over one side of their shaped surface more rapidly than another (**Figure 2**). This lift spins the turbine blades and rotor, which is connected to a generator through a gearbox inside the housing. The generator, and accompanying power conditioning equipment, then delivers electricity to the transmission grid at the appropriate voltage and frequency. The process is roughly opposite to a common household fan, which uses electricity to turn the blades and create air motion.

Figure 2. Wind Power Aerodynamics



Source: How Stuff Works, 2006.

Wind turbines can stand alone or be integrated into wind farms with power generating capacity equaling that of a traditional power plant.[25] This report focuses only on large, utility-scale wind turbines. Smaller, off-grid wind power applications are also growing rapidly, although their aggregate impact is limited.[26]

Physical Relationships. The evolution of wind power technology and market development has been influenced by three physical relationships. First, a

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24 "Economic Impacts of Tax Credit Expiration," Navigant Consulting, prepared for the American Wind Energy Association and the Solar Energy Research and Education Foundation, February 2008, p. 21.

25 Typical new U.S. wind plants ranged from 100 to 300 megawatts of installed capacity in 2007. Horse Hollow (Texas) is the largest U.S. wind plant, at 736 megawatts. Although some wind plants have capacity on par with traditional fossil fuel power plants, they produce comparatively less electricity because winds blow inconsistently.

26 See Energy Efficiency and Renewable Energy, *Small Wind Electric Systems: A U.S. Consumer's Guide*, DOE, March 2005.

wind turbine's power output varies with the cube of wind speed.[27] Thus, all else held constant, if wind velocity doubles, power output increases eight-fold. Wind power developers, therefore, face the challenge of finding where winds blow best. Winds at 250 feet in altitude are stronger and steadier than those closer to the ground; this factor explains why wind turbine towers are placed high in the air.

Second, power output varies with the area swept out by the turbine blades during their rotation. Doubling a turbine blade's length will yield a quadrupling of power output. Today's utility-scale wind turbine blades are commonly 130 feet long or more in an attempt to harness more energy. Turbine manufacturers have devoted attention over the past two decades to finding materials strong and durable enough to handle the twisting forces that are transmitted from the longer blades through the rotor and gearbox in fluctuating winds.

Finally, power output increases directly with air density. Density is typically higher in winter months and at low altitudes, and lower in summer months and at high altitudes. Winds near the cold Scandinavian seas, for example, contain more exploitable energy than those of the hot, high-altitude desserts of the American Southwest.

Wind Resources

Wind resources in the United States, and elsewhere, have been studied for decades. The National Renewable Energy Laboratory (NREL) has produced national and state wind resource maps that indicate areas with promising winds (**Figure 3**).[28] "Excellent" winds mean those that average about 17 miles per hour or above at 150 feet in altitude. Additional mapping efforts characterize seasonal and even daily variations in average wind speed. After using these maps to identify promising regions, wind plant developers must still study and document local conditions carefully — often for 12 months or longer — to ensure potential financiers that revenue streams will be sufficient and stable.

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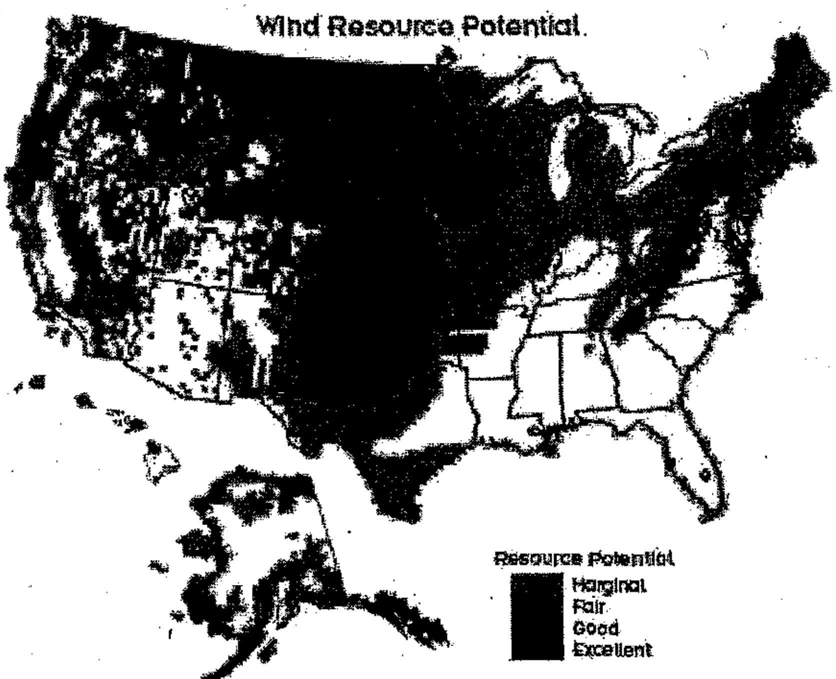
[27] Cubing a number requires multiplying it by itself 2 additional times (i.e, $2^3 = 2x2x2 = 8$). The mathematical formula for wind turbine power output (P), usually measured in watts, is

$$P = k \rho A V^3,$$

where k is a constant that depends on turbine design characteristics and physical limitations, ρ is the density of air, A is the area swept out by the turbine rotor blades (namely, πr^2, with r being the length of the rotor blade), and V is the wind velocity.

[28] For wind mapping resources, see NREL website [http://www.nrel.gov/wind].

Figure 3. U.S. Wind Resources Potential



Source: National Renewable Energy Laboratory.

DOE estimates that total U.S. wind energy potential is over 10,000 billion kilowatt-hours annually — more than twice the total electricity generated from all sources in America today.[29] While this potential is not realistically achievable, wind power advocates, supported by a recent DOE study, believe that wind power could realistically contribute 20% of the nation's total electricity generation by the year 2030.[30] The U.S. Great Plains states contain most of the best onshore wind resources.[31] The main drawback to these rich wind resources is that they are located far from densely populated areas and thus require the construction of transmission lines to send the electricity to the load. Building these lines is often expensive, time consuming, and controversial.[32]

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[29] This is the theoretical potential. Energy Efficiency and Renewable Energy, *Wind Powering America: Clean Energy for the 21st Century*, DOE, September 2004.

[30] Office of Energy Efficiency and Renewable Energy, *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply*, DOE, May 2008.

[31] The U.S. Great Plains states include parts of Colorado, Kansas, Montana, Wyoming, North Dakota, South Dakota, Nebraska, Oklahoma, New Mexico, and Texas. From a geographical standpoint the region extends into the Canadian provinces of Alberta, Manitoba, and Saskatchewan.

[32] See CRS Report RL33875, *Electric Transmission: Approaches for Energizing a Sagging Industry*, by Amy Abel.

Offshore Wind. The U.S. Department of the Interior (DOI) estimates that over 90,000 megawatts of wind resource potential lies off the coasts of New England and the Mid-Atlantic states in waters less than 100 feet deep.[33] Offshore sites generally have higher quality winds and are located closer to population centers, but their development costs are significantly higher. Offshore wind projects have been slow to develop in the United States due to these high costs and public opposition. In Europe, a total of 1,099 megawatts of offshore wind had been installed by the end of 2007.[34]

The 420 megawatt Cape Wind project near Cape Cod, Massachusetts, is the largest proposed U.S. offshore wind project to date and is currently awaiting a permit from the DOI's Minerals Management Service (MMS).[35] During the 109th Congress, a debate erupted over the project's safety, cost, and environmental impact.[36] Cape Wind and other proponents say the project is a safe, clean way to develop renewable energy and create jobs. Opponents of the project have collaborated to create the Alliance to Protect Nantucket Sound. According to the Alliance, the project poses threats to the area's ecosystem, maritime navigation, and the Cape Cod tourism industry.

MMS released a Draft Environmental Impact Statement (EIS) for the Cape Wind project in March 2008.[37] The draft EIS did not indicate any critical factors that could derail the project. A final EIS is expected later in 2008. Other offshore U.S. wind projects have been proposed in Delaware (Bluewater) and Texas (Galveston).[38]

Wind Power Technology

Commercial, utility-scale wind turbines have evolved significantly from their early days in the 1980s and 1990s (**Figure 4**). They are larger, more efficient, and more durable. How wind technology evolves in the future could be influenced by

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[33] This estimate excludes two-thirds of the offshore areas ranging from 5 to 20 nautical miles from the shoreline to account for shipping lanes and wildlife, and view shed concerns; and one-third of the areas from 20 to nautical 50 miles out. See *Technology White Paper: Wind Energy Potential on the U.S. Outer Continental Shelf*, DOI, May 2006, pp. 1-2.

[34] R. Wiser and M. Bolinger, *Annual Report on U.S. Wind Power Installation, Cost and Performance Trends: 2007*, U.S. Department of Energy, May 2008, p. 9.

[35] MMS manages the nation's Outer Continental Shelf oil, natural gas, and other mineral resources. The Energy Policy Act of 2005 (EPACT05) granted MMS additional authority to act as the lead federal agency for offshore renewable energy projects. EPACT05 §388 stipulates that MMS authority does not supercede the existing authority of any other agency for project permitting, so a wind project on the OCS may also require other permits to operate, although leasing and environmental review would be conducted by MMS.

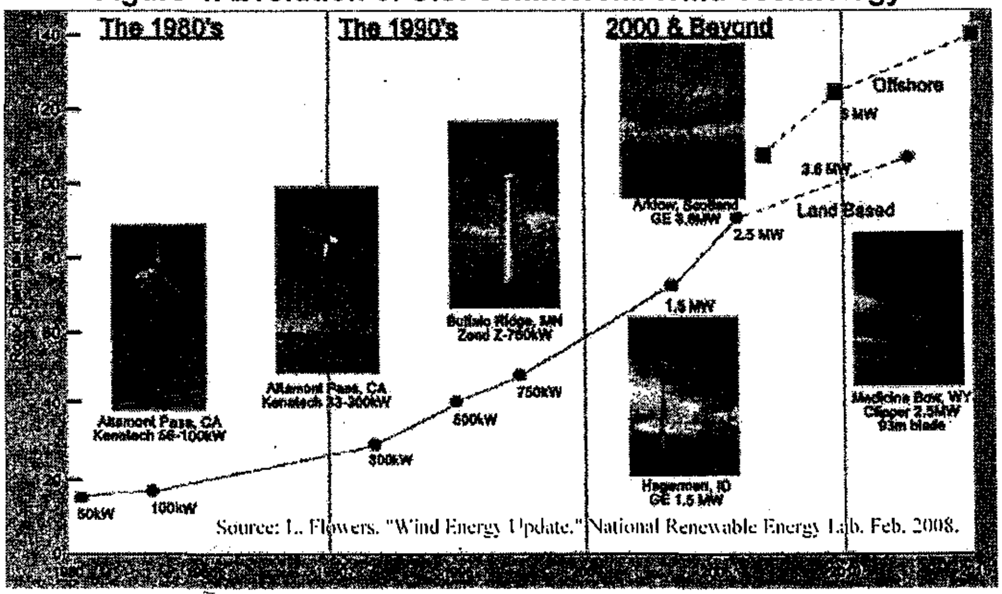
[36] In 2006, the Senate considered a provision to the Coast Guard appropriations bill giving the governor of Massachusetts authority to veto the Cape Wind project. A compromise was reached that gave the Coast Guard greater authority over navigational safety related to the project, but denied gubernatorial veto power. See §414 of P.L. 209-241.

[37] See [http://www.mms.gov/offshore/RenewableEnergy/RenewableEnergyMain.htm].

[38] See Offshore Wind Energy website [http://www.offshorewindenergy.org].

congressional policy, both in research and development funding, and through regulatory frameworks that influence market behavior.

Figure 4. Evolution of U.S. Commercial Wind Technology



Source: L. Flowers. "Wind Energy Update." National Renewable Energy Lab. Feb. 2008.

Utility-scale wind turbines have grown in size from dozens of kilowatts in the late 1970s and early 1980s to a maximum of 6 megawatts in 2008.[39] The average size of a turbine deployed in the United States in 2007 was 1.6 megawatts, enough to power approximately 430 U.S. homes.[40] The average size of turbines continues to expand as units rated between 2 and 3 megawatts become more common. Larger turbines provide greater efficiency and economy of scale, but they are also more complex to build, transport, and deploy.

Types of Wind Turbines. Industrial wind turbines fall into two general classes depending on how they spin: horizontal axis and vertical axis, also known as "eggbeater" turbines. Vertical axis machines, which spin about an axis perpendicular to the ground, have advantages in efficiency and serviceability since all of the control equipment is at ground level. The main drawback to this configuration, however, is that the blades cannot be easily elevated high into the air where the best winds blow. As a result, horizontal axis machines — which spin about an axis parallel to the ground rather than perpendicular to it — have come to dominate today's markets.[41]

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[39] The German company Enercon is testing two different 6 megawatt turbines, although they are not yet available on commercial markets. The largest commonly used commercial wind turbines are the 3.6 megawatt offshore units produced by Siemens and General Electric.

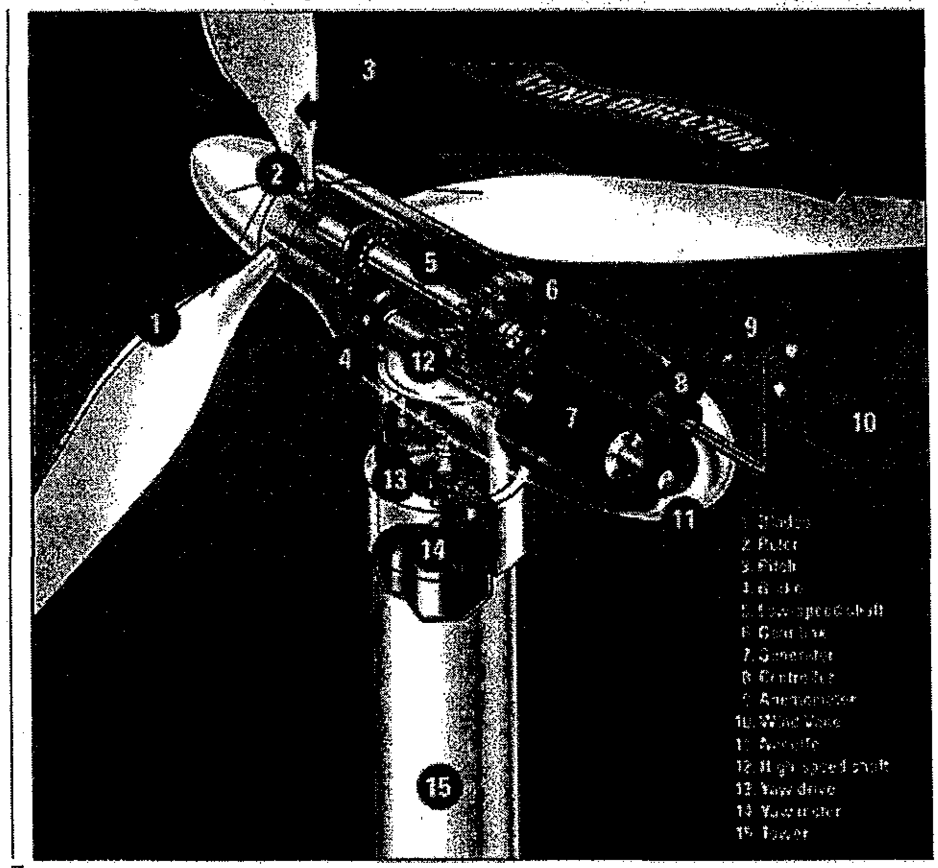
[40] This assumes a capacity factor (see following subsection) of 34% and an EIA estimate of the average U.S. household consumption of 11,000 kilowatt-hours per year.

[41] Horizontal turbines are further divided into classes depending on generator placement, type of generator, and blade control. For example, downwind turbines have their blades

(continued...)

A simplified diagram of a typical horizontal axis wind turbine is shown in **Figure 5**. The blades connect to the rotor and turn a low-speed shaft that is geared to spin a higher-speed shaft in the generator. An automated yaw motor system turns the turbine to face the wind at an appropriate angle.[42]

Figure 5. Components in a Simplified Wind Turbine



There are barriers to the size of wind turbines that can be efficiently deployed, especially at onshore locations. Wind turbine components larger than standard over-the-road trailer dimensions and weight limits face expensive transport penalties.[43]

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[41] (...continued)
behind the generator and upwind turbines, in front. Generators can be asynchronous with the grid, or operate at the same frequency. Blade speed can be fixed or variable, and controlled through pitch or stall aerodynamics. For a more complete discussion of wind turbine technical issues, see P. Carlin, A. Laxson, and E. Muljadi, *The History and State of the Art of Variable-Speed Wind Turbines*, NREL, February 2001.

[42] Generally, the yaw control will position the turbine to face the wind at a perpendicular angle. The turbine can avoid damage from excessive wind speeds by yawing away from the wind or applying the brake.

[43] The standard trailer for an 18-wheel tractor trailer is approximately 12.5 feet high and 8 feet wide. Gross vehicle weight limitations are 80,000 pounds, corresponding to a cargo
(continued...)

Other barriers to increasingly large turbines include (1) potential for aviation and radar interference, (2) local opposition to siting, (3) erection challenges (i.e, expensive cranes are needed to lift the turbine hubs to a height of 300 feet or more), and (4) material fatigue issues. Some of these issues are discussed in more detail later.

Capacity Factor. As noted above, a wind turbine's power output depends on wind speed. Capacity factor — a measure of how much electricity a power plant actually produces compared to its potential running at full load over a given period of time — is a useful tool to summarize average annual wind availability and speed for wind projects. The capacity factor a wind plant achieves strongly influences the cost of electricity produced and the profitability of the project. (See Wind Power Economics section later in this report.)

Capacity factors for power generation technologies vary considerably. Nuclear plants run nearly continuously at full load and only shut down under normal conditions to be refueled. The industry-wide average capacity factor for U.S. nuclear power plants has been about 90% in recent years. Coal plants average a capacity factor of 70%, but individual plants can have a much higher or lower utilization rate. Wind plants, on the other hand, have capacity factors typically ranging from 20% to 40%.[44] Wind turbines usually spin 65% to 90% of the time, but only at their full rated capacity about 10% of the time. A recent study pegs the typical capacity factor for wind turbines at 34%.[45] Offshore wind turbines generally have higher capacity factors than onshore units because ocean winds are steadier than those over land.

A high capacity factor helps lower a plant's levelized, or annualized, cost of electricity (see section on Wind Power Economics). While a low capacity factor may result in relatively high costs per kilowatt-hour, a complete economic analysis would depend on when the electricity was produced. Since electricity is valued at different prices according to daily and seasonal demand profiles, when a wind turbine actually produces electricity can be as important as its overall capacity factor.

Wind Research and Development Emphasis. Future advances in wind turbine technology are likely to be evolutionary rather than revolutionary.[46] According to the NREL, which carries out much of DOE's wind research and

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[43] (...continued)
weight of 42,000 pounds. According to NREL, the trailer limitations have the greatest impact on the base diameter of wind turbine towers. R. Thresher and A. Laxson, "Advanced Wind Technology: New Challenges for a New Century," NREL, June 2006.

[44] Renewable Energy Research Laboratory, "Wind Power: Capacity Factor, Intermittency, and What Happens When the Wind Doesn't Blow?," University of Massachusetts at Amherst, p. 1, November 2004.

[45] *Comparative Costs of California Central Station Electricity Generation Technologies*, California Energy Commission, Appendix B, December 2007, p. 67.

[46] B. Parsons, "Grid-Connected Wind Energy Technology: Progress and Prospects," NREL, 1998, p. 5.

development (R&D) program, current efforts to improve wind power technology and reduce costs includes:

- offshore turbine deployment,
- drivetrain (gearbox) innovation,
- blade design innovation,
- mechanical and power controls,
- low wind speed turbine development,
- manufacturing economies of scale, and
- system integration improvement.[47]

Another general area of R&D activity is in energy storage. Energy storage does not increase power output — in fact, energy conversion always results in lost power — but storage can make wind power available when it is most needed. Currently, most energy storage options are expensive and still under development.

The most common energy storage method is hydroelectric pumped storage. During periods of strong winds and low power demand, wind turbine output can be used to pump water into a reservoir at a higher elevation. The water can be released through a hydroelectric generator later when the power is most needed. Many countries have only limited pumped storage capacity and may have already exploited what exists. In the United States, pumped storage accounts for several percent of conventional hydroelectric power generation,[48] but probably does not have potential to grow significantly since many of the most economic sites have already been developed and the public opposes new large-scale hydroelectric projects.

Other energy storage options such as compressed air energy storage and advanced batteries face technical hurdles and high costs. Public and private sector R&D is underway to bring down costs for these options, not just for the benefit of wind power, but other variable energy sources as well.[49] A technological breakthrough in one of these storage options could enhance the ability of wind energy to supply large quantities of electricity on demand, but whether such breakthroughs are forthcoming is unpredictable.[50]

Wind Industry Composition and Trends

Within the United States, Texas is now the dominant state for wind power, followed by California, Minnesota, Iowa, Washington, and Colorado. Total installed wind capacity for each state at the end of 2007 is shown in **Figure 6**. California's early lead in wind power has been eclipsed by rapid growth in Texas. Wind power

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[47] S. Butterfield, "Technology Overview: Fundamentals of Wind Energy," NREL, 2005.

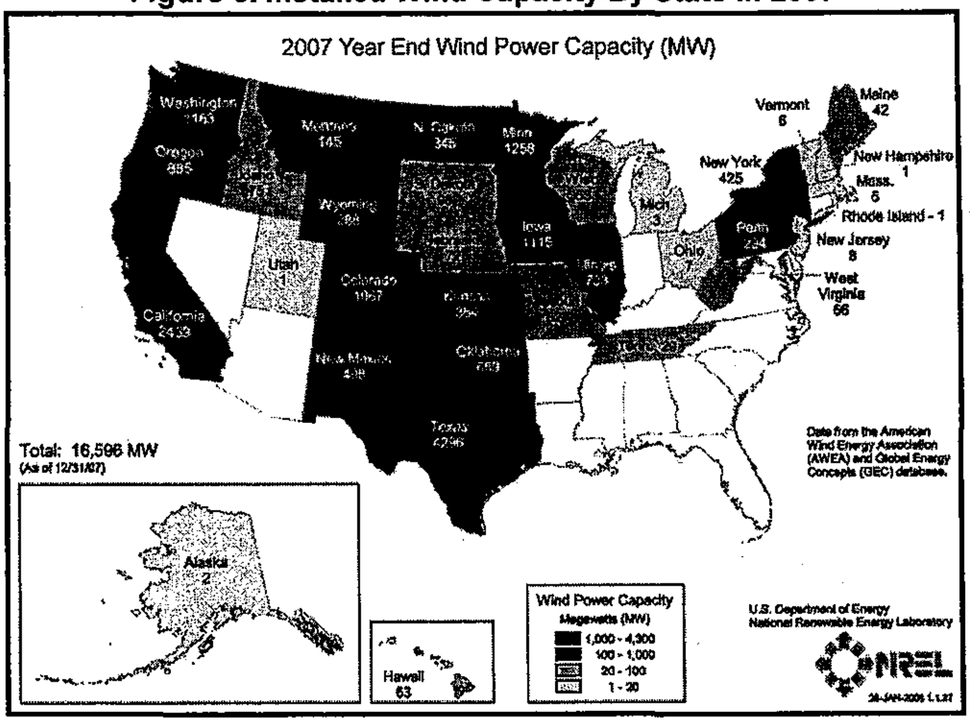
[48] EIA, *Annual Energy Review 2006*, U.S. DOE, 2007, Table 8.2a.

[49] For more information, see U.S. Climate Change Technology Program: *Technical Options for the Near and Long Term*, August 2005. [http://www.climatetechnology.gov]

[50] For more information on U.S. R&D on wind power, see *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply*, DOE, May 2008.

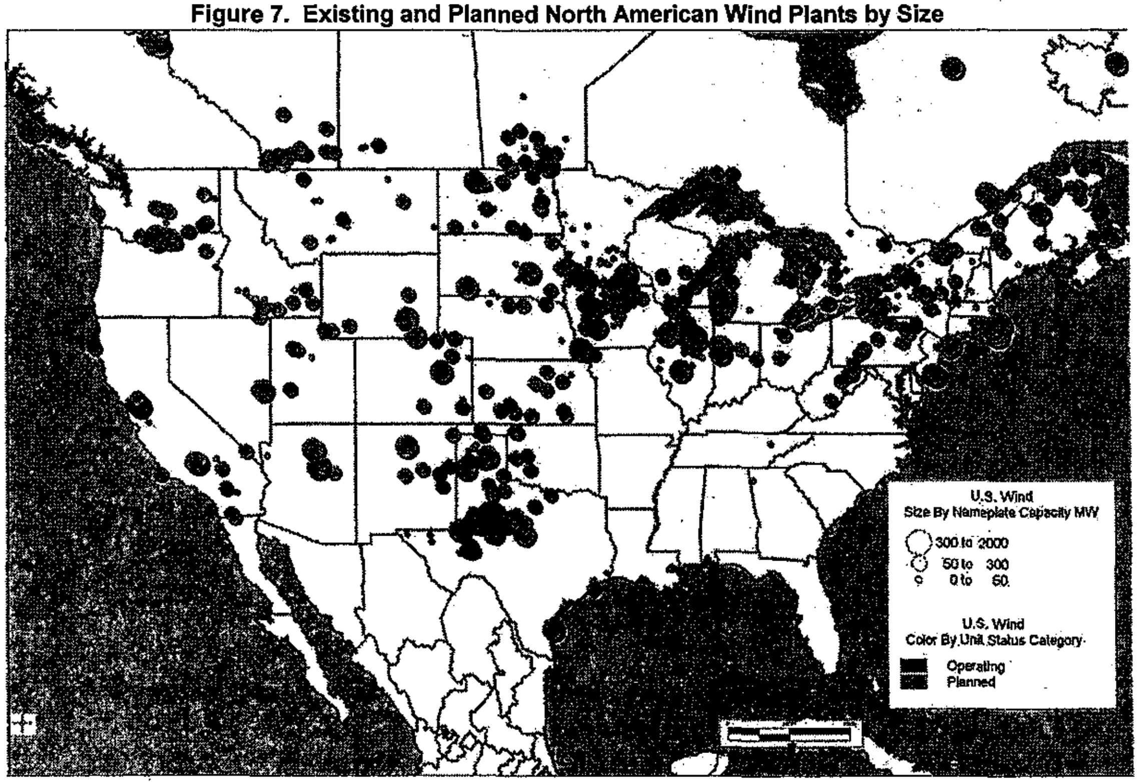
installations are also growing rapidly in the Pacific Northwest states of Washington and Oregon, as well as in Colorado, Minnesota, Iowa, Illinois, and the Dakotas. Most of these states have good wind resources, renewable portfolio standards, and local government proponents to help overcome construction barriers. These state and local incentives supplement the federal production tax credit incentive. The Southeastern region of the United States is noticeably empty of wind power projects due primarily to poor wind resources. This issue may also influence the region's general opposition to a national RPS.

Figure 6. Installed Wind Capacity By State in 2007



A more detailed map showing the location of each existing and planned wind plant in North America by size is presented in **Figure 7**. Although planned wind projects far surpass the number of existing ones, there is no guarantee that they will all be constructed. Comparing wind resources from **Figure 3** with existing and planned wind plants in **Figure 7** shows significant potential to continue tapping some of the best wind sites in the upper Great Plains region. Limited transmission capacity is one of the reasons high-quality wind regions like this are not seeing greater wind plant development.

Figure 7. Existing and Planned North American Wind Plants by Size



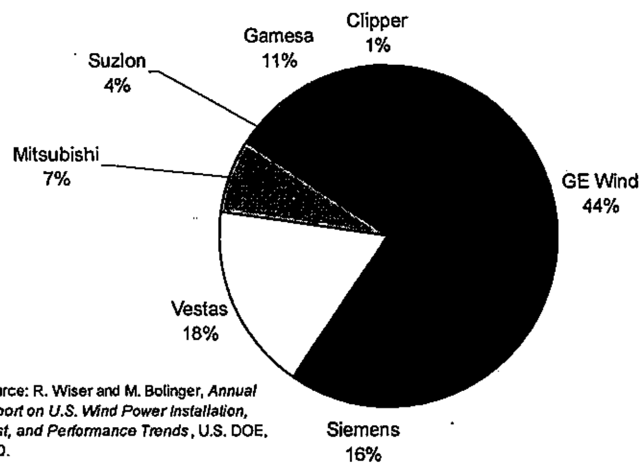
Source: Ventyx Energy, the Velocity Suite. Data reportedly updated through June 5, 2008. **Note:** Data for wind plants in Hawaii and Alaska are not available for this map.

Wind Turbine Manufacturers and Wind Plant Developers

The major wind turbine suppliers to wind plants in the United States include General Electric (GE) Wind, Siemens, Vestas, Mitsubishi, Suzlon, and Gamesa.

The 2007 U.S. market share for each of these suppliers is shown in **Figure 8.** The GE 1.5 megawatt turbine was the most commonly installed unit in 2007. Vestas, Siemens, and Gamesa — European manufacturers with an increasing number of production facilities in the United States — account for a combined market share roughly equivalent to that of GE. Suzlon, an Indian manufacturer and the world's fifth largest turbine producer, may face new challenges after having to recall many of the turbine blades it sold into the U.S. market due to premature cracking.[51] Other new manufacturers are also entering the field. Clipper Windpower is gaining market share as manufacturing capacity grows for its new 2.5 megawatt turbines. According to the Global Wind Energy Council, two Chinese firms, Gold Wind and Sinovel, are also likely to enter international markets in 2009 with low-cost turbines.

Figure 8. U.S. Wind Turbine Market Share by Manufacturer in 2007



Source: R. Wiser and M. Bolinger, *Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends*, U.S. DOE, p.10.

Because shipping large wind turbine parts is expensive, suppliers build manufacturing facilities close to where wind plants will be installed. According to AWEA, wind industry manufacturing facilities in the United States grew from a small base in 2005 to over 100 in 2007. New wind turbine component manufacturing facilities opened in Illinois, Iowa, South Dakota, Texas, and Wisconsin in 2007, while seven other facilities were announced in Arkansas, Colorado, Iowa, North Carolina, New York, and Oklahoma.[52] Expanding production and operations in the United States is especially attractive to European companies given the current value

[51] T. Wright, "India Windmill Empire Begins to Show Cracks," *Wall Street Journal*, April 18, 2008, P. A1.

[52] *Wind Power Outlook 2008*, AWEA, 2008, p. 4.

of the euro to the dollar. Despite the expansion in turbine manufacturing facilities in the United States, Europe, and Asia, demand continues to exceed supply.[53]

Most wind plants in the United States are built and operated by independent power producers (IPPs), also known as merchant providers, that are not regulated utilities. IPPs have the most flexibility in taking advantage of the renewable tax incentives since regulated utilities cannot claim the renewable PTC. Still, investor-owned utilities do build and operate some wind plants; one estimate states that utilities built just over 10% of the total new capacity in wind electricity in 2007.[54]

Dozens of companies from around the world develop and operate wind plants in the United States. Selected examples of active developers and operators in early 2008 include Acciona, AES, Babcock & Brown, Edison Mission, FPL Energy, Gamesa Energy, Horizon, Invenergy, John Deere, Noble Environmental, PPM Energy, and RES Americas.[55] According to DOE, consolidation among companies remains strong, including the purchase of Horizon Wind by Energias de Portugal (from Portugal) and the acquisition of Airtricity North America by E.ON AG (from Germany).[56]

International Comparisons

The United States led the world in wind power deployment until 1996 when it was surpassed by Germany (**Figure 9**). Strong U.S. growth in new wind capacity pushed the United States into the number two spot ahead of Spain in 2007, and the Global Wind Energy Council (GWEC) expects the United States to become the world leader in installed capacity again by the end of 2009.[57]

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[53] According to one report, in early 2008 General Electric had a backlog of wind turbines on order equal to $12 billion, more than twice the backlog in early 2007. M. Kanellos, "GE Confirms That Wind Turbine Supply Is Getting Worse," *CNet News.com*, April 13, 2008.

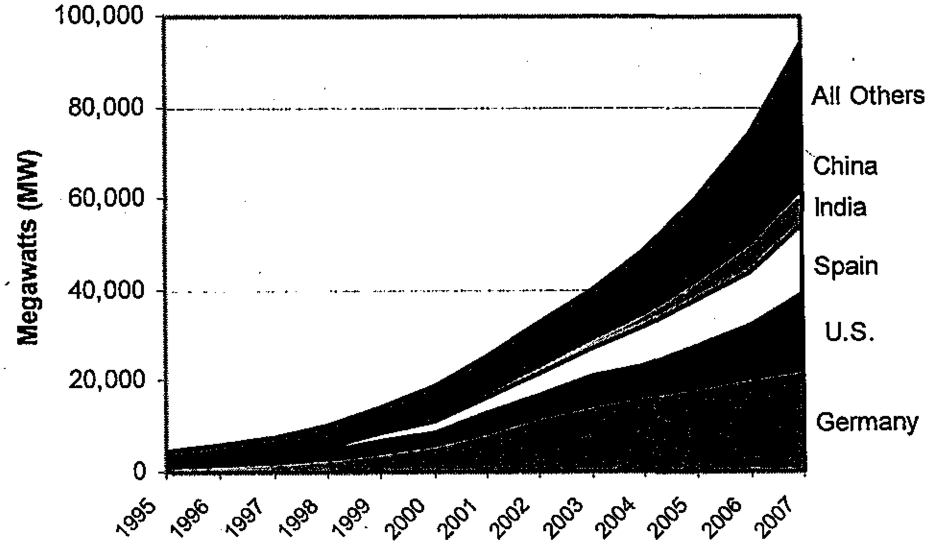
[54] R. Wiser and M. Bolinger, *Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2007*, DOE, May 2008, p. 15.

[55] *AWEA 2007 Market Report*, AWEA, January 2008, pp. 9-11.

[56] R. Wiser and M. Bolinger, *Annual Report on U.S. Wind Power Installation, Cost and Performance Trends: 2007*, DOE, May 2008, p. 13.

[57] *Global Wind 2007 Report*, Global Wind Energy Council, 2008, p. 6.

Figure 9. Global Installed Wind Capacity By Country



Source: Adapted from J. Dorn, "Global Wind Power Capacity Reaches 100,000 Megawatts," Earth Policy Institute, March 2004.

As countries deploy increasing quantities of wind capacity, new operational issues need to be addressed. Grid operators must become accustomed to dealing with the variability of wind in order to operate the system efficiently and reliably. Despite the near parity in total wind generating capacity among the top three countries, the United States has a much lower percentage penetration rate of actual wind power generation than Denmark, Spain, Portugal, Ireland, and Germany (**Table 1**). These European countries have gained experience operating their electricity grids at higher wind integration rates.

Table 1. Wind Energy Penetration Rates by Country

Country	Wind Energy Penetration Rate (%)
Denmark	20
Spain	12
Portugal	9
Ireland	8
Germany	7
United States	1

Source: R. Wiser and M. Bolinger, *Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2007*, U.S. DOE, May 2008, p. 6.

Note: Wind energy penetration is defined here as the ratio of wind-generated electricity to the total electricity generated by all sources.

China has the most rapidly growing wind sector in the world, but started from a very low base. New wind power additions in China are dwarfed by the amount of new coal-fired power plant construction.[58] Chinese leaders are reportedly considering a new wind power target of 100,000 megawatts by 2020, five-fold the previous target.[59] The German experience with wind power is highlighted in **Text Box 3**.

In summary, wind technology has evolved over the past two decades, resulting in larger, more reliable machines. Manufacturing capacity in the United States has expanded significantly. These advances have led to increasingly competitive wind electricity costs, the topic of the next section.

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[58] According to GWEC, installed wind power capacity in China grew by an average annual rate of 56% between 2001 and 2007. Approximately 3,500 megawatts of new wind were installed in 2007. (*Global Wind 2007 Report*, GWEC, April 2008, p. 28.) According to a statement by Zhang Guobao, Vice Premier of the National Development and Reform Commission, China installed approximately 70,000 megawatts of new coal-fired generating capacity in 2007 as reported in Y. Wang, "China May Boost Power Capacity 40% in 3 Years as Demand Rises," *Bloomberg*, May 12, 2008.

[59] C. Fu, "Fanning Wind Power Capacity," *Shanghai Daily*, April 28, 2008.

Text Box 3. Focus on Wind Power in Germany

Germany is the world leader in installed wind power capacity. Given the country's relatively modest wind and solar resources, it has ambitious plans for renewable energy, including a goal that renewable energy meet 20% of total energy needs by 2020.

The primary driver of wind power growth in Germany is the country's "feed-in tariff" policy that gives producers of wind power a guaranteed constant minimum price over a maximum term of 20 years. The amount of the tariff depends on the location of the wind turbine and the specific year. The average 2007 payment was about 12.9 U.S. cents/kWh and is scheduled to slowly decline to about 10.9 cents/kWh by 2015. Electricity in Germany is relatively expensive; the wind industry's impact on overall electricity price is not clearly known.

Wind accounts for about 18% of installed capacity and generates 7% of the country's electricity. Most of Germany's wind farms lie in the northern Baltic coast region where wind resources are superior. Wind plants are widely deployed in Germany and few onshore areas with good wind resources remain to be developed. The shortage of onshore sites is leading Germany to replace older, less efficient wind turbines with larger, more powerful models.

The shortage of high-quality onshore sites is also leading to an expansion of offshore wind plants. In 2006, the federal government passed a law stating that grid operators must bear the cost for connecting to offshore wind plants as soon as they are ready to begin producing power. At the end of 2007, Germany had installed only seven megawatts of offshore wind generating capacity, although it had hundreds of megawatts more under development.

The German wind industry is not without critics. As elsewhere, critics state that wind energy depends on expensive subsidies, especially the feed-in tariff and grid connection requirements. As Germany is a relatively mature wind user, much of the countryside is dotted with wind plants. Some Germans oppose the visual impact these wind plants create and are concerned that they may damage the tourism industry. Finally, a recent study by the German Energy Agency claimed that wind power is an expensive way to lower carbon dioxide emissions compared with other options.

a. German Energy Agency, *Planning of the Grid Integration of Wind Energy in Germany Onshore and Offshore up to the Year 2020*, February 2005. The exchange rate used in this conversion was 1.55 U.S. dollars per euro.

b. The impact of growing wind use on Germany's electricity prices is obscured by larger restructuring and liberalization within the sector. B. Odent, "Les factures d'électricité germaniques se shootent à la libéralisation," *L'Humanité*, June 29, 2007.

c. Project Steering Group, "Planning of the Grid Integration of Wind Energy in Germany Onshore and Offshore Up to the Year 2020," German Energy Agency, March 2005.

Wind Power Economics

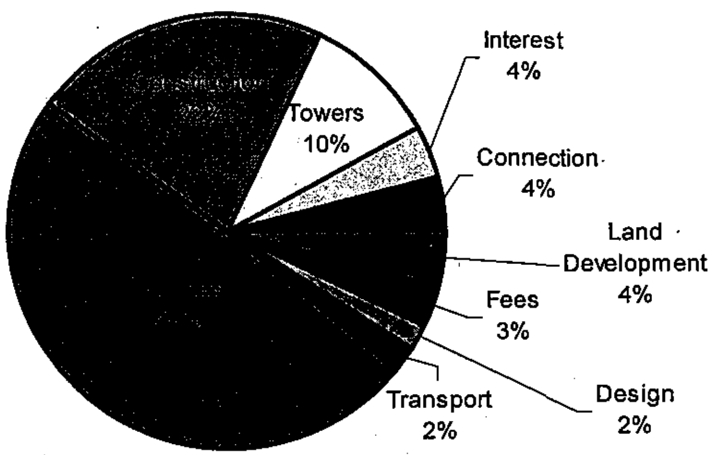
Numerous complex variables affect the economics of wind power. This section includes a financial analysis that compares the cost of building and operating wind plants with competing technologies (coal, natural gas, and nuclear power). The financial analysis provides an indicative picture of how the economics of wind compare with other bulk power sources. A comprehensive analysis for a specific project would take many other factors into consideration, including the cost of any necessary transmission upgrades and other options (e.g., purchased power or demand reduction).

Cost and Operating Characteristics of Wind Power

Wind power is characterized by low variable costs and relatively high fixed costs. Wind turbines have, of course, no fuel costs, and minimal variable operations and maintenance (O&M) expense.[60] In addition to having no direct expense for fuel, wind also does not incur the ancillary expenses associated with fossil fuel combustion, such as air pollution control equipment and allowances needed to comply with current law and, possibly, future carbon controls. Wind also does not incur the waste disposal costs associated with conventional generation, such as scrubber sludge disposal for coal plants and radioactive waste storage for nuclear plants.

As reported in 2005, the initial cost of wind turbines is about half of total wind plant development costs (**Figure 10**).[61]

Figure 10. Component Costs for Typical Wind Plants



Source: National Renewable Energy Laboratory, 2005.

[60] Variable O&M costs vary with the output of a generating station, such as the cost of the consumables used by pollution control equipment. Fixed O&M, which is insensitive to the level of plant output, includes such costs as the salaries of plant staff and scheduled maintenance.

[61] S. Butterfield, "Fundamentals of Wind Technology," NREL, presentation at American Wind Energy Association conference, May 15, 2005.

Although wind plants have low variable costs, the fixed O&M costs are relatively high, and wind power plants are capital intensive.[62] As with other generation technologies, the cost of building a wind plant has increased in recent years. The reported unit cost of wind projects constructed in the United States declined steadily through the 1990s and, according to one study, bottomed out at about $1,400 per kilowatt of capacity in the 2000-2002 time period.[63]

Subsequently, project costs have risen steadily and averaged over $1,700 per kilowatt in 2007. Higher input prices (steel, cooper, concrete), a shortage of skilled workers, unfavorable currency exchange, and shortages in key wind turbine components and manufacturing capacity explain much of the overall cost increase.[64] Rapidly rising costs have also been experienced by all other utility-scale generation technologies.[65] In the case of wind, some analysts believe that the lapses in the production tax credit contributed to boom-and-bust cycles in the sector and discouraged steadier investment in new production capacity.[66]

Wind Operation and System Integration Issues. Operators try to maximize the power output from units with high fixed costs so that those costs can be spread over as many kilowatt-hours of electric generation as possible. This reduces the average cost of power from the unit and makes the unit's power more economical for consumers (and more marketable if the unit is operating in a competitive market).

Wind plants, however, cannot run as baseload units (i.e., continuously operating) because generation is subject to wind variability. Like solar power, wind is a source of *variable renewable power* that is dependent on daily, seasonal, and locational variations in the weather. Geographic diversity — that is, installing wind turbines over a large area — may compensate to some degree for local variations in wind conditions, but ultimately wind power cannot achieve the same degree of reliability or continuous operation as fossil or nuclear technology. The combination

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[62] Capital intensive means that compared to some other generating sources, such as gas-fired plants, wind plants require a relatively large initial outlay to build the plant. This large outlay also translates into higher fixed costs, in the form of repayment of the debt portion of construction financing.

[63] These data were gathered by analysts at Lawrence Berkeley National Lab from 227 completed wind projects totaling 12,998 megawatts of capacity. Reported in R. Wiser and M. Bolinger, *Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2007*, U.S. DOE, May 2008, pp. 21.

[64] L. Flowers, "Wind Energy Update," NREL, February 2008.

[65] According to Cambridge Energy Research Associates, coal, gas, wind, and nuclear power plants were, on average, 131% more expensive to build in late 2007 compared to 2000. Sector-specific cost increases include wind 108%, nuclear 173%, coal 78% and gas 92%. See "Costs to Build Power Plants Pressure Rates," *Wall Street Journal*, May 27, 2008.

[66] R. Wiser, M. Bolinger, and G. Barbose, "Using the Production Tax Credit to Build a Durable Market for Wind Power in the United States," Lawrence Berkeley National Laboratory, 2007.

of the relatively low capacity factor of wind plants and high fixed costs drives up the cost of wind-generated electricity.

The variable nature of wind power has an additional cost implication. Electric power systems must be able to reliably meet all firm customer loads at all times. For this reason power systems are built around generating technologies that are dispatchable and predictable — that is, units that can be reliably turned on or off, or have their output ramped up or down, as needed to meet changes in load. However, because a wind turbine is weather dependent it is not dispatchable or as predicable as a fossil or nuclear unit. As noted previously, energy storage can help address this shortcoming in wind energy, although it also results in higher costs.

When a power system is dependent on only small amounts of wind generation to meet load, the variations in wind output can be absorbed by the system's existing buffer capacity. This capacity is either fossil fuel, nuclear, or dispatchable renewable energy (e.g., hydroelectric, geothermal, and biomass). However, when wind constitutes a large part of the system's total generating capacity, perhaps 10% to 15% or greater, the system must incur additional costs to provide reliable backup for the wind turbines. For example, in 2007 a utility in Montana built a gas-fired plant for the primary purpose of compensating for wind power variability.[67] Various estimates have been made of the cost of integrating large blocks of wind capacity into a power system. Estimates for integration costs range from $1.85 to $4.97 per megawatt-hour.[68] In 2008, the Bonneville Power Administration established a wind integration charge of $2.82 per megawatt-hour.[69] (See **Text Box 4** below for a description of a recent system integration issue in Texas.)

In summary, wind power has the economic advantage of zero fuel costs and no costs for the pollution controls associated with the consumption of fossil and nuclear fuel. However, wind plants have relatively high fixed costs, and the plants cannot be operated as intensively as fossil or nuclear plants due to the variability of the wind. Wind variability also creates system integration costs at high levels of wind penetration. These cost disadvantages are partly offset by the federal renewable production tax credit (discussed below) and also, in effect, by state renewable portfolio standards that mandate the use of renewable power.

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[67] Mike Mercer, "Power for a Calm Day," *Diesel & Gas Turbine Worldwide*, October 2007. The station is Northwestern Energy's Basin Creek plant, a 51.8 MW plant consisting of 9 gas-fired diesel generators.

[68] B. Parsons, M. Milligan, et al. "Grid Impacts of Wind Power Variability: Recent Assessments from a Variety of Utilities in the United States," conference paper presented at the European Wind Energy Conference. Athens, Greece, 2006 [http://www.nrel.gov/docs/fy06osti/39955.pdf], p. 9.

[69] This is equivalent to 0.282 cents per kilowatt-hour. Gail Kinsey Hill, "BPA Calculates Administrative Costs of Wind Power," *The Oregonian*, March 29, 2008.

Text Box 4. Electricity Curtailment Event in Texas

A recent event in Texas serves to illustrate the challenge of integrating wind power into existing electricity grids. At 6:41 p.m. on February 26, 2008, the Electric Reliability Council of Texas (ERCOT, the manager of most of the electric power grid in Texas) activated its emergency electric curtailment plan due to low frequency on the electricity grid. The emergency measure cut power to customers who had agreed in advance to such action in order to prevent more serious grid problems from occurring. The frequency drop was caused by an unplanned shortfall in available generation sources (primarily wind) at the same time demand was increasing. According to ERCOT's summary report, wind generator availability dropped from 1,700 megawatts three hours before the event to about 300 megawatts at the point the emergency procedures were activated.

An action item ERCOT took from the event is to accelerate plans to implement an improved wind forecasting system. The summary report is available at [http://interchange.puc.state.tx.us/WebApp/Interchange/Documents/27706_114_577769.PDF].

Levelized Cost Comparison

Although wind power is not dispatchable, it is often seen as a replacement or supplement for conventional baseload power plants. This is because when wind conditions are favorable a wind turbine is used like a baseload plant: the wind turbine is run at full load as continuously as possible. The following economic analysis therefore compares wind power to the primary baseload alternative technologies using coal, nuclear power, or natural gas. Each technology is described briefly in **Text Box 5.**

The generation costs of these technologies and wind power are compared using the financial analysis technique of levelized costs, which summarizes the estimated lifetime costs of each system as a levelized ("annualized") cost per megawatt-hour of generation. This analysis is for plants entering commercial service in 2015, and costs are measured in constant 2008 dollars. The financial methodology and the key assumptions concerning plant costs and operations are described in Appendix A. The current estimate of "overnight" construction costs for each technology — that is, the cost that would be incurred if a plant could be built instantly — are summarized below in **Table 2,** along with the assumed capacity factor. **Table 2** also indicates the type of entity assumed to build each kind of plant. Coal and nuclear plants are assumed to be constructed by regulated utilities that have the financial resources and regulatory support to undertake these very large and expensive projects. The natural gas combined-cycle plant is assumed to be built by an independent power producer (IPP). IPPs generally prefer gas-fired projects because of their relatively low capital costs and risk profiles. The wind plant is also assumed to be an IPP project because regulated utilities normally cannot make use of the production tax credit.[70]

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[70] Assuming the natural gas combined cycle was built by a utility reduces the estimated cost in the Base Case by about $4 per megawatt-hour. This is due to the lower financing costs available to regulated utilities compared to IPPs. If the wind plant is built by a utility the (continued...)

Text Box 5. Description of Primary Power Generation Technologies

- **Conventional (pulverized) coal.** This is the conventional technology used in most existing coal-fired power plants. Coal is ground to a fine powder, and then burned in a boiler to create steam which drives a generator. Modern coal plants are equipped with environmental control equipment that can greatly reduce air emissions, with the exception of carbon dioxide. No pulverized coal plants — or, for that matter, any other kind of fossil-fueled power plant — have been built with carbon control technology.

- **Natural Gas Combined Cycle.** This is a standard technology widely used to generate electricity. Natural gas is burned in a combustion turbine (the same type of technology used in a jet engine) to rotate a generator and produce electricity. The waste heat, in the form of exhaust gases, from the combustion turbine is then captured and used to produce steam, which drives a second generator to produce more electricity. Combined cycle plants are relatively inexpensive to build and very efficient, but use expensive natural gas as the fuel.

- **Nuclear Power.** These plants use heat from nuclear fission to produce steam for power generation. This report uses projected costs and performance for next generation nuclear plants, characterized, for example, by simplified designs and modularized construction techniques.

Table 2. Assumptions for Generating Technologies

Technology	Overnight Cost in 2008 (2008$ per Kilowatt of Capacity)	Assumed Capacity Factor	Type of Project Developer
Wind	$1,900	34%	IPP
Coal	$2,600	85%	Utility
Nuclear	$3,700	90%	Utility
Natural Gas	$1,200	70%	IPP

Sources: Overnight capital costs estimated by CRS based on a review of published information on recent power projects. Capacity factor for coal plants is from Massachusetts Institute of Technology, *The Future of Coal*, 2007, p. 128. Natural gas plants are assumed to operate as baseload units with a capacity factor of 70%. Capacity factor for wind from California Energy Commission, "Comparative Costs of California Central Station Electricity Generation Technologies," December 2007, Appendix B, p. 67. Nuclear plant capacity factor reflects the recent industry average performance as reported in EIA, *Monthly Energy Review*, Table 8.1. Also see Appendix A to this report.

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[70] (...continued)
estimated cost increases by about $1 per megawatt-hour. This is the net effect of the lower financing costs and the loss of the production tax credits. The renewable production tax credit applies to sales of electricity by the wind plant owner to another entity. A utility which operates a wind plant to serve its own load cannot take the credit. See 10 C.F.R. § 451.4

Costs were estimated for six cases intended to illustrate some of the important economic, operational, and government incentive factors that influence the relative economics of wind power.[71] The **Base Case** (Case 1) assumes continuation of the renewable production tax credit as currently formulated. It also assumes the nuclear plant qualifies for the nuclear production tax credit (at an effective rate of $12 per megawatt-hour)[72] and loan guarantee program established by the Energy Policy Act of 2005. No carbon costs are assumed. The five alternative cases have the following characteristics (each is identical to the Base Case except as indicated):

- **Case 2: Reduced Incentives.** The renewable production tax credit is assumed to terminate and is not renewed. The nuclear plant is assumed to not receive a loan guarantee.[73]
- **Case 3: High Natural Gas Prices.** Natural gas prices are assumed to be 50% higher than the current EIA forecast used in the Base Case.
- **Case 4: Carbon Costs.** This case assumes the imposition of controls on carbon emissions from fossil fueled power plants. An illustrative allowance price of $25 per metric ton of carbon dioxide is assumed, escalating at a real rate of one percent per year, first imposed in 2013.[74]
- **Case 5: Wind Capacity Factor.** This case assumes that the wind plant has a capacity factor of 44% rather than the 34% used in the Base Case. The higher capacity factor could be the result of improved technology or a better-than-average location.[75]

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[71] Other factors, combinations of factors, and alternative cost forecasts could be evaluated. The economic analyses presented here consider just one subset of many potential alternative assumptions. The subset was chosen to highlight some of the important determinants of the competitiveness of wind power.

[72] The nominal value of the nuclear production tax credit of $18 per megawatt-hour will be reduced if more than 6,000 megawatts of new nuclear capacity qualify for the credit. The Base Case follows EIA's long-term forecast assumption that the effective rate will be reduced to $12 per megawatt-hour because 9,000 megawatts of new nuclear capacity will qualify. See EIA, *Annual Energy Outlook 2007, pp. 20-21.*

[73] The status of the renewable PTC is discussed elsewhere in this report.

[74] In 2008, the Congressional Budget Office (CBO) estimated the price of carbon dioxide allowances in 2013 at $30 per metric ton in nominal dollars. Given an estimated change in the implicit price deflator of 17.2% between 2005 and 2013, this converts to $25.60 per metric ton in constant 2005 dollars. This value was rounded to $26 per metric ton to simplify the presentation. See CBO, "Cost Estimate for S. 2191, America's Climate Security Act of 2007," April 10, 2008, p. 8.

[75] EIA assumes that a 44% capacity factor would be achievable by 2010 for a wind plant located in the northwest. The wind capacity factor for this region actually declines over time, to 41% by 2030, presumably because wind plants are increasingly located in less favorable locations. See EIA, *Assumptions to the Annual Energy Outlook 2007*, Table 73. Planning consultants to the utility Westar Energy assumed that wind plants located in Kansas could achieve capacity factors of 42%. See Direct Testimony of Michael Elenbaas on behalf of Westar Energy, before the Kansas State Corporation Commission, Docket 08-

(continued...)

- **Case 6: Wind Integration Cost.** A system integration charge is added to the cost of wind power. The assumed cost is the Bonneville Power Administration charge of $2.82 per megawatt-hour. This cost is assumed to remain constant in real dollar terms for the forecast period.

The results for the six cases are summarized below in **Table 3**. These estimates should be viewed as indicative and not definitive, and are subject to a high degree of uncertainty. As shown in the table:

- In Case 1, the levelized cost of wind power is a few percent higher than coal or gas-fired power; given the range of uncertainty in the assumptions, the costs of these options are essentially similar. Nuclear power, which is assumed to benefit from the full range of federal incentives (a production tax credit and loan guarantee) is about 10% less expensive than wind and the least expensive of all the alternatives examined.
- In Case 2, reducing incentives significantly changes the results. If the renewable production tax credit is assumed to terminate, the cost of wind power increases by 10%. In this situation coal and gas have a 14% to 15% cost advantage over wind. However, the biggest impact of reducing incentives is on nuclear power. Assuming no loan guarantee, the cost of nuclear power increases by 28% (from $60 to $77 per megawatt-hour).[76] In this situation, wind power's cost (also without a production tax credit) is essentially similar (slightly lower) than nuclear power.
- Natural gas prices have historically been difficult to forecast and often underestimated.[77] When gas prices are assumed to be 50% higher than in the Base Case, wind has an 18% cost advantage over gas-fired electricity (Case 3).
- The imposition of an illustrative cost of $25 per metric ton of carbon dioxide on fossil-fired generation (Case 4) has the greatest impact on

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[75] (...continued)
WSEE-309-PRE, October 1, 2007, pp. 11 and 13.

[76] The loan guarantee allows the nuclear plant to be financed with 80% debt at a low interest rate. In the absence of the loan guarantee the cost of debt increases and the debt portion of the financial structure drops to 50%. The balance of the financing is equity, which is more expensive than debt. Eliminating the loan guarantee, therefore, has a major impact on the cost of a nuclear project. The chief nuclear officer for Exelon, the power company with the largest fleet of nuclear reactors in the United States, stated that constructing new nuclear plants will be "impossible" in the absence of loan guarantees (S. Dolley, "Nuclear Power Key to Exelon's Low-Carbon Plan," *Nucleonics Week*, February 14, 2008). For further discussion of the importance of loan guarantees, see Tom Tiernan, "Nuclear Interests, Wall Street Concerned about Loan Guarantee Program, Legislation," *Electric Utility Week*, August 20, 2007. Wind power is not eligible for the loan guarantees provided in EPACT05 because it is not considered a commercial technology.

[77] For example, see EIA, *Annual Energy Outlook Retrospective Review: Evaluation of Projections in Past Editions (1982-2006)*, pp. 2, 3, and 5.

the relative competitiveness of wind with coal. The carbon cost takes coal from a 4% cost advantage over wind in the Base Case to a 19% disadvantage. The impact on gas-fired power is significant, but less dramatic; gas goes from a 6% cost advantage to a 4% disadvantage when carbon costs are imposed.[78]

- As discussed above, the combination of high capital costs and relatively low utilization rates, as measured by the capacity factor, creates a cost disadvantage for wind power. The importance of utilization is illustrated by Case 5, which assumes a wind capacity factor of 44%, compared to the 34% rate used in the Base Case. With a high capacity factor, wind has the lowest cost of the alternatives examined, and in particular is over 25% less costly than coal or gas.
- The final case (Case 6) assumes the imposition of a system integration charge of $2.82 per Mwh on wind generation. As Table 5 shows, costs under this case and the Base Case are similar.

In summary, the financial analysis suggests the following:

- Given the Base Case assumptions, including continuation of the renewable production tax credit, the cost of wind power is comparable to coal and gas. The addition of an illustrative system integration charge, to account for large-scale wind penetration of a utility system, does not greatly change these results.
- Federal financial incentive policies have a significant impact on the financial analysis. The economics of wind are materially worse when the production tax credit is eliminated, and materially improved versus nuclear power when nuclear incentives are reduced.
- Improved technology or prime locations that allow wind projects to achieve high rates of utilization would significantly lower the cost of wind power.
- Assuming higher natural gas prices than the current EIA reference forecast, or the imposition of carbon charges on coal and gas, greatly enhances the cost competitiveness of wind.

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[78] Carbon costs have less impact on the gas plant because gas emits about half as much carbon dioxide per unit burned than coal, and a combined cycle gas-fired plant requires less fuel to produce a unit of electricity than a pulverized coal plant.

Table 3. Economic Comparison of Wind Power with Alternatives

(New Plants Entering Commercial Service in 2015,
Levelized 2008$ Per Megawatt-hour and Percent Difference)

Case	Levelized Cost of Power: 2008$ per megawatt-hour				Wind Cost Advantage (Disadvantage) Comparison: Percent Difference		
	Wind	Pulverized Coal	Nuclear	Natural Gas CC	Pulverized Coal	Nuclear	Natural Gas CC
1. Base Case	$67	$64	$60	$63	[redacted]	[redacted]	[redacted]
2. Reduced Incentives	$74	$64	$77	$63	[redacted]	[redacted]	[redacted]
3. High Natural Gas Prices	$67	$64	$60	$79	[redacted]	[redacted]	[redacted]
4. Carbon Cost	$67	$80	$60	$70	[redacted]	[redacted]	[redacted]
5. Higher Wind Capacity Factor	$50	$64	$60	$63	[redacted]	[redacted]	[redacted]
6. Wind Integration Cost	$69	$64	$60	$63	[redacted]	[redacted]	[redacted]

Sources and Methodology: See main body of the report and Appendix A.
Notes: "CC" = Combined Cycle. "PTC" = production tax credit. These estimates are approximations subject to a high degree of uncertainty over such factors as future fuel and capital costs. The rankings of the technologies by cost are therefore also an approximation and should not be viewed as a definitive estimate of the relative cost-competitiveness of each option.

Wind Policy Issues

This section of the report discusses government policy issues related to wind power. Some issues, such as permitting, are primarily state and local issues, but still may be a concern to congressional constituents. Other issues, such as the extension of the renewable production tax credit, are clearly federal issues.

Siting and Permitting Issues

Like other electric power projects, wind energy projects built and operated in the United States must comply with applicable federal, state, and local requirements. Most wind energy projects in the United States today are built on private land. As a result, local and state jurisdictions play the most important role in siting and permitting wind energy projects.[79] These projects, however, usually must also meet certain federal requirements such as those in the Endangered Species Act (U.S.C.§1531-1544), Migratory Bird Treaty Act (U.S.C.§§703-711), or Hazard Determination by the Federal Aviation Administration (FAA).[80] Key siting and permitting issues are discussed below.[81]

Wildlife Constraints. The main environmental objection to wind power is concern about bird and bat collisions with wind turbines. A National Academy of Sciences report states that, "Out of a total of perhaps 1 billion birds killed annually as a result of human structures, vehicles and activities, somewhere between 20,000 and 37,000 died in 2003 as a result of collisions with wind-energy facilities."[82] Although this is a small percentage of total birds killed, the impact on particular species could be significant, especially if wind power continues to expand rapidly.

Early wind turbines in California killed birds — especially raptors (hunting birds like hawks, eagles, and owls, some of which are protected under the Endangered Species Act) — and catalyzed opposition to wind power among bird

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[79] Energy projects built on private land that receive federal grants or use federal transmission lines must also meet federal requirements in the National Environmental Policy Act (42 U.S.C. §4321).

[80] Others might include the Bald and Golden Eagle Protection Act (16 U.S.C. §§668-668d), National Historic Preservation Act (16 USC §470), Clean Water Act (33 U.S.C. §1251), Rivers and Harbors Act of 1899 (33 U.S.C. §401), Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund, 42 U.S.C. §§9601-9675).

[81] More comprehensive information on federal, state and local regulations related to wind energy projects is found in: Energy Efficiency and Renewable Energy, "Federal Wind Siting Information Center," DOE [http://www1.eere.energy.gov/windandhydro/federalwindsiting/], *Wind Energy Siting Handbook*, AWEA, 2008 and *Permitting of Wind Energy Facilities: A Handbook*, National Wind Coordinating Committee, Revised 2002.

[82] National Research Council, *Environmental Impacts of Wind-Energy Projects: Report in Brief*, The National Academy of Sciences, 2007, p. 2.

enthusiasts.[83] Although bird concerns remain, today's turbines kill far fewer birds per unit of electricity generated than early models, especially in California.[84] More recently, a relatively large number of bat fatalities have occurred at wind plants in West Virginia, Pennsylvania, New York, Alberta, and elsewhere.[85] As a result, the wind industry and bat supporters formed a new organization, the Bats & Wind Energy Cooperative (BWEC) to fund studies designed to reduce bat mortality.[86]

Most experts concede that not enough is known about avian behavior to predict accurately what the affect on species will be if wind plants continue to expand. More collaborative study is underway to improve understanding of ways to minimize avian deaths.[87] Potential mitigation options include:

- Stopping wind plants during key migratory periods,
- Painting blades to improve visibility,
- Avoiding locations, such as some mountain passes, already known to be migration corridors,
- Employing acoustic deterrents, and
- Moving selected turbines.

In addition to birds and bats, wildlife protection experts are studying how wind plant construction and operation affects terrestrial animals.[88] Greater prairie chickens, for example, shy away from tall structures and may thus avoid living near wind plants.[89]

Federal agencies produced interim recommended guidelines in 2003 to assist project developers in considering and minimizing wildlife impacts.[90] The DOI (through Fish and Wildlife Services, FWS) has established a Wind Turbine

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[83] These early turbines were not designed with avian populations in mind. The blades spun much more quickly than today's turbines and the towers were often constructed of lattice steel, an enticing nesting feature for birds.

[84] *Wind Power: Impacts on Wildlife and Government Responsibilities for Regulating Development and Protecting Wildlife*, Government Accountability Office, GAO-05-906, September 2005, pp. 10-13.

[85] J. Layke, K. Porter, and A. Perera, "Diversifying Corporate Energy Purchasing with Wind Power," World Resources Institute, February 2008, p. 14.

[86] BWEC includes AWEA, Bat Conservation International, the U.S. Fish and Wildlife Service, and the U.S. Department of Energy's National Renewable Energy Laboratory. "Wind Energy and Wildlife: Frequently Asked Questions," AWEA, 2008, p. 2.

[87] See, for example, "Bats and Wind Energy Cooperative" [http://www.batsandwind.org/].

[88] See, for example, National Research Council, *Environmental Impacts of Wind-Energy Projects: Report in Brief*, The National Academy of Sciences, 2007

[89] J. Layke, K. Porter, A. Perera, "Diversifying Corporate Energy Purchasing with Wind Power," World Resources Institute, 2008, p. 9.

[90] See "Interim Guidelines to Avoid and Minimize Wildlife Impacts from Wind Turbines," U.S. Department of the Interior, Fish and Wildlife Service, 2003, [http://www.fws.gov/habitatconservation/wind.pdf].

Guidelines Advisory Committee to advise the Secretary on developing effective voluntary measures to minimize impacts to wildlife related to land-based wind turbines.[91] Early in the 110th Congress, Title VII of the New Direction for Energy Independence, National Security, and Consumer Protection Act (H.R. 3221) had required formation of such a committee, but the provision was removed when the bill was merged with H.R. 6. As noted previously, Congress gave MMS primary authority over most aspects of siting off-shore wind plants through EPACT05.

Aesthetic and Social Issues. Some landowners object to the visual impact that wind turbines create, especially near shore, mountainous, forested, protected, or other "valuable" areas. They view wind turbines as an unacceptable human or industrial fingerprint on lands that should remain natural. These objections are reflected in the offshore Cape Wind project, where opponents argue that natural "landscapes" (or seascapes, in this case) will be forever altered by the wind turbines.

In addition to the visual impacts, there are other objections. All wind turbines produce mechanical and aerodynamic noise. Noise is thus a siting criterion for regulatory purposes. Early wind turbine models were often loud, especially downwind versions (blades behind the generator). Newer models are designed to minimize noise.[92] Like visual aesthetics, wind turbine noise is often a matter of individual preferences and tolerances. For residences over 1 kilometer (0.6 miles) from a wind turbine, noise is generally not an issue.

Shadow flicker, also know as shadow casting or blinking, is defined as alternating changes in light intensity caused by the moving blades casting shadows on the ground or objects. No flicker shadow will be cast when the sun is obscured by clouds or when the turbine is not rotating. This phenomenon can be annoying for residents who live very close to turbines. Computer simulations can help project developers position turbines so that flicker does not interfere with nearby residences. Shadow flicker generally does not affect residences located 10 rotor diameters or more (about 0.5 miles) from the turbine, except possibly early in the morning or late in the evening when shadows are long.[93]

Radar Issues. Wind turbines can interfere with civilian and military radar at some locations. The potential interference occurs when wind turbines reflect radar waves and cause ghosting (false readings) or shadowing (dead zones) on receiving monitors. Radar interference thus raises national security and safety concerns.[94]

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[91] The Charter describing the committee's formation is available on the FWS website at [http://www.fws.gov/habitatconservation/Advisory_Committee_Charter_3_20_07.pdf].

[92] A. Rogers, J. Manwell, and S. Wright, *Wind Turbine Acoustic Noise*, University of Massachusetts at Amherst, Renewable Energy Research Laboratory, June 2002.

[93] B. Voll, "Black Springs Wind Farm Shadow Flicker Study," Energreen Wind, 2006, p. 6.

[94] See also M. Brenner, et al., *Wind Farms and Radar*, The MITRE Corporation, JSR-08-126, January 2008.

Concern over wind power and radar interference appeared to peak after Congress enacted the National Defense Authorization Act for Fiscal Year 2006 (P.L. 109-163) on January 3, 2006. Section 358 of the law required the Department of Defense (DOD) to submit to Congress within 120 days a report on the impacts of wind plants on military readiness. In response, DOD and the Department of Homeland Security (DHS) issued a temporary ruling on March 21, 2006, contesting the construction of any wind plant within radar line of sight of key military radar facilities until the report could be completed. AWEA stated in a June 2006 fact sheet that the *de facto* moratorium on billions of dollars worth of wind investment in parts of the country was inappropriate.[95] The temporary ruling was clarified on July 10, 2006, in a joint DOD-DHS memo to the Federal Aviation Administration (FAA),[96] calling for a case-by-case evaluation of the potential of wind projects on radar systems. Permitting resumed for most of the affected projects later that year.

The DOD impacts report[97] concluded that wind farms located within radar line of sight of an air defense radar have the potential to degrade the ability of that radar to perform its intended function. It also noted that currently proven mitigation options to completely prevent any degradation in primary radar performance of air defense radars are limited to methods that avoid locating wind turbines within their radar line of sight. DOD has initiated research efforts to develop additional mitigation approaches that in the future could enable wind turbines to be placed within radar line of sight of air defense radars without impacting their performance.[98]

The FAA has oversight over any object that could have an impact on communications in navigable airspace, either commercial or military. DOD participates in the FAA review and evaluation of applications for potential impacts to its ability to defend the nation. The FAA requires that a Notice of Proposed Construction or Alteration be filed for any project that would extend more than 200 feet above ground level (or less in certain circumstances, for example if the object is closer than 20,000 feet away from a public-use airport with a runway more than 3,200 feet long).[99]

Although the DOD report noted limited options to "completely prevent" the degradation of any performance of air defense radar systems, DOE believes that practical solutions to radar interference are achievable. DOE notes that in the majority of cases, interference is either not present, is not deemed significant, or can

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[95] AWEA, "Wind Turbines and Radar: An Informational Resource," June 2, 2006 [http://www.awea.org/pubs/factsheets/060602_Wind_Turbines_and%20_Radar_Fact_Sheet.pdf].

[96] K. Kinsmore, and R. Wright, "Intent of March 21, 2006 Memorandum," Department of Defense and Department of Homeland Security Joint Program Office, July 10, 2006.

[97] The report was issues on September 27, 2006 and is available at [http://www.defense.gov/pubs/pdfs/WindFarmReport.pdf]

[98] Office of the Director of Defense Research and Engineering, *The Effect of Windmill Farms on Military Readiness*, DOD, September 2006, pp. 56-57.

[99] FAA requirements on potential obstructions are discussed at [https://oeaaa.faa.gov/oeaaa/external/portal.jsp].

be readily mitigated.[100] Potential interference is highly site specific and depends on local features, type of radar, and wind plant characteristics. In most cases, radar interference can be corrected with software that deletes radar signals from stationary targets.

Transmission Constraints

Transmission constraints are considered to be one of the biggest challenges facing the U.S. wind industry.

The electricity grid in the United States is aging and overloaded in some regions, and new investment is required to ensure reliable, efficient transmission of electricity.[101] Siting new transmission lines is an expensive, time consuming, and, often, controversial endeavor. Wind plant developers seek access to transmission capacity that allows them to send their electricity to market without having to build new lines, especially ones they need to pay for themselves. As noted previously, much of the nation's best wind resources are located in remote, lightly populated areas where little transmission capacity exists. Demand centers, where the electricity is consumed, can be hundreds of miles away. A 2006 estimate puts the cost of new transmission lines at $1.5- $2 million per mile, and costs may have increased since.[102]

Transmission constraints occur in at least 3 ways:

- **Limited transmission capacity,**
- **Scheduling difficulties** in using existing lines, and
- **Delays in interconnecting** new wind power sources to the grid.

Limited Transmission Capacity. Good sites for wind plants may be located in areas with limited available capacity on the transmission network, or the sites may be distant from any existing transmission lines. These capacity limits are the most fundamental constraint facing wind power project developers. It can take many years to plan and build new infrastructure. Wind plant developers who build in regions with limited or no transmission capacity may have to incur all construction costs for new or improved transmission infrastructure, an expensive proposition.

Texas is attempting to address its wind power transmission constraints through competitive renewable energy zones (CREZs), which attempt to optimize the linking of promising wind zones with demand centers and overcome the "chicken and egg" problem between wind plant developers and transmission providers. California is pursuing a similar CREZ policy, and other states, including New Mexico, Wyoming,

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[100] U.S. DOE, "Wind Powering America," available at [http://www.eere.energy.gov/windandhydro/windpoweringamerica/ne_issues_interference.asp].

[101] See CRS Report RL33875, *Electric Transmission: Approaches for Energizing a Sagging Industry*, by Amy Abel.

[102] Actual costs are location dependent. Northwest Power Pool, "Canada — Northwest — California Transmission Options Study," pp. 16-27, May 16, 2006.

and Colorado, are expanding transmission infrastructure to accommodate wind and other electricity options.[103]

Under the Energy Policy Act of 2005 (EPACT05), in certain cases where transmission congestion exists, the Federal Energy Regulatory Commission (FERC) may use federal over-ride (eminent domain) authority to site new transmission lines when states have not acted to site those lines.[104] Also under EPACT05, FERC is authorized to approve a funding plan for new transmission that would charge the new generator for all costs associated with interconnection rather than socializing the interconnection costs over all users of the transmission network.[105] This type of funding could be cost prohibitive for small wind facilities.

Finally, EPACT05 also directed FERC to establish incentive rules to encourage greater investment in the nation's transmission infrastructure, promote electric power reliability, and lower costs for consumers by reducing transmission congestion. Order No. 679 allows a public utility to obtain incentive rate treatment for transmission infrastructure investments under certain conditions.

Scheduling Difficulties. Transmission scheduling difficulties for wind power can result because the original rules for access to transmission capacity were not designed with intermittent sources, like wind, in mind. As the electricity sector slowly transforms itself from one with several hundred vertically integrated utilities with their own transmission control areas to one with a combination of regional transmission organizations (RTOs) and traditional control centers, the rules are being rewritten. Under the old rules, economic penalties were applied to generators that did not meet their day-ahead schedule requirements. For wind power, this occurred frequently since power output varies with wind variability, making scheduling difficult. Wind developers claim that the old rules discriminated against intermittent sources. In February 2007, FERC issued Order No. 890 to allow greater access to transmission lines for power generators of all types, including renewable energy projects.[106]

Rate pancaking (using the transmission facilities of multiple operators and incurring access charges from each) is another scheduling barrier for wind power in some regions. Only large transmission systems acting as a single network resource allow wind plants to avoid pancaking. FERC tried to promote a Standard Market Design order in 2002-2003 that might have provided greater uniformity to transmission pricing, but the effort was dropped due to opposition.[107]

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[103] L. Chaset, "Comments of the Public Utility Commission of California," FERC Docket No. AD08-2-00, December 11, 2007; and S. Smith, "Wind on the Wires: Can Transmission Infrastructure Adapt?," *Utility Automation and Engineering T&D*, May 2008.

[104] P.L. 109-58, §1221.

[105] P.L. 109-58, §1242.

[106] *Preventing Undue Discrimination and Preference in Transmission Service* (Order 890), Federal Energy Regulatory Commission, February 16, 2007.

[107] See CRS Report RS21407, *Federal Energy Regulatory Commission's Standard Market*
(continued...)

Transmission Interconnection. There are long queues (waiting lists) in some regions of the country for wind and other power plant developers to get approval to interconnect their new facilities with the grid.[108] FERC issued Orders 2003 and 661 to clarify transmission interconnection requirements and help address potential discrimination.[109] FERC is also preparing new guidance to help RTOs and independent system operators (ISOs) improve their queuing methodology.[110] As long as there is a shortage of transmission capacity, however, transmission interconnection queuing is likely to remain a problem.[111]

Federal Renewable Transmission Initiatives. Two bills were introduced in the 110th Congress to address transmission of wind power and other renewable electricity. The Clean Renewable Energy and Economic Development Act (S. 2076), introduced in September 2007, would, among other things, amend the Federal Power Act to require national renewable energy zones. These zones would be specified areas that have the potential to generate 1,000 megawatts of electricity from renewable energy, a significant portion of which could be generated in a rural area or on federal land.

The legislation would also require FERC to promulgate regulations to ensure that (1) specified public utility transmission providers that finance renewable electricity connection facilities in such zones recover incurred costs and a reasonable return on equity associated with the new transmission capacity; and (2) not less than 75% of the capacity of specified high-voltage transmission facilities and lines is used for electricity from renewable energy. The legislation was referred to the Committee on Energy and Natural Resources, which held a hearing on transmission issues for renewable electricity resources on June 17, 2008.[112]

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107 (...continued)
Design Activities, by Amy Abel.

108 According to a recent DOE report, there were 225,000 megawatts of proposed wind power capacity in interconnection queues within 11 RTO, ISO, and utility regions at the end of 2007. As noted in the report, being in the queue does not guarantee that a project will be built; many are at an early stage of development and may never achieve commercial operations. For comparison, the report noted that about 212,000 megawatts of natural gas, coal, nuclear, solar, and "other" projects were also in queues. R. Wiser and M. Bolinger, *Annual Report on U.S. Wind Power Installation, Cost and Performance Trends: 2007*, U.S. Department of Energy, May 2008, pp. 9-10.

109 *Standardization of Generator Interconnection Agreements and Procedures* (Order 2003), Federal Energy Regulatory Commission, July 24, 2003; *Interconnection for Wind Energy* (Order 661), Federal Energy Regulatory Commission, June 2, 2005.

110 *Interconnection Queuing Practices* (Docket No. AD08-2-000), Federal Energy Regulatory Commission, March 20, 2008.

111 For more information on recent electricity transmission issues that may relate to wind power, see CRS Report RL33875, *Electric Transmission: Approaches for Energizing a Sagging Industry*, by Amy Abel; and *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply*, U.S. DOE, 2008.

112 Testimony from this hearing is available at [http://energy.senate.gov/public/

A similar bill in the House, the Rural Clean Energy Superhighways Act (H.R. 4059), was introduced in November 2007. It would also focus on creating national renewable energy zones under certain conditions. It requires the President to identify, and provide public notice of, additional renewable energy trunkline facilities and network upgrades required to increase substantially the generation of electricity from renewable energy within each potential zone. It directs FERC to pass regulations to ensure that a public utility that finances transmission capacity to transmit electricity from renewable energy from a zone to an electricity consuming area recovers through transmission service rates all prudently incurred costs and a reasonable return on equity associated with construction and operation of the new transmission capacity. It also directs FERC, in specified circumstances, to permit a renewable energy trunkline built by a public utility located in a zone to be initially funded through transmission charges imposed upon (1) all the utility's transmission customers in advance of significant generation interconnection requests; or (2) all the transmission customers of a Regional Transmission Organization (RTO) or independent system operator, if the trunkline is built in an area served by one or the other. Cost allocation procedures are prescribed for new projects and network upgrades. A federal power marketing administration, including the Tennessee Valley Authority (TVA), that owns or operates electric transmission facilities is required to finance a network upgrade or a renewable energy trunkline facility, if within a certain time frame no privately or publicly funded entity commits to do so.

Renewable Production Tax Credit

The renewable production tax credit is an incentive to business developers of wind plants and some other renewable energy projects that produce electricity. For each kilowatt-hour of energy produced, a developer can apply for a credit against taxes. In 2007, the credit stood at 2.0 cents per kilowatt-hour for claims against 2006 taxes. According to industry members, the PTC expirations in 2000, 2002, and 2004 have had a negative impact on the U.S. wind industry's ability to invest in new production facilities efficiently.[113]

Proponents of extending the credit past 2008 argue that the PTC is merited because it corrects a market failure by providing economic value for the environmental benefits of "clean" energy sources. Also, they contend it helps "level the playing field," noting that there is an even longer history of federal subsidies for

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[112] (...continued)
index.cfm?FuseAction=Hearings.Hearing&Hearing_ID=7344491e-df7f-9a28-80ce-47fe52e63f1b].

[113] U.S. Congress, House Committee on Ways and Means, *Tax Credits for Electricity Production from Renewable Sources.* Hearing held May 24, 2005. Testimony of Dean Gosselin, FPL Energy. pp. 25-26. [http://waysandmeans.house.gov/hearings.asp?formmode=detail&hearing=411].

conventional energy.[114] For example, they point to the percentage depletion allowance for oil and natural gas that has been in place for many decades.[115]

Opponents of extending the production tax credit beyond the end of 2008 argue that generally there are no market failures that warrant special tax subsidies for particular types of renewable energy technologies. They argue further that subsidies generally distort the free market and that renewables should not get special treatment that exempts them from this principle. Also, regarding the concern about the environmental problems of conventional energy sources, they contend that the most cost-effective economic policy is to put a tax on the pollution from energy sources and let the free market make the necessary adjustments. Another argument against the PTC is that intermittent renewable energy production has a fluctuating nature that makes it less valuable than energy produced by conventional facilities.

PTC Eligibility: IOUs vs. IPPs. The renewable PTC is not available to investor owned utilities (IOUs), although utilities do finance and own wind plants. Typically, independent power producers (IPPs) build, finance, and own wind plants and sell power to regulated utilities. There are a number of financing mechanisms where other providers of capital assist with financing wind plants in exchange for a portion of the tax credits. One question for Congress is whether utilities should become eligible to receive the PTC. Doing so would allow them to finance wind plants at a lower cost since the interest rates they pay on debt is lower than what an IPP pays. This would reduce the cost of wind power. One impact of allowing utilities to receive the renewable tax credits is that they could become more competitive at producing wind than IPPs. This could threaten the growth of the dozens of companies that now build wind plants.

Specific PTC Legislative Options. Congress is considering a variety of bills that would extend or modify selected renewable energy and energy efficiency tax incentives, including wind power. Title IV of the Alternative Minimum Tax and Extenders Tax Relief Act (S. 2886), which was introduced on April 17, 2008, would extend eight incentives. Title X of the Foreclosure Prevention Act (H.R. 3221), which passed the Senate on April 10, 2008, incorporates eight renewable energy and energy efficiency tax incentives from the Clean Energy Tax Stimulus Act (S. 2821). The Renewable Energy and Energy Conservation Tax Act (H.R. 5351), which passed the House on February 27, 2008, includes 16 incentives for renewable energy and energy efficiency. Features of these bills as they relate to the PTC for wind energy are summarized in **Table 4**. For updated status on legislation related to the PTC, see

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114 Federal subsidies for conventional energy resources and technologies and for electric power facilities (including large hydroelectric power plants) have been traced back as far as the 1920s and 1930s. See DOE (Pacific Northwest Laboratory), *An Analysis of Federal Incentives Used to Stimulate Energy Production,* 1980. p. 300. The EIA recently published the latest in a series on federal energy incentives and subsidies: EIA, *Federal Financial Interventions and Subsidies in Energy Markets 2007*, DOE, April 2008.

115 GAO. *Petroleum and Ethanol Fuels: Tax Incentives and Related GAO Work.* (GAO/RCED-00-301R) September 25, 2000. The report notes that from 1968 through 2000, about $150 billion (constant 2000 dollars) worth of tax incentives were provided to support the oil and natural gas industries.

CRS Report RL33831, *Energy Efficiency and Renewable Energy Legislation in the 110th Congress*, by Fred Sissine, Lynn Cunningham, and Mark Gurevitz.

Table 4. Selected Wind Power Tax Incentive Bills Compared

	H.R. 6049	Senate Substitute to H.R. 6049	H.R. 5984 H.R. 3221 (S. 2821)
Renewable Energy			
Production Tax Credit Extension	1 year	1 year	1 year
Clean Renewable Energy Bonds	$2 billion	$2 billion	$400 million
Revenue Offsets			
Offsets from reduced oil and gas subsidies	yes	yes	no

Carbon Constraints and the PTC. Climate change is almost certain to be an important topic in this and future Congresses. Most proposals call for a cap-and-trade system to reduce greenhouse gas emissions, although carbon taxes have also been proposed. Either way of constraining greenhouse gas emissions would create an effective cost on emissions. As noted in the Economics Section of this report, the Congressional Budget Office estimated the price of carbon dioxide allowances in S. 2091 at $30 per metric ton in 2013.[116] While this legislation did not pass, future versions of legislation are likely to have similar price levels on carbon dioxide allowances. According to the levelized cost analysis presented earlier, such a price would make wind power about 19% less expensive than power derived from coal. Even without the PTC, wind power would be more competitive than coal. For natural gas, the impact of carbon allowance costs would be less dramatic, although the levelized cost of wind as modeled here would be noticeably lower than natural gas power. Congress will need to reconsider the policy goal of the renewable PTC if and when a carbon constraint is imposed.

Alternatives to the PTC. One alternative to the PTC is the renewable energy payment system, also known as the feed-in tariff. This policy is widely used in Europe (see Text Box 1 above for the German experience). It guarantees interconnection with the electricity grid and a premium price to renewable energy producers. Financing renewable energy projects under a renewable energy payment system is reportedly easier since there is a transparent source of revenue for a fixed period, usually 20 years. Even in Germany, however, critics claim that feed-in tariffs

[116] CBO's analysis was performed in accordance with S. 2191 (the Lieberman-Warner Climate Security Act of 2008). See CRS Report RL34515 *Climate Change: Comparisons of S. 2191 as Reported (now S. 3036) with Proposed Boxer Amendment*, by Brent Yacobucci and Larry Parker.

can be expensive. A summary of the Renewable Energy Jobs and Security Act, which incorporates renewable energy payments, was circulated in mid-June 2008.[117]

Renewable Portfolio Standards

In the late 1990s, many states began to restructure their electric utility industries to allow for increased competition. Some of these states established an RPS, in part, as a way to create a continuing role for renewable energy in power production.[118] An RPS requires utilities to provide a minimum percentage of their electricity from approved renewable energy sources. Some states without a restructured industry also adopted an RPS. The number of states with an RPS has grown steadily but without consistency — RPS requirements vary from state to state. In April 2008, FERC reported that 26 states and the District of Columbia had an RPS in place, collectively covering about 54% of the national electric load.[119] Mandatory state RPS targets range from a low of 2% to a high of 25% of electricity generation. However, most targets range from 10% to 20% and are scheduled to be reached between 2010 and 2025.

Most states include wind energy as an eligible resource and allow some form of trading between holders of the "renewable energy credits" that result from operating wind projects.[120] Non-compliance penalties imposed by states range from about 1.0 to 5.5 cents per kilowatt-hour. Many states in the Southeast and Midwest regions do not have an RPS requirement. Several states have broadened their RPS provisions to allow certain energy efficiency measures and technologies to help satisfy the requirement.

Federal RPS Debate. State RPS action has provided an experience base for the design of a possible national requirement. Proponents of a federal RPS contend that a national system of tradable credits would enable retail suppliers in states with

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[117] The summary is available at [http://www.eesi.org/briefings/2008/061808_hboell_rep/Inslee_REJSA_061808.pdf].

[118] Section 210 of the Public Utility Regulatory Policies Act (PURPA) of 1978 had guaranteed a market for the purchase of electric power produced from small renewable energy facilities. PURPA let states determine the avoided cost pricing of the electricity production from renewable energy facilities. The effectiveness of this mechanism lessened with the advent of electric industry restructuring. Provided that certain conditions are met in any given state, Section 1253 of the Energy Policy Act of 2005 retrospectively terminates the PURPA mandatory purchase requirements.

[119] Federal Energy Regulatory Commission, *Renewable Energy Portfolio Standards (RPS)*, DOE. For a map showing the status of state action on RPS, see [http://www.ferc.gov/market-oversight/mkt-electric/overview/elec-ovr-rps.pdf].

[120] Details about eligible resources and other provisions of state RPS programs are available from the online Database of State Incentives for Renewable Energy and Energy Efficiency, [http://www.dsireusa.org/]. See also R. Wiser and G. Barbose, *Renewables Portfolio Standards in the United States — A Status Report with Data Through 2007*, Lawrence Berkeley National Laboratory, April 2008; and A. Selting, *The Race for the Green: How Renewable Portfolio Standards Could Affect U.S. Utility Credit Quality*, Standard & Poors, March 2008.

fewer resources to comply at the least cost by purchasing credits from organizations in states with a surplus of low-cost production. Opponents counter that regional differences in availability, amount, and types of renewable energy resources would make a federal RPS costly and unfair.

Efforts to include a federal RPS in the Energy Independence and Security Act (P.L. 110-140) were unsuccessful. In June 2007, S.Amdt. 1537 to H.R. 6 proposed a 15% federal RPS. Senate floor action on the proposal triggered a lively debate, but the amendment was ultimately ruled non-germane. In that debate, opponents argued that a national RPS would raise retail electricity prices and disadvantage Southeastern states because they lack sufficient renewable energy resources to meet a 15% RPS requirement. RPS proponents countered that an Energy Information Administration (EIA) report indicated that the South has sufficient biomass power potential from existing plants to meet a 15% RPS without becoming "unusually dependent" on other regions.[121] Further, EIA estimated that the 15% RPS would likely raise retail prices by slightly less than 1% over the 2005 to 2030 period, but would also be likely to cause retail natural gas prices to fall slightly over that period. In December 2007, the House approved H.R. 6 with a 15% RPS, but the Senate dropped the provision under threat of an Administration veto of the bill. The prospects for another federal RPS initiative in the 110th Congress are unclear.

Conclusions

Wind power in the United States is growing rapidly. Although it currently supplies only about 1% of the country's electricity needs, some states and regions have a much higher level of wind penetration. Furthermore, the amount of proposed new wind plants either under construction or waiting to be built is significant, and could soon make wind the largest source of new power supply at the national level. Continued expansion of wind power in the United States could be slowed by lack of transmission capacity and expiration of the federal renewable production tax credit. On the other hand, federal policy on climate change, expected by many in the 111th Congress, would likely put a value on carbon dioxide emissions and give wind power additional advantages compared to coal- and natural gas-based electricity. Congress will need to carefully consider the interactive nature of energy and climate legislation when crafting future policy.

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[121] EIA, *Impacts of a 15-Percent Renewable Portfolio Standard*, DOE, June 2007. 24 p.

Appendix. Financial Analysis Methodology and Assumptions

The financial analysis of power plant costs in this report estimates the operating costs and required capital recovery of each generating technology for an analysis period through 2050. Plant operating costs will vary from year to year depending, for example, on changes in fuel prices and the start or end of government incentive programs. To simplify the comparison of alternatives, these varying yearly expenses are converted to a uniform annual cost expressed as 2008 present value dollars.[122]

Similarly, the capital costs for the generating technologies are also converted to levelized annual payments. An investor-owned utility or independent power project developer must recover the cost of the investment and a return on the investment, accounting for income taxes, tax law (depreciation rates), and the cost of money. These variables are encapsulated within an annualized capital cost for a project computed using a "capital charge rate." The financial model used for this study computes a project-specific capital charge rate that reflects, for example, the assumed cost of money and the applicable depreciation schedule.

In the case of publicly owned utilities the return on capital is a function of the interest rate. A "capital recovery factor" reflecting each project's cost of money is computed and used to calculate a mortgage-type levelized annual payment.[123]

Combining the annualized capital cost with the annualized cash flows yields the total estimated annualized cost of a project. This annualized cost is divided by the projected yearly output of electricity to produce a cost per Mwh for each technology. By "annualizing" the costs in this manner it is possible to compare alternatives with different year-to-year cost patterns on an apples-to-apples basis.

Inputs to the financial model include financing costs, forecasted fuel prices, non-fuel operations and maintenance expense, the efficiency with which fossil-fueled plants convert fuel to electricity, and typical utilization rates (see **Tables A-1, A-2,** and **A-3**, below). Most of these inputs are taken from published sources, such as the

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[122] Converting a series of cash flows to a financially-equivalent uniform annual payment is a two-step process. First, the cash flows for the project are converted to a 2008 "present value." The present value is the total cost for the analysis period, adjusted ("discounted" using a "discount factor") to account for the time value of money and the risk that projected costs will not occur as expected. This lump-sum 2008 present value is then converted to an equivalent annual payment using a uniform payments factor (the "capital recovery factor"). For a more detailed discussion of the levelization method see, for example, Chan Park, *Fundamentals of Engineering Economics*, 2004, Chapter 6; or Eugene Grant, et al., *Principles of Engineering Economy*, 6th Ed., 1976, Chapter 7.

[123] For additional information on capital charge rates see Hoff Stauffer, "Beware Capital Charge Rates," *The Electricity Journal*, April 2006. The capital recovery factor is equivalent to the PMT function in the Excel spreadsheet program. For additional information on the calculation of capital recovery factors see Chan Park, *Fundamentals of Engineering Economics*, 2004, Chapter 2; or Eugene Grant, et al., *Principles of Engineering Economy*, 6th Ed., 1976, Chapter 4.

Energy Information Administration's (EIA) assumptions used to produce its 2007 and 2008 long-term energy forecasts. Overnight power plant capital costs — that is, the cost to construct a plant before financing expenses — are estimated by CRS based on a review of public information on recent projects.

Government incentives are also an important part of the financial analysis. EPACT05 created or extended federal incentive programs for coal, nuclear, and renewable technologies. This study assumes the following incentives:

- *A renewable energy production tax credit of 2.0 cents per kWh, with the value indexed to inflation.* The credit applies to the first 10 years of a plant's operation. The Base Case analysis assumes that the tax credit, which is currently scheduled to expire at the end of 2008, will be extended (as has happened in the past). The credit is available only to wind power production that is sold to an unaffiliated third party. Under most circumstances this requirement effectively limits the production tax credit to independent power producers. A utility that owns a wind plant and uses the power to serve its own load would not qualify.[124] The credit is currently available to new wind, geothermal, and several other renewable energy sources. New solar energy systems do not qualify, and geothermal systems can take the production tax credit only if they do not use the renewable investment tax credit (discussed below).

- *A nuclear energy production tax credit for new advanced nuclear plants of 1.8 cents per kWh.* The credit applies to the first eight years of operation. Unlike the renewable production tax credit described above, the nuclear credit is not indexed to inflation and therefore drops in real value over time. This credit is subject to several limitations:
  - It is available to plants that begin construction before January 1, 2014, and enter service before January 1, 2021.
  - For each project the annual credit is limited to $125 million per thousand megawatts of generating capacity.
  - The full amount of the credit will be available to qualifying facilities only if the total capacity of the qualifying facilities is 6,000 megawatts or less. If the total qualifying capacity exceeds 6,000 megawatts the amount of the credit available to each plant will be prorated. For example, EIA assumes in its 2007 *Annual Energy Outlook* that 9,000 megawatts of new nuclear capacity qualifies; in this case the credit amount drops to 1.2 cents per kWh.[125] The Base Case for this study follows EIA in using the 1.2 cent per kWh assumption for the effective value of the credit.

- *Loan guarantees for carbon-control technologies, including nuclear power.* Under final Department of Energy (DOE) rules the loan

[124] See 10 CFR § 451.4.

[125] For a discussion of the credit see EIA, *Annual Energy Outlook 2007*, p. 21.

guarantees can cover up to 80% of the cost of a project. Guarantees are made available based on a case-by-case evaluation of applicants and are dependent on congressional authority (in April 2008, the Department of Energy announced plans to solicit up to $18.5 billion in loan guarantee applications for nuclear projects[126]). Entities receiving loan guarantees must make a "credit subsidy cost" payment to the federal treasury that reflects the net anticipated cost of the guarantee to the government, including a probability of default. The guarantees are, under current rules, unlikely to be available to public power entities.[127]

- *Energy Investment Tax Credit.* Tax credits under this program are available to certain renewable energy systems, including solar and geothermal electricity generation, and some other innovative energy technologies. Wind energy systems do not qualify. The credit is 10% for systems installed after January 1, 2009. Geothermal projects that take the investment tax credit cannot take the renewable production tax credit.[128]

The results of the analysis are shown in the main body of the report. Note that these estimates are approximations subject to a high degree of uncertainty over such factors as future fuel and capital costs. The rankings of the technologies by cost are therefore also an approximation and should not be viewed as a definitive estimate of the relative cost-competitiveness of each option. Also note that site-specific factors would influence an actual developer's choice of generating technologies. For example, coal may be less costly if a plant is close to coal mines, and the economics of wind depend in part on the strength and consistency of the wind in a given area.

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[126] *DOE Announces Plans for Future Loan Guarantee Solicitations*, Department of Energy press release, April 11, 2008. Loan guarantee authority of $18.5 billion for nuclear power plants is provided by P.L. 110-161.

[127] Entities receiving loan guarantees must make a substantial equity contribution to the project's financing. Public power entities normally do not have the retained earnings needed to make such payments. The rules also preclude granting a loan guarantee if the federal guarantee would cause what would otherwise be tax exempt debt to become subject to income taxes. Under current law this situation would arise if the federal government were to guarantee public power debt. For further information on these and other aspects of the loan guarantee program see U.S. DOE, final rule, "Loan Guarantees for Projects that Employ Innovative Technologies," 10 C.F.R. § 609 (RIN 1901-AB21), October 4, 2007 [http://www.lgprogram.energy.gov/keydocs.html].

[128] For additional information see the discussion of the investment tax credit in the federal incentives section of the Database of State Incentives for Renewable Energy website, [http://www.dsireusa.org/].

Table A-1. Base Case Financial Factors

Item	Value	Sources and Notes
Representative Bond Interest Rates		
Utility Aa	2010: 6.8% 2015: 7.0% 2020: 7.0%	When available, interest rates for investment grade bonds with a rating of Baa or higher (i.e., other than high yield bonds) are Global Insight forecasts. When Global Insight does not forecast an interest rate for an investment grade bond the value is estimated based on historical relationships between bond interest rates (the historical data for this analysis is from the Global Finance website). High yield interest rates are estimated based on the differential between Merrill Lynch high yield bond indices and corporate Baa rates, as reported by WSJ.com (*Wall Street Journal* website).
IPP High Yield	2010: 9.8% 2015: 10.0% 2020: 10.0%	
Public Power Aaa	2010: 5.1% 2015: 5.4% 2020: 5.4%	
Corporate Aaa	2010: 6.3% 2015: 6.5% 2020: 6.5%	
Cost of Equity — Utility	14.00%	California Energy Commission, "Comparative Cost of California Cental Station Electricity Generating Technologies," December 2007, Table 8.
Cost of Equity — IPP	15.19%	
Debt Percent of Capital Structure	Utility: 50% IPP: 60% Utility or IPP with federal loan guarantee: 80% POU: 100%	Northwest Power and Conservation Council, "The Fifth Northwest Electric Power and Conservation Plan," May 2005, Table I-1.
Federal Loan Guarantees		
Cost of equity premium for entities using 80% financing.	1.75 percentage points	Congressional Budget Office, *Nuclear Power's Role in Generating Electricity*, May 2008, web supplement ("The Methodology Behind the Levelized Cost Analysis"), Table A-5 and page 9.
Credit Subsidy Cost	12.5% of loan value	
Long-Term Inflation Rate (change in the implicit price deflator)	1.9%	Global Insight
Composite Federal/State Income Tax Rate	38%	EIA, National Energy Modeling System Documentation, Electricity Market Module, March 2006, p. 85.

Notes: EIA = Energy Information Administration; IOU = Investor Owned Utility; POU = Publicly Owned Utility; IPP = Independent Power Producer. For a summary of bond rating criteria see [http://www.bondsonline.com/Bond_Ratings_Definitions.php]. "High yield" refers to bonds with a rating below Baa.

Table A-2. Base Case Fuel and Allowance Price Forecasts

	Delivered Fuel Prices, Constant 2008$ per Million Btus			Air Emission Allowance Price, 2008$ per Allowance	
	Coal	Natural Gas	Nuclear Fuel	Sulfur Dioxide	Nitrogen Oxides
2010	$1.93	$7.51	$0.58	$249	$2,636
2020	$1.80	$6.41	$0.67	$1,074	$3,252
2030	$1.87	$7.48	$0.67	$479	$3,360
2040	$1.96	$9.17	$0.65	$158	$3,180
2050	$2.06	$11.24	$0.63	$52	$3,009

Sources: Forecasts are from the assumptions to the Energy Information Administration's 2008 Annual Energy Outlook, which assumes implementation of current law and regulation. The original values in 2006 dollars were converted to 2008 dollars using the Global Insight forecast of the change in the implicit price deflator. The EIA forecasts are to 2030; the forecasts are extended to 2050 using the 2025 to 2030 growth rates. The sulfur dioxide and nitrogen oxides allowance forecasts are for the eastern region of the United States (allowance prices are expected to vary regionally under the Clean Air Interstate Rule).

Note: Btu = British thermal unit.

Table A-3. Power Plant Technology Assumptions

Energy Source	Technology	Overnight Construction Cost for Units Entering Service in 2015 (2008$ per Kilowatt)	Capacity (Megawatts)	Heat Rate for Units Entering Service in 2015 (Btu per kWh)	Variable O&M Cost (2008$ per Mwh)	Fixed O&M (2008$ per Megawatt)	Capacity Factor
Wind	Onshore	$1,900	50	Not Applicable	$0.00	$30,921	34%
Coal	Supercritical Pulverized Coal	$2,577	600	8,742	$4.46	$28,100	85%
Natural Gas	Combined Cycle	$1,186	400	6,506	$1.95	$11,936	70%
Nuclear	Generation III/III+	$3,682	1,350	10,400	$0.48	$69,279	90%

Sources: Heat rates, O&M costs, and nominal plant capacities are from the assumptions to EIA's 2007 and 2008 Annual Energy Outlooks. Capital cost estimates are based on a CRS review of public information on current projects. Capital costs and heat rates are adjusted based on the learning rates used by EIA in the Annual Energy Outlook. EIA costs are adjusted to 2008 dollars using Global Insight's forecast of the implicit price deflator. Capacity factor for coal plants is from Massachusetts Institute of Technology, *The Future of Coal*, 2007, p. 128. Natural gas plants are assumed to operate as baseload units with a capacity factor of 70%. Capacity factor for wind from California Energy Commission, "Comparative Costs of California Central Station Electricity Generation Technologies," December 2007, Appendix B, p. 67. Nuclear plant capacity factor reflects the recent industry average performance as reported in EIA, *Monthly Energy Review*, Table 8.1.

Notes: kWh = kilowatt-hour; Mwh = megawatt-hour.

Public Health Impacts of Wind Turbines

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Minnesota Department of Health
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In response to a request from:
Minnesota Department of Commerce
Office of Energy Security

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I. Introduction

In late February 2009 the Minnesota Department of Health (MDH) received a request from the Office of Energy Security (OES) in the Minnesota Department of Commerce, for a "white paper" evaluating possible health effects associated with low frequency vibrations and sound arising from large wind energy conversion systems (LWECS). The OES noted that there was a request for a Contested Case Hearing before the Minnesota Public Utilities Commission (PUC) on the proposed Bent Tree Wind Project in Freeborn County Minnesota; further, the OES had received a long comment letter from a citizen regarding a second project proposal, the Lakeswind Wind Power Plant in Clay, Becker and Ottertail Counties, Minnesota. This same commenter also wrote to the Commissioner of MDH to ask for an evaluation of health issues related to exposure to low frequency sound energy generated by wind turbines. The OES informed MDH that a white paper would have more general application and usefulness in guiding decision-making for future wind projects than a Contested Case Hearing on a particular project. (Note: A Contested Case Hearing is an evidentiary hearing before an Administrative Law Judge, and may be ordered by regulatory authorities, in this case the PUC, in order to make a determination on disputed issues of material fact. The OES advises the PUC on need and permitting issues related to large energy facilities.)

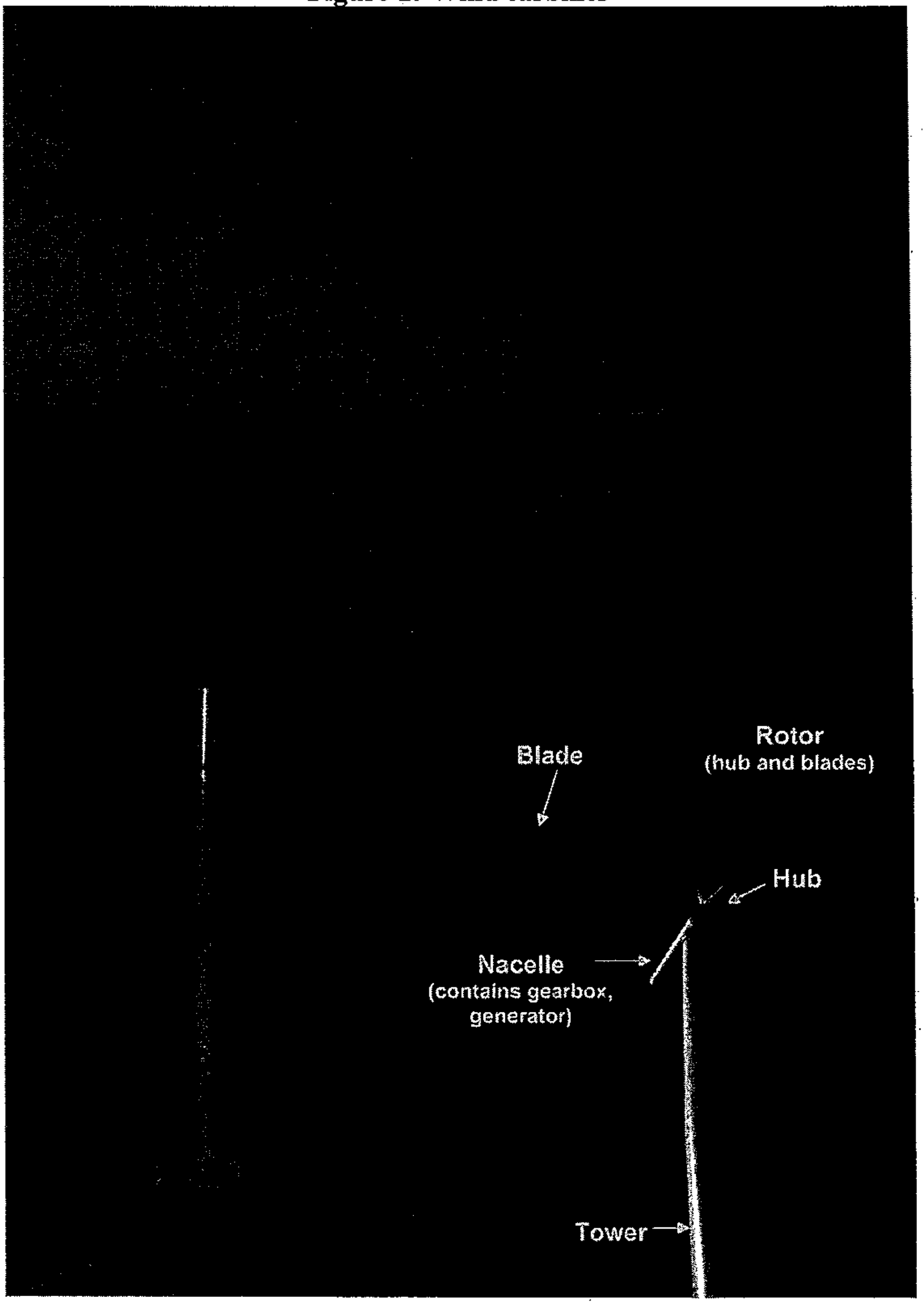
In early March 2009, MDH agreed to evaluate health impacts from wind turbine noise and low frequency vibrations. In discussion with OES, MDH also proposed to examine experiences and policies of other states and countries. MDH staff appeared at a hearing before the PUC on March 19, 2009, and explained the purpose and use of the health evaluation. The Commissioner replied to the citizen letter, affirming that MDH would perform the requested review.

A brief description of the two proposed wind power projects, and a brief discussion of health issues to be addressed in this report appear below.

A. Site Proposals

Wind turbines are huge and expensive machines requiring large capitol investment. Figure 1 shows some existing wind turbines in Minnesota. Large projects require control of extensive land area in order to optimize spacing of turbines to minimize turbulence at downwind turbines. Towers range up to 80 to 100 meters (260 to 325 feet), and blades can be up to 50 meters long (160 feet) (see Tetra Tech, 2008; WPL, 2008). Turbines are expected to be in place for 25-30 years.

Figure 1: Wind turbines



1. Bent Tree Wind Project in Freeborn County

This is a proposal by the Wisconsin Power and Light Company (WPL) for a 400 megawatt (MW) project in two phases of 200 MW each (requiring between 80 and 130 wind turbines). The cost of the first phase is estimated at $497 million. The project site area would occupy approximately 40 square miles located 4 miles north and west of the city of Albert Lea, approximately 95 miles south of Minneapolis (Figure 2) (WPL, 2008). The Project is a LWECS and a Certificate of Need (CON) from the PUC is required (*Minnesota Statutes 216B.243)*. The PUC uses the CON process to determine the basic type of facility (if any) to be constructed, the size of the facility, and when the project will be in service. The CON process involves a public hearing and preparation of an Environmental Report by the OES. The CON process generally takes a year, and is required before a facility can be permitted.

WPL is required to develop a site layout that optimizes wind resources. Accordingly, project developers are required to control areas at least 5 rotor diameters in the prevailing (north-south) wind directions (between about 1300 and 1700 feet for the 1.5 to 2.5 MW turbines under consideration for the project) and 3 rotor diameters in the crosswind (east-west) directions (between about 800 and 1000 feet). Thus, these are minimum setback distances from properties in the area for which easements have not been obtained. Further, noise rules promulgated by the Minnesota Pollution Control Agency (MPCA; *Minnesota Rules* Section 7030), specify a maximum nighttime noise in residential areas of 50 A-weighted decibels (dB(A). WPL has proposed a minimum setback of 1,000 feet from occupied structures in order to comply with the noise rule.

2. Noble Flat Hill Wind Park in Clay, Becker and Ottertail Counties

This is a LWECS proposed by Noble Flat Hill Windpark I (Noble), a subsidiary of Noble Environmental Power, based in Connecticut. The proposal is for a 201 MW project located 12 miles east of the City of Moorhead, about 230 miles northwest of Minneapolis (Figure 3) (Tetra Tech, 2008). The cost of the project is estimated to be between $382 million and $442 million. One hundred thirty-four GE 1.5 MW wind turbines are planned for an area of 11,000 acres (about 17 square miles); the site boundary encompasses approximately 20,000 acres. Setback distances of a minimum of 700 feet are planned to comply with the 50 dB(A) noise limit. However, rotor diameters will be 77 meters (250 feet). Therefore, setback distances in the prevailing wind direction of 1,300 feet are planned for properties where owners have not granted easements. Setbacks of 800 feet are planned in the crosswind direction.

Figure 2: Bent Tree Wind Project, Freeborn County

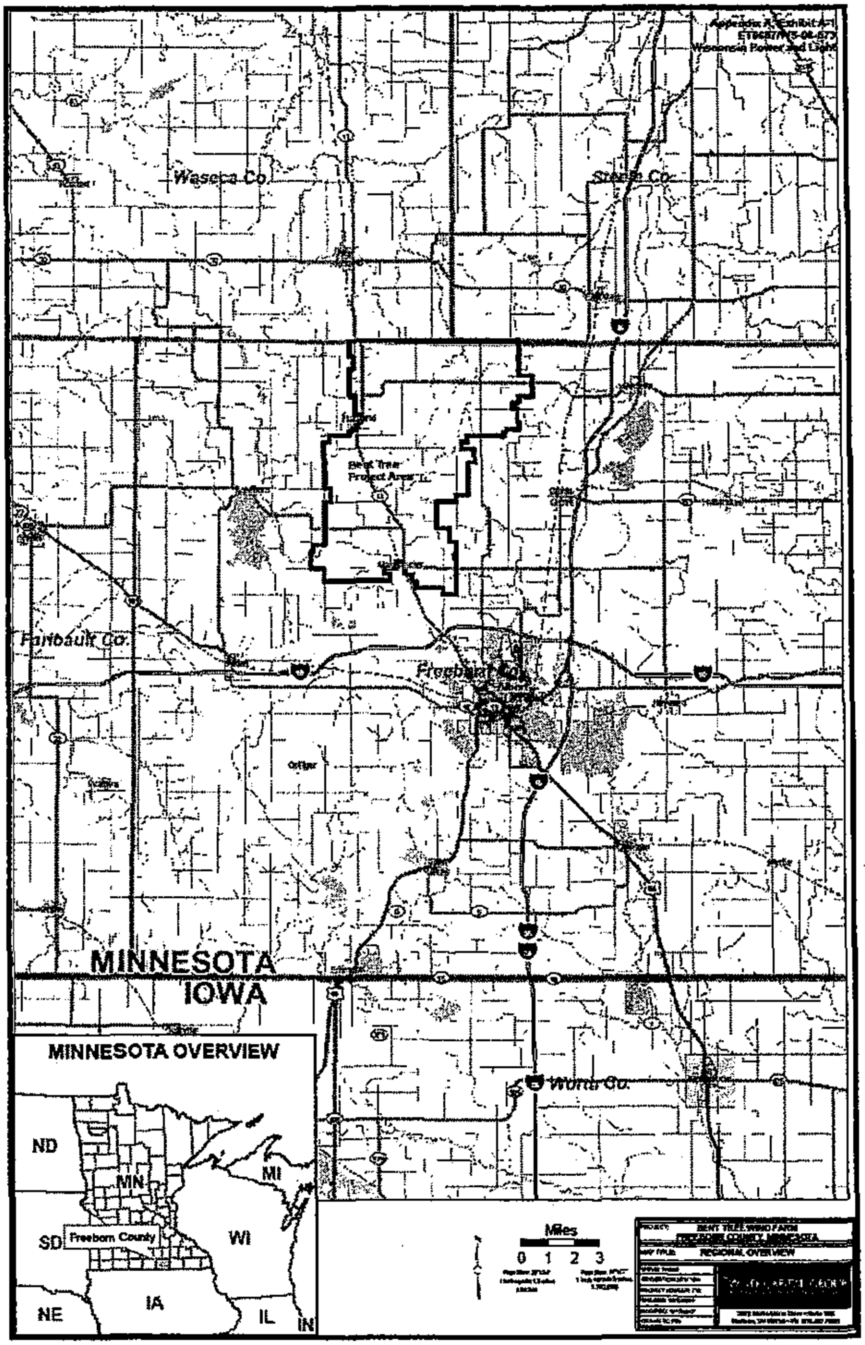
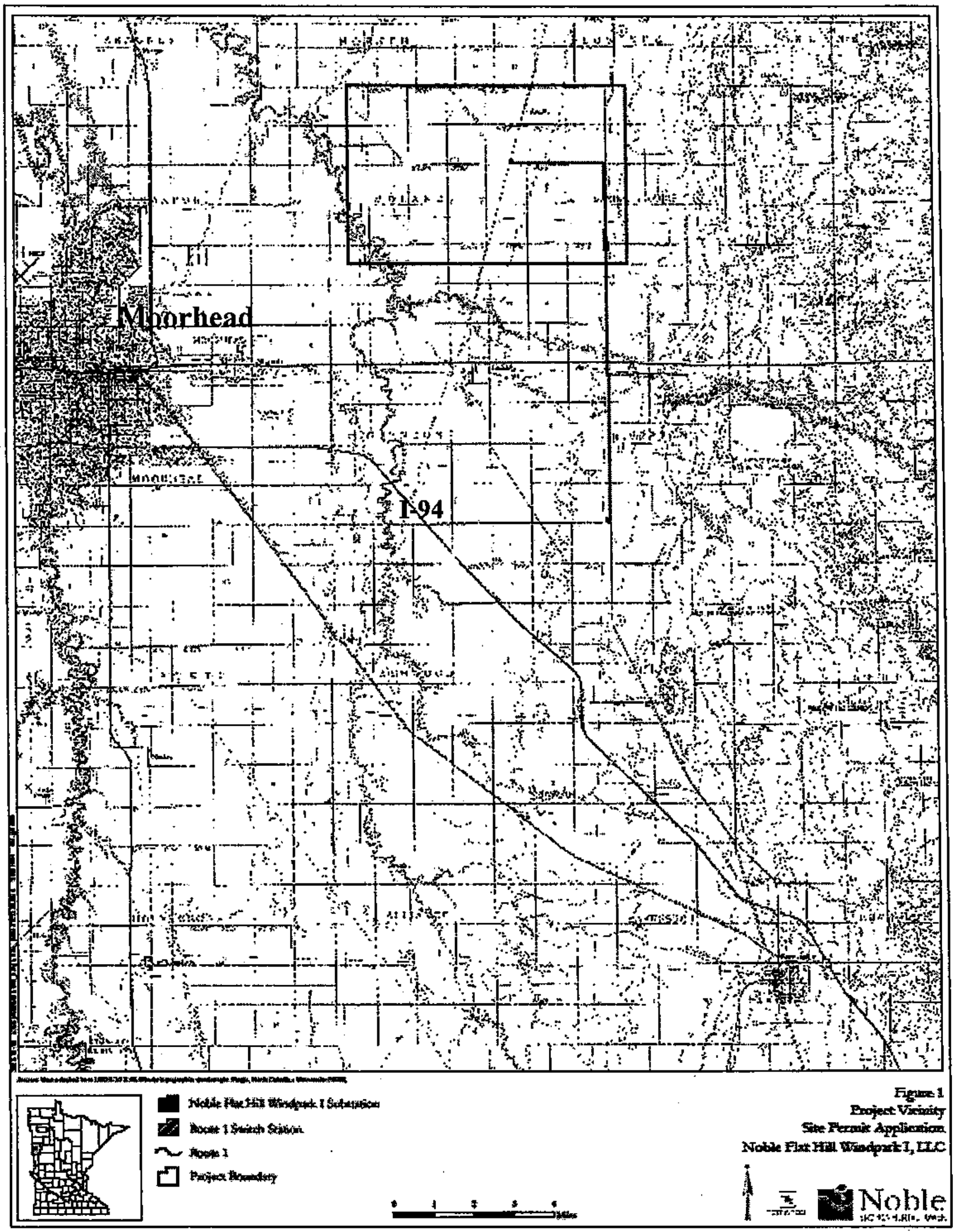


Figure 3: Noble Flat Hill Wind Park, Clay, Becker, Ottertail Counties



B. Health Issues

The National Research Council of the National Academies (NRC, 2007) has reviewed impacts of wind energy projects on human health and well-being. The NRC begins by observing that wind projects, just as other projects, create benefits and burdens, and that concern about impacts is natural when the source is near one's home. Further, the NRC notes that different people have different values and levels of sensitivity. Impacts noted by the NRC that may have the most effect on health include noise and low frequency vibration, and shadow flicker. While noise and vibration are the main focus of this paper, shadow flicker (casting of moving shadows on the ground as wind turbine blades rotate) will also be briefly discussed.

Noise originates from mechanical equipment inside the nacelles of the turbines (gears, generators, etc.) and from interaction of turbine blades with wind. Newer wind turbines generate minimal noise from mechanical equipment. The most problematic wind turbine noise is a broadband "whooshing" sound produced by interaction of turbine blades with the wind. Newer turbines have upwind rotor blades, minimizing low frequency "infrasound" (i.e., air pressure changes at frequencies below 20-100 Hz that are inaudible). However, the NRC notes that during quiet conditions at night, low frequency modulation of higher frequency sounds, such as are produced by turbine blades, is possible. The NRC also notes that effects of low frequency (infrasound) vibration (less than 20 Hz) on humans are not well understood, but have been asserted to disturb some people.

Finally, the NRC concludes that noise produced by wind turbines is generally not a major concern beyond a half mile. Issues raised by the NRC report and factors that may affect distances within which wind turbine noise may be problematic are discussed more extensively below.

II. Elementary Characteristics of Sensory Systems and Sound

A. Sensory Systems

1. Hearing

Sensory systems respond to a huge dynamic range of physical stimuli within a relatively narrow dynamic range of mechanical, chemical and/or neuronal (electrophysiological) output. Compression of the dynamic range is accomplished by systems that respond to logarithmic increases in intensity of physical stimuli with arithmetically increasing sensory responses. This general property is true for hearing, and has been recognized since at least the mid-19th century (see e.g., Woodworth and Schlosberg, 1964). "Loudness" is the sensory/perceptual correlate of the physical intensity of air pressure changes to which the electro-mechanical transducers in the ear and associated neuronal pathways are sensitive. Loudness increases as the logarithm of air pressure, and it is convenient to relate loudness to a reference air pressure (in dyne/cm^2 or pascals) in tenths of logarithmic units (decibels; dB). Further, the ear is sensitive to only a relatively narrow frequency range of air pressure changes: those between approximately 20 and 20,000 cycles per second or Herz (Hz). In fact, sensitivity varies within this range, so that the sound pressure level relative to a reference value that is audible in the middle of the range (near 1,000 Hz) is about 4 orders of magnitude smaller than it is at 20 Hz and about 2 orders of magnitude smaller than at 20,000 Hz (Fig. 3). Accordingly, measurements of loudness in dB generally employ filters to equalize the loudness of sounds at different frequencies or "pitch." To approximate the sensitivity of the ear, A-weighted filters weigh sound pressure changes at frequencies in the mid-range more than those at higher or lower frequencies. When an A-weighted filter is used, loudness is measured in dB(A). This is explained in greater detail in Section B below.

The ear accomplishes transduction of sound through a series of complex mechanisms (Guyton, 1991). Briefly, sound waves move the eardrum (tympanic membrane), which is in turn connected to 2 small bones (ossicles) in the middle ear (the malleus and incus). A muscle connected to the malleus keeps the tympanic membrane tensed, allowing efficient transmission to the malleus of vibrations on the membrane. Ossicle muscles can also relax tension and attenuate transmission. Relaxation of muscle tension on the tympanic membrane protects the ear from very loud sounds and also masks low frequency sounds, or much background noise. The malleus and incus move a third bone (stapes). The stapes in turn applies pressure to the fluid of the cochlea, a snail-shaped structure imbedded in temporal bone. The cochlea is a complex structure, but for present purposes it is sufficient to note that pressure changes or waves of different frequencies in cochlear fluid result in bending of specialized hair cells in regions of the cochlea most sensitive to different frequencies or pitch. Hair cells are directly connected to nerve fibers in the vestibulocochlear nerve (VIII cranial nerve).

Transmission of sound can also occur directly through bone to the cochlea. This is a very inefficient means of sound transmission, unless a device (e.g. a tuning fork or hearing aid) is directly applied to bone (Guyton, 1991).

2. Vestibular System

The vestibular system reacts to changes in head and body orientation in space, and is necessary for maintenance of equilibrium and postural reflexes, for performance of rapid and intricate body movements, and for stabilizing visual images (via the vestibulo-ocular reflex) as the direction of movement changes (Guyton, 1991).

The vestibular apparatus, like the cochlea, is imbedded in temporal bone, and also like the cochlea, hair cells, bathed in vestibular gels, react to pressure changes and transmit signals to nerve fibers in the vestibulocochlear nerve. Two organs, the utricle and saccule, called otolith organs, integrate information about the orientation of the head with respect to gravity. Otoliths are tiny stone-like crystals, embedded in the gels of the utricle and saccule, that float as the head changes position within the gravitational field. This movement is translated to hair cells. Three semi-circular canals, oriented at right angles to each other, detect head rotation. Stimulation of the vestibular apparatus is not directly detected, but results in activation of motor reflexes as noted above (Guyton, 1991).

Like the cochlea, the vestibular apparatus reacts to pressure changes at a range of frequencies; optimal frequencies are lower than for hearing. These pressure changes can be caused by body movements, or by direct bone conduction (as for hearing, above) when vibration is applied directly to the temporal bone (Todd et al., 2008). These investigators found maximal sensitivity at 100 Hz, with some sensitivity down to 12.5 Hz. The saccule, located in temporal bone just under the footplate of the stapes, is the most sound-sensitive of the vestibular organs (Halmagyi et al., 2004). It is known that brief loud clicks (90-95 dB) are detected by the vestibular system, even in deaf people. However, we do not know what the sensitivity of this system is through the entire range of sound stimuli.

While vestibular system activation is not directly felt, activation may give rise to a variety of sensations: vertigo, as the eye muscles make compensatory adjustments to rapid angular motion, and a variety of unpleasant sensations related to internal organs. In fact, the vestibular system interacts extensively with the "autonomic" nervous system, which regulates internal body organs (Balaban and Yates, 2004). Sensations and effects correlated with intense vestibular activation include nausea and vomiting and cardiac arrhythmia, blood pressure changes and breathing changes.

While these effects are induced by relatively intense stimulation, it is also true that A-weighted sound measurements attuned to auditory sensitivity, will underweight low frequencies for which the vestibular system is much more sensitive (Todd et al., 2008). Nevertheless, activation of the vestibular system *per se* obviously need not give rise to unpleasant sensations. It is not known what stimulus intensities are generally required for for autonomic activation at relatively low frequencies, and it is likely that there is considerable human variability and capacity to adapt to vestibular challenges.

B. Sound

1. Introduction

Sound is carried through air in compression waves of measurable frequency and amplitude. Sound can be tonal, predominating at a few frequencies, or it can contain a random mix of a broad range of frequencies and lack any tonal quality (white noise). Sound that is unwanted is called noise.

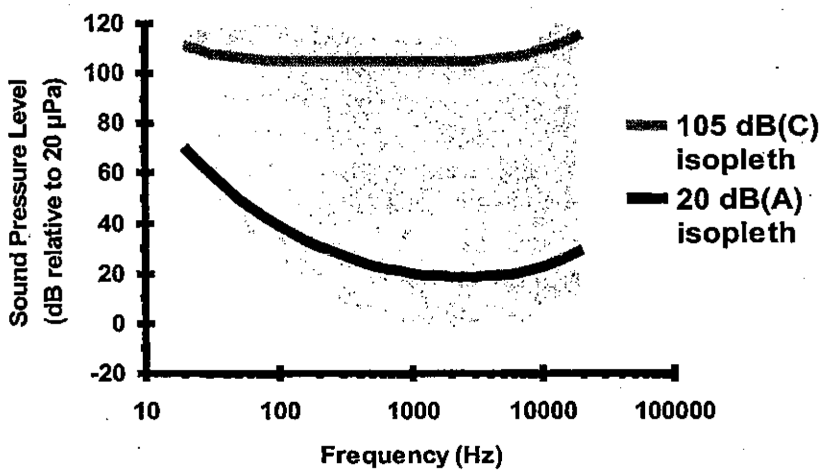
Audible Frequency Sound

Besides frequency sensitivity (between 20 and 20,000 Hz), humans are also sensitive to changes in the amplitude of the signal (compression waves) within this audible range of frequencies. Increasing amplitude, or increasing sound pressure, is perceived as increasing volume or loudness. The sound pressure level in air (SPL) is measured in micro Pascals (μPa). SPLs are typically converted in measuring instruments and reported as decibels (dB) which is a log scale, relative unit (see above). When used as the unit for sound, dBs are reported relative to a SPL of 20 μPa. Twenty μPa is used because it is the approximate threshold of human hearing sensitivity at about 1000 Hz. Decibels relative to 20 μPa are calculated from the following equation:

$$\text{Loudness (dB)} = \text{Log}\left((\text{SPL} / 20\ \mu\text{Pa})^2\right) * 10$$

Figure 4 shows the audible range of normal human hearing. Note that while the threshold sensitivity varies over the frequency range, at high SPLs sensitivity is relatively consistent over audible frequencies.

Figure 4: Audible Range of Human Hearing



Equivalence curves for different frequencies, when sound meter readings in dB are taken with A or C-weighting filters. (Adapted from EPD Hong Kong SAR, 2009)

Sub-Audible Frequency Sound

Sub-audible frequency sound is often called infrasound. It may be sensed by people, similar to audible sound, in the cochlear apparatus in the ear; it may be sensed by the vestibular system which is responsible for balance and physical equilibrium; or it may be sensed as vibration.

Resonance and modulation

Sound can be attenuated as it passes through a physical structure. However, because the wavelength of low frequency sound is very long (the wavelength of 40 Hz in air at sea level and room temperature is 8.6 meters or 28 ft), low frequencies are not effectively attenuated by walls and windows of most homes or vehicles. (For example, one can typically hear the bass, low frequency music from a neighboring car at a stoplight, but not the higher frequencies.) In fact, it is possible that there are rooms within buildings exposed to low frequency sound or noise where some frequencies may be amplified by resonance (e.g. ½ wavelength, ¼ wavelength) within the structure. In addition, low frequency sound can cause vibrations within a building at higher, more audible frequencies as well as throbbing or rumbling.

Sounds that we hear generally are a mixture of different frequencies. In most instances these frequencies are added together. However, if the source of the sound is not constant, but changes over time, the effect can be re-occurring pulses of sound or low frequency modulation of sound. This is the type of sound that occurs from a steam engine, a jack hammer, music and motor vehicle traffic. Rhythmic, low frequency pulsing of higher frequency noise (like the sound of an amplified heart beat) is one type of sound that can be caused by wind turbine blades under some conditions.

2. Human Response to Low Frequency Stimulation

There is no consensus whether sensitivity below 20 Hz is by a similar or different mechanism than sensitivity and hearing above 20 Hz (Reviewed by Møller and Pedersen, 2004). Possible mechanisms of sensation caused by low frequencies include bone conduction at the applied frequencies, as well as amplification of the base frequency and/or harmonics by the auditory apparatus (eardrum and ossicles) in the ear. Sensory thresholds are relatively continuous, suggesting (but not proving) a similar mechanism above and below 20 Hz. However, it is clear that cochlear sensitivity to infrasound (< 20 Hz) is considerably less than cochlear sensitivity to audible frequencies.

Møller and Pedersen (2004) reviewed human sensitivity at low and infrasonic frequencies. The following findings are of interest:

- When whole-body pressure-field sensitivity is compared with ear-only (earphone) sensitivity, the results are very similar. These data suggest that the threshold sensitivity for low frequency is through the ear and not vestibular.
- Some individuals have extraordinary sensitivity at low frequencies, up to 25 dB more sensitive than the presumed thresholds at some low frequencies.
- While population average sensitivity over the low frequency range is smooth, sound pressure thresholds of response for individuals do not vary smoothly but are inconsistent, with peaks and valleys or "microstructures". Therefore the sensitivity response of individuals to different low frequency stimulation may be difficult to predict.
- Studies of equal-loudness-levels demonstrate that as stimulus frequency decreases through the low frequencies, equal-loudness lines compress in the dB scale. (See Figure 4 as an example of the relatively small difference in auditory SPL range between soft and loud sound at low frequencies).
- The hearing threshold for pure tones is different than the hearing threshold for white noise at the same total sound pressure.

3. Sound Measurements

Sound measurements are taken by instruments that record sound pressure or the pressure of the compression wave in the air. Because the loudness of a sound to people is usually the primary interest in measuring sound, normalization schemes or filters have been applied to absolute measurements. dB(A) scaling of sound pressure measurements was intended to normalize readings to equal loudness over the audible range of frequencies at low loudness. For example, a 5,000 Hz (5 kHz) and 20 dB(A) tone is expected to have the same intensity or loudness as a 100 Hz, 20 dB(A) tone. However, note that the absolute sound pressures would be about 200 μPa and 2000 μPa, respectively, or about a difference of 20 dB (relative to 20 μPa), or as it is sometimes written 20 dB(linear).

Most sound is not a single tone, but is a mixture of frequencies within the audible range. A sound meter can add the total SPLs for all frequencies; in other words, the dB readings over the entire spectrum of audible sound can be added to give a single loudness metric. If sound is reported as A-weighted, or dB(A), it is a summation of the dB(A) scaled sound pressure from 20 Hz to 20 kHz.

In conjunction with the dB(A) scale, the dB(B) scale was developed to approximate equal loudness to people across audible frequencies at medium loudness, and dB(C) was developed to approximate equal-loudness for loud environments. Figure 4 shows isopleths for 20 dB(A) and 105 dB(C). While dB(A), dB(B), dB(C) were developed from empirical data at the middle frequencies, at the ends of the curves these scales were extrapolated, or sketched in, and are not based on experimental or observational data (Berglund et al., 1996). As a result, data in the low frequency range (and probably the highest audible frequencies as well) cannot be reliably interpreted using these scales. The World Health Organization (WHO, 1999) suggests that A-weighting noise that has a large low frequency component is not reliable assessment of loudness.

The source of the noise, or the noise signature, may be important in developing equal-loudness schemes at low frequencies. C-weighting has been recommended for artillery noise, but a linear, unweighted scale may be even better at predicting a reaction (Berglund et al., 1996). A linear or equal energy rating also appears to be the most effective predictor of reaction to low frequency noise in other situations, including blast noise from mining. The implication of the analysis presented by Berglund et al. (1996) is that annoyance from non-tonal noise should not be estimated from a dB(A) scale, but may be better evaluated using dB(C), or a linear non-transformed scale.

However, as will be discussed below, a number of schemes use a modified dB(A) scale to evaluate low frequency noise. These schemes differ from a typical use of the dB(A) scale by addressing a limited frequency range below 250 Hz, where auditory sensitivity is rapidly changing as a function of frequency (see Figure 4).

III. Exposures of Interest

A. Noise From Wind Turbines

1. Mechanical noise

Mechanical noise from a wind turbine is sound that originates in the generator, gearbox, yaw motors (that intermittently turn the nacelle and blades to face the wind), tower ventilation system and transformer. Generally, these sounds are controlled in newer wind turbines so that they are a fraction of the aerodynamic noise. Mechanical noise from the turbine or gearbox should only be heard above aerodynamic noise when they are not functioning properly.

2. Aerodynamic noise

Aerodynamic noise is caused by wind passing over the blade of the wind turbine. The tip of a 40-50 meter blade travels at speeds of over 140 miles per hour under normal operating conditions. As the wind passes over the moving blade, the blade interrupts the laminar flow of air, causing turbulence and noise. Current blade designs minimize the amount of turbulence and noise caused by wind, but it is not possible to eliminate turbulence or noise.

Aerodynamic noise from a wind turbine may be underestimated during planning. One source of error is that most meteorological wind speed measurements noted in wind farm literature are taken at 10 meters above the ground. Wind speed above this elevation, in the area of the wind turbine rotor, is then calculated using established modeling relationships. In one study (van den Berg, 2004) it was determined that the wind speeds at the hub at night were up to 2.6 times higher than modeled. Subsequently, it was found that noise levels were 15 dB higher than anticipated.

Unexpectedly high aerodynamic noise can also be caused by improper blade angle or improper alignment of the rotor to the wind. These are correctable and are usually adjusted during the turbine break-in period.

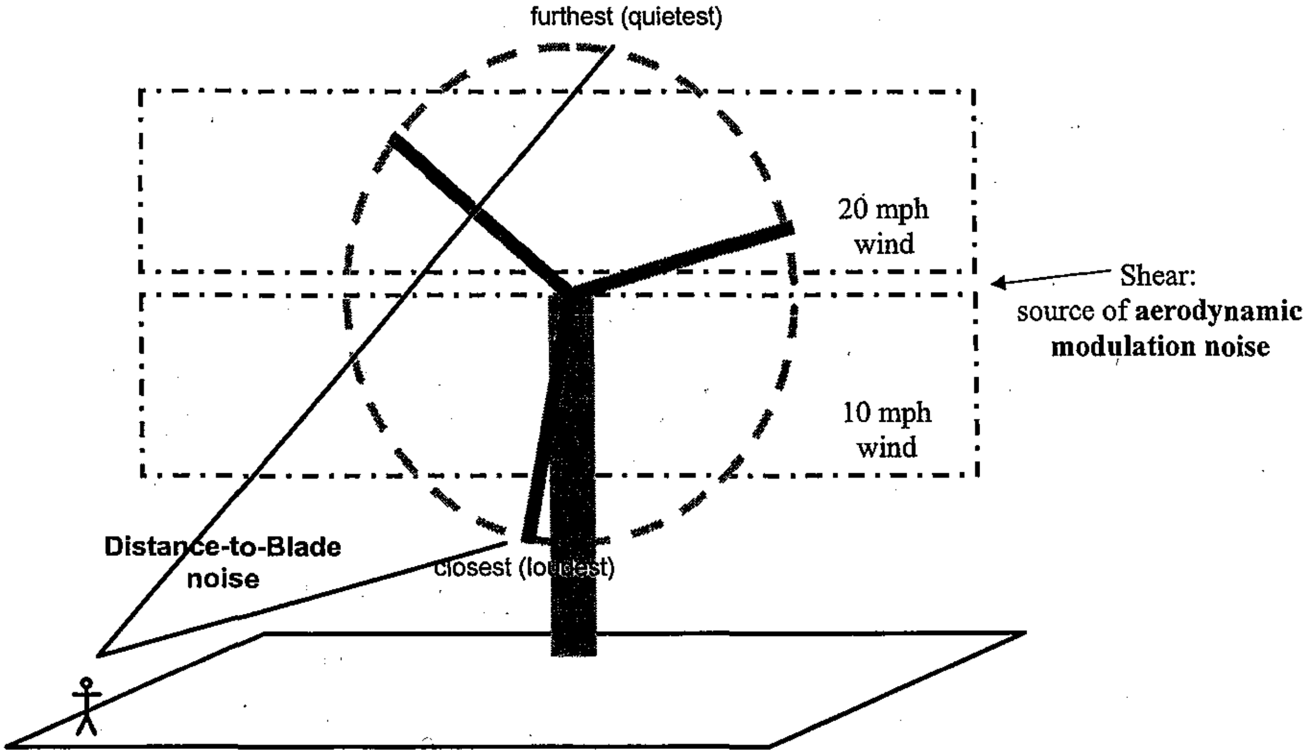
3. Modulation of aerodynamic noise

Rhythmic modulation of noise, especially low frequency noise, has been found to be more annoying than steady noise (Bradley, 1994; Holmberg et al., 1997). One form of rhythmic modulation of aerodynamic noise that can be noticeable very near to a wind turbine is a distance-to-blade effect. To a receptor on the ground in front of the wind turbine, the detected blade noise is loudest as the blade passes, and quietest when the blade is at the top of its rotation. For a modern 3-blade turbine, this distance-to-blade effect can cause a pulsing of the blade noise at about once per second (1 Hz). On the ground, about 500 feet directly downwind from the turbine, the distance-to-blade can cause a difference in sound pressure of about 2 dB between the *tip* of the blade at its farthest point and the *tip* of the blade at its nearest point (48 meter blades, 70 meter tower). Figure 5 demonstrates why the loudness of blade noise (aerodynamic noise) pulses as the distance-to-blade varies for individuals close to a turbine.

If the receptor is 500 feet from the turbine base, in line with the blade rotation or up to 60° off line, the difference in sound pressure from the *tip* of the blade at its farthest and nearest point can be about 4-5 dB, an audible difference. The tip travels faster than the rest of the blade and is closer to (and then farther away from) the receptor than other parts of the blade. As a result, noise from other parts of the blade will be modulated less than noise from the tip. Further, blade design can also affect the noise signature of a blade. The distance-to-blade effect diminishes as receptor distance increases because the relative difference in distance from the receptor to the top or to the bottom of the blade becomes smaller. Thus, moving away from the tower, distance-to-blade noise gradually appears to be more steady.

Another source of rhythmic modulation may occur if the wind through the rotor is not uniform. Blade angle, or pitch, is adjusted for different wind speeds to maximize power and to minimize noise. A blade angle that is not properly tuned to the wind speed (or wind direction) will make more noise than a properly tuned blade. Horizontal layers with different wind speeds or directions can form in the atmosphere. This wind condition is called shear. If the winds at the top and bottom of the blade rotation are different, blade noise will vary between the top and bottom of blade rotation, causing modulation of aerodynamic noise. This noise, associated with the blades passing through areas of different air-wind speeds, has been called aerodynamic modulation and is demonstrated in Figure 5.

Figure 5: Sources of noise modulation or pulsing



In some terrains and under some atmospheric conditions wind aloft, near the top of the wind turbine, can be moving faster than wind near the ground. Wind turbulence or even wakes from adjacent turbines can create non-uniform wind conditions as well. As a result of aerodynamic modulation a rhythmic noise pattern or pulsing will occur as each blade passes through areas with different wind speed. Furthermore, additional noise, or thumping, may occur as each blade passes through the transition between different wind speed (or wind direction) areas.

Wind shear caused by terrain or structures on the ground (e.g. trees, buildings) can be modeled relatively easily. Wind shear in areas of flat terrain is not as easily understood. During the daytime wind in the lower atmosphere is strongly affected by thermal convection which causes mixing of layers. Distinct layers do not easily form. However, in the nighttime the atmosphere can stabilize (vertically), and layers form. A paper by G.P. van den Berg (2008) included data from a study on wind shear at Cabauw, The Netherlands (flat terrain). Annual average wind speeds at different elevations above ground was reported. The annual average wind speed at noon was about 5.75 meters per second (m/s; approximately 12.9 miles per hour(mph)) at 20 m above ground, and about 7.6 m/s (17 mph) at 140 m. At midnight, the annual averages were about 4.3 m/s (9.6 mph) and 8.8 m/s (19.7 mph) for 20m and 140 m, respectively, above ground. The data show that while the average windspeed (between 20m and 140m) is very similar at noon and midnight at Cabauw, the windspeed difference between elevations during the day is much less than the difference at night (1.85 m/s (4.1 mph) and 4.5 m/s (10 mph), respectively). As a result one would expect that the blade angle can be better tuned to the wind speed during the daytime. Consequently, blade noise would be greater at night.

A number of reports have included discussion of aerodynamic modulation (van den Berg, 2005; UK Department of Transport and Industry, 2006; UK Department for Business Enterprise and Regulatory Reform, 2007; van den Berg, 2008). They suggest that aerodynamic modulation is typically underestimated when noise estimates are calculated. In addition, they suggest that detailed modeling of wind, terrain, land use and structures may be used to predict whether modulation of aerodynamic noise will be a problem at a proposed wind turbine site.

4. Wind farm noise

The noise from multiple turbines similarly distant from a residence can be noticeably louder than a lone turbine simply through the addition of multiple noise sources. Under steady wind conditions noise from a wind turbine farm may be greater than noise from the nearest turbine due to synchrony between noise from more than one turbine (van den Berg, 2005). Furthermore, if the dominant frequencies (including aerodynamic modulation) of different turbines vary by small amounts, an audible beat or dissonance may be heard when wind conditions are stable.

B. Shadow Flicker

Rhythmic light flicker from the blades of a wind turbine casting intermittent shadows has been reported to be annoying in many locations (NRC, 2007; Large Wind Turbine Citizens Committee, 2008). (Note: Flashing light at frequencies around 1 Hz is too slow to trigger an epileptic response.)

Modeling conducted by the Minnesota Department of Health suggests that a receptor 300 meters perpendicular to, and in the shadow of the blades of a wind turbine, can be in the flicker shadow of the rotating blade for almost 1½ hour a day. At this distance a blade may completely obscure the sun each time it passes between the receptor and the sun. With current wind turbine designs, flicker should not be an issue at distances over 10 rotational diameters (~1000 meters or 1 km (0.6 mi) for most current wind turbines). This distance has been recommended by the Wind Energy Handbook (Burton et al., 2001) as a minimum setback distance in directions that flicker may occur, and has been noted in the Bent Tree Permit Application (WPL, 2008).

Shadow flicker is a potential issue in the mornings and evenings, when turbine noise may be masked by ambient sounds. While low frequency noise is typically an issue indoors, shadow flicker can be an issue both indoors and outdoors when the sun is low in the sky. Therefore, shadow flicker may be an issue in locations other than the home.

Ireland recommends wind turbines setbacks of at least 300 meters from a road to decrease driver distraction (Michigan State University, 2004). The NRC (2007) recommends that shadow flicker is addressed during the preliminary planning stages of a wind turbine project.

IV. Impacts of Wind Turbine Noise

A. Potential Adverse Reaction to Sound

Human sensitivity to sound, especially to low frequency sound, is variable. Individuals have different ranges of frequency sensitivity to audible sound; different thresholds for each frequency of audible sound; different vestibular sensitivities and reactions to vestibular activation; and different sensitivity to vibration.

Further, sounds, such as repetitive but low intensity noise, can evoke different responses from individuals. People will exhibit variable levels of annoyance and tolerance for different frequencies. Some people can dismiss and ignore the signal, while for others, the signal will grow and become more apparent and unpleasant over time (Moreira and Bryan, 1972; Bryan and Tempest, 1973). These reactions may have little relationship to will or intent, and more to do with previous exposure history and personality.

Stress and annoyance from noise often do not correlate with loudness. This may suggest, in some circumstances, other factors impact an individual's reaction to noise. A number of reports, cited in Staples (1997), suggest that individuals with an interest in a project and individuals who have some control over an environmental noise are less likely to find a noise annoying or stressful.

Berglund et al. (1996) reviewed reported health effects from low frequency noise. Loud noise from any source can interfere with verbal communication and possibly with the development of language skills. Noise may also impact mental health. However, there are no studies that have looked specifically at the impact of low frequency noise on communication, development of language skills and mental health. Cardiovascular and endocrine effects have been demonstrated in studies that have looked at exposures to airplane and highway noise. In addition, possible effects of noise on performance and cognition have also been investigated, but these health studies have not generally looked at impacts specifically from low frequency noise. Noise has also been shown to impact sleep and sleep patterns, and one study demonstrated impacts from low frequency noise in the range of 72 to 85 dB(A) on chronic insomnia (Nagai et al., 1989 as reported in Berglund et al., 1996).

Case studies have suggested that health can be impacted by relatively low levels of low frequency noise. But it is difficult to draw general conclusions from case studies. Feldmann and Pitten (2004)) describe a family exposed during the winter to low frequency noise from a nearby heating plant. Reported health impacts were: "indisposition, decrease in performance, sleep disturbance, headache, ear pressure, crawl parästhesy [crawling, tingling or numbness sensation on the skin] or shortness of breath."

Annoyance, unpleasant sounds, and complaints

Reported health effects from low frequency stimulation are closely associated with annoyance from audible noise. "There is no reliable evidence that infrasounds below the hearing threshold produce physiological or psychological effects" (WHO, 1999). It has not been shown whether annoyance is a symptom or an accessory in the causation of health impacts from low frequency noise. Studies have been conducted on some aspects of low frequency noise that can cause annoyance.

Noise complaints are usually a reasonable measure of annoyance with low frequency environmental noise. Leventhall (2004) has reviewed noise complaints and offers the following conclusions:

> " The problems arose in quiet rural or suburban environments
> The noise was often close to inaudibility and heard by a minority of people
> The noise was typically audible indoors and not outdoors
> The noise was more audible at night than day
> The noise had a throb or rumble characteristic
> The main complaints came from the 55-70 years age group
> The complainants had normal hearing.
> Medical examination excluded tinnitus.
>
> " These are now recognised as classic descriptors of low frequency noise problems."

These observations are consistent with what we know about the propagation of low intensity, low frequency noise. Some people are more sensitive to low frequency noise. The difference, in dB, between soft (acceptable) and loud (annoying) noise is much less at low frequency (see Figure 4 audible range compression). Furthermore, during the daytime, and especially outdoors, annoying low frequency noise can be masked by high frequency noise.

The observation that "the noise was typically audible indoors and not outdoors" is not particularly intuitive. However, as noted in a previous section, low frequencies are not well attenuated when they pass through walls and windows. Higher frequencies (especially above 1000 Hz) can be efficiently attenuated by walls and windows. In addition, low frequency sounds may be amplified by resonance within rooms and halls of a building. Resonance is often characterized by a throbbing or a rumbling, which has also been associated with many low frequency noise complaints.

Low frequency noise, unlike higher frequency noise, can also be accompanied by shaking, vibration and rattling. In addition, throbbing and rumbling may be apparent in some low frequency noise. While these noise features may not be easily characterized, numerous studies have shown that their presence dramatically lowers tolerance for low frequency noise (Berglund et al., 1996).

As reviewed in Leventhall (2003), a study of industrial exposure to low frequency noise found that fluctuations in total noise averaged over 0.5, 1.0 and 2.0 seconds correlated with annoyance (Holmberg et al., 1997). This association was noted elsewhere and led (Broner and Leventhall, 1983) to propose a 3dB "penalty" be added to evaluations of annoyance in cases where low frequency noise fluctuated.

In another laboratory study with test subjects controlling loudness, 0.5 – 4 Hz modulation of low frequency noise was found to be more annoying than non-modulated low frequency noise. On average test subjects found modulated noise to be similarly annoying as a constant tone 12.9 dB louder (Bradley, 1994).

B. Studies of Wind Turbine Noise Impacts on People

1. Swedish Studies

Two studies in Sweden collected information by questionnaires from 341 and 754 individuals (representing response rates of 68% and 58%, respectively), and correlated responses to calculated exposure to noise from wind farms (Pedersen and Waye, 2004; Pedersen, 2007; Pedersen and Persson, 2007). Both studies showed that the number of respondents perceiving the noise from the wind turbines increased as the calculated noise levels at their homes increased from less than 32.5 dB(A) to greater than 40 dB(A). Annoyance appeared to correlate or trend with calculated noise levels. Combining the data from the two studies, when noise measurements were greater than 40 dB(A), about 50% of the people surveyed (22 of 45 people) reported annoyance. When noise measurements were between 35 and 40 dB(A) about 24% reported annoyance (67 of 276 people). Noise annoyance was more likely in areas that were rated as quiet and in areas where turbines were visible. In one of the studies, 64% respondents who reported noise annoyance also reported sleep disturbance; 15% of respondents reported sleep disturbance without annoyance.

2. United Kingdom Study

Moorhouse et al. (UK Department for Business Enterprise and Regulatory Reform, 2007) evaluated complaints about wind farms. They found that 27 of 133 operating wind farms in the UK received formal complaints between 1991 and 2007. There were a total of 53 complainants for 16 of the sites for which good records were available. The authors of the report considered that many complaints in the early years were for generator and gearbox noise. However, subjective analyses of reports about noise ("like a train that never gets there", "distant helicopter", "thumping", "thudding", "pulsating", "thumping", "rhythmical beating", and "beating") suggested that aerodynamic modulation was the likely cause of complaints at 4 wind farms. The complaints from 8 other wind farms may have had "marginal" association with aerodynamic modulation noise.

Four wind farms that generated complaints possibly associated with aerodynamic modulation were evaluated further. These wind farms were commissioned between 1999 and 2002. Wind direction, speed and times of complaints were associated for 2 of the sites and suggested that aerodynamic modulation noise may be a problem between 7% and 25% of the time. Complaints at 2 of the farms have stopped and at one farm steps to mitigate aerodynamic modulation (operational shutdown under certain meteorological conditions) have been instituted.

3. Netherlands Study

F. van den Berg et al. (2008) conducted a postal survey of a group selected from all residents in the Netherlands within 2.5 kilometers (km) of a wind turbine. In all, 725 residents responded (37%). Respondents were exposed to sound between 24 and 54 dB(A). The percentage of respondents annoyed by sound increased from 2% at levels of 30 dB(A) or less, up to 25% at between 40 and 45 dB. Annoyance decreased above 45 dB. Most residents exposed above 45 dB(A) reported economic benefits from the turbines. However, at greater than 45 dB(A) more respondents reported sleep interruption. Respondents tended to report more annoyance when they also noted a negative effect on landscape, and ability to see the turbines was strongly related to the probability of annoyance.

4. Case Reports

A number of un-reviewed reports have catalogued complaints of annoyance and some more severe health impacts associated with wind farms. These reports do not contain measurements of noise levels, and do not represent random samples of people living near wind turbines, so they cannot assess prevalence of complaints. They do generally show that in the people surveyed, complaints are more likely the closer people are to the turbines. The most common complaint is decreased quality of life, followed by sleep loss and headache. Complaints seem to be either from individuals with homes quite close to turbines, or individuals who live in areas subject to aerodynamic modulation and, possibly, enhanced sound propagation which can occur in hilly or mountainous terrain. In some of the cases described, people with noise complaints also mention aesthetic issues, concern for ecological effects, and shadow flicker concerns. Not all complaints are primarily about health.

Harry (2007) describes a meeting with a couple in Cornwall, U.K. who live 400 meters from a wind turbine, and complained of poor sleep, headaches, stress and anxiety. Harry subsequently investigated 42 people in various locations in the U.K. living between 300 meters and 2 kilometers (1000 feet to 1.2 miles) from the nearest wind turbine. The most frequent complaint (39 of 42 people) was that their quality of life was affected. Headaches were reported by 27 people and sleep disturbance by 28 people. Some people complained of palpitations, migraines, tinnitus, anxiety and depression. She also mentions correspondence and complaints from people in New Zealand, Australia, France, Germany, Netherlands and the U.S.

Phipps (2007) discusses a survey of 619 households living up to 10 kilometers (km; 6 miles) from wind farms in mountainous areas of New Zealand. Most respondents lived between 2 and 2.5 km from the turbines (over 350 households). Most respondents (519) said they could see the turbines from their homes, and 80% of these considered the turbines intrusive, and 73% considered them unattractive. Nine percent said they were affected by flicker. Over 50% of households located between 2 and 2.5 km and between 5 and 9.5 km reported being able to hear the turbines. In contrast, fewer people living between 3 and 4.5 km away could hear the turbines. Ninety-two households said that their quality of life was affected by turbine noise. Sixty-eight households reported sleep disturbances: 42 of the households reported occasional sleep disturbances, 21 reported frequent sleep disturbances and 5 reported sleep disturbances most of the time.

The Large Wind Turbine Citizens Committee for the Town of Union (2008) documents complaints from people living near wind turbines in Wisconsin communities and other places in the U.S. and U.K. Contained in this report is an older report prepared by the Wisconsin Public Service Corporation in 2001 in response to complaints in Lincoln County, Wisconsin. The report found essentially no exceedances of the 50 dB(A) requirement in the conditional use permit. The report did measure spectral data accumulated over very short intervals (1 minute) in 1/3 octave bands at several sites while the wind turbines were functioning, and it is of interest that at these sites the sound pressure level at the lower frequencies (below 125 Hz) were at or near 50 dB(A).

Pierpont (2009) postulates wind turbine syndrome, consisting of a constellation of symptoms including headache, tinnitus, ear pressure, vertigo, nausea, visual blurring, tachycardia, irritability, cognitive problems and panic episodes associated with sensations of internal pulsation. She studied 38 people in 10 families living between 1000 feet and slightly under 1 mile from newer wind turbines. She proposes that the mechanism for these effects is disturbance of balance due to "discordant" stimulation of the vestibular system, along with visceral sensations, sensations of vibration in the chest and other locations in the body, and stimulation of the visual system by moving shadows. Pierpont does report that her study subjects maintain that their problems are caused by noise and vibration, and the most common symptoms reported are sleep disturbances and headache. However, 16 of the people she studied report symptoms consistent with (but not necessarily caused by) disturbance of equilibrium.

V. Noise Assessment and Regulation

1. Minnesota noise regulation

The Minnesota Noise Pollution Control Rule is accessible online at: https://www.revisor.leg.state.mn.us/rules/?id=7030 . A summary of the Minnesota Pollution Control Agency (MPCA) noise guidance can be found online at: http://www.pca.state.mn.us/programs/noise.html . The MPCA standards require A-weighting measurements of noise; background noise must be at least 10 dB lower than the noise source being measured. Different standards are specified for day and night, as well as standards that may not be exceeded for more than 10 percent of the time during any hour (L10) and 50 percent of the time during any hour (L50). Household units, including farm houses, are Classification 1 land use. The following are the Class 1 noise limits:

Table 1: Minnesota Class 1 Land Use Noise Limits

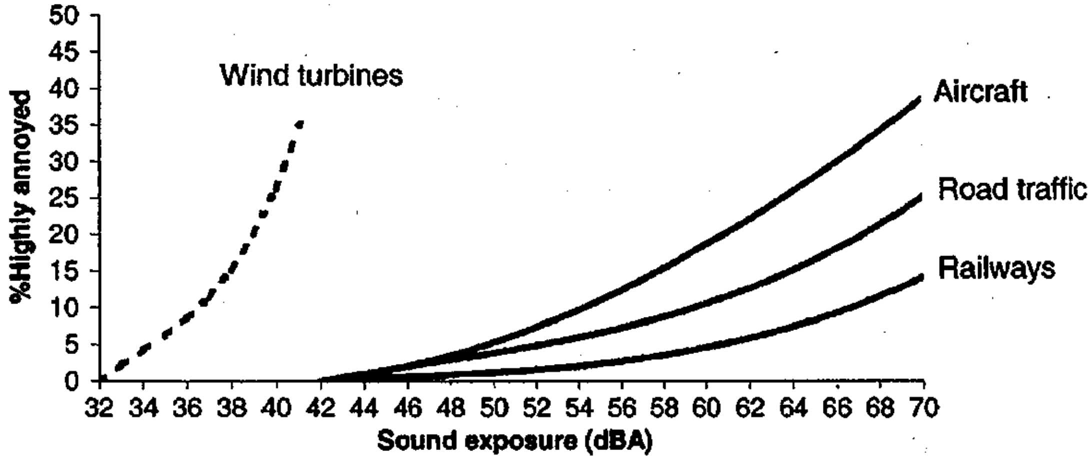
Daytime		Nighttime	
L50	L10	L50	L10
60 dB(A)	65 dB(A)	50 dB(A)	55 dB(A)

These noise limits are single number limits that rely on the measuring instrument to apply an A-weighting filter over the entire presumed audible spectrum of frequencies (20 Hz to 20 KHz) and then integrating that signal. The result is a single number that characterizes the audible spectrum noise intensity.

2. Low frequency noise assessment and regulation

Pedersen and Waye (2004) looked at the relationship between total dB(A) sound pressure and the annoyance of those who are environmentally exposed to noise from different sources. Figure 6 demonstrates the difficulty in using total dB(A) to evaluate annoyance. Note how lower noise levels (dB(A)) from wind turbines engenders annoyance similar to much higher levels of noise exposure from aircraft, road traffic and railroads. Sound impulsiveness, low frequency noise and persistence of the noise, as well as demographic characteristics may explain some of the difference.

Figure 6: Annoyance associated with exposure to different environmental noises



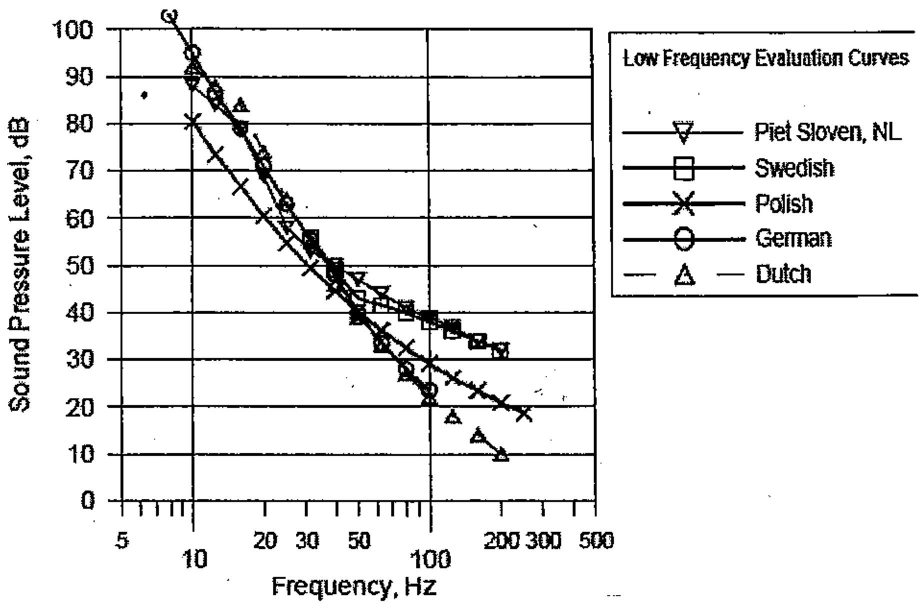
Reprinted with permission from Pedersen, E. and K.P. Waye (2004). Perception and annoyance due to wind turbine noise—a dose-response relationship. The Journal of the Acoustical Society of America 116: 3460. Copyright 2004, Acoustical Society of America.

Kjellberg et al. (1997) looked at the ability of different full spectrum weighting schemes to predict annoyance caused by low frequency audio noise. They found that dB(A) is the worst predictor of annoyance of available scales. However, if 6 dB ("penalty") is added to dB(A) when dB(C) – dB(A) is greater than 15 dB, about 71% of the predictions of annoyance are correct. It is important to remember that integrated, transformed measurements of SPL (e.g. dB(A), dB(C)) do not measure frequencies below 20 Hz. While people detect stimuli below 20 Hz, as discussed in above sections, these frequencies are not measured using an A-weighted or C-weighted meter.

The World Health Organization (WHO) recommends that if dB(C) is greater than 10 dB more than dB(A), the low frequency components of the noise may be important and should be evaluated separately. In addition, WHO says "[i]t should be noted that a large proportion of low-frequency components in noise may increase considerably the adverse effects on health." (WHO, 1999)

Many governments that regulate low frequency noise look at noise within bands of frequencies instead of summing the entire spectrum. A study by Poulsen and Mortensen (Danish Environmental Protection Agency, 2002) included a summary of low frequency noise guidelines. German, Swedish, Polish, and Dutch low frequency evaluation curves were compared (see Figure 7). While there are distinctions in how the evaluation curves are described, generally, these curves are sound pressure criterion levels for 1/3 octaves from about 8 Hz to 250 Hz. Exceedance in any 1/3 octave measurement suggests that the noise may be annoying. However, note that regulations associated with low frequency noise can be quite complex and the regulatory evaluations associated with individual curves can be somewhat different.

Figure 7: 1/3 Octave Sound Pressure Level Low frequency Noise Evaluation Curves



(Danish Environmental Protection Agency, 2002)

The Danish low frequency evaluation requires measuring noise indoors with windows closed; SPL measurements are obtained in 1/3 octave bands and transformed using the A-weighting algorithm for all frequencies between 10 and 160 Hz. These values are then summed into a single metric called $L_{pA,LF}$. A 5 dB "penalty" is added to any noise that is "impulsive". Danish regulations require that 20 dB $L_{pA,LF}$ is not exceeded during the evening and night, and that 25 dB $L_{pA,LF}$ is not exceeded during the day.

Swedish guidance recommends analyzing 1/3 octave bands between 31.5 and 200 Hz inside a home, and comparing the values to a Swedish assessment curve. The Swedish curve is equal to the United Kingdom (UK) Department of Environment, Food and Rural Affairs (DEFRA) low frequency noise criterion curve for overlapping frequencies (31.5 – 160 Hz).

The German "A-level" method sums the A-weighted equivalent levels of 1/3 octave bands that exceed the hearing threshold from 10 – 80 Hz. If the noise is not tonal, the measurements are added. The total cannot exceed 25 dB at night and 35 dB during the day. A frequency-dependent adjustment is applied if the noise is tonal.

In the Poulsen and Mortensen, Danish EPA study (2002), 18 individuals reported annoyance levels when they were exposed through earphones in a controlled environment to a wide range of low frequency environmental noises, all attenuated down to 35 dB, as depicted in Table 2. Noise was simulated as if being heard indoors, filtering out noise at higher frequencies and effectively eliminating all frequencies above 1600 Hz. Noise levels in 1/3 octave SPLs from 8 Hz to 1600 Hz were measured and low frequencies (below 250 Hz) were used to predict annoyance using 7 different methods (Danish, German A-level, German tonal, Swedish, Polish, Sloven, and C-level). Predictions of annoyance were compared with the subjective annoyance evaluations. Correlation coefficients for these analyses ranged from 0.64 to 0.94, with the best correlation in comparison with the Danish low frequency noise evaluation methods.

As would be expected, at 35 dB nominal (full spectrum) loudness, every low frequency noise source tested exceeded all of the regulatory standards noted in the Danish EPA report. Table 2 shows the Danish and Swedish regulatory exceedances of the different 35 dB nominal (full spectrum) noise.

Table 2: 35 dB(A) (nominal, 8 Hz-20KHz) Indoor Noise from Various Outdoor Environmental Sources

	Traffic Noise	Drop Forge	Gas Turbine	Fast Ferry	Steel Factory	Generator	Cooling Compressor	Discotheque
Noise	67.6 dB(lin)	71.1 dB(lin)	78.4 dB(lin)	64.5 dB(lin)	72.7 dB(lin)	60.2 dB(lin)	60.3 dB(lin)	67.0 dB(lin)
Noise ≥ 20 Hz	35.2 dB(A)	36.6 dB(A)	35.0 dB(A)	35.1 dB(A)	33.6 dB(A)	36.2 dB(A)	36.6 dB(A)	33.6 dB(A)
	62.9 dB(C)	67.3 dB(C)	73.7 dB(C)	61.7 dB(C)	66.0 dB(C)	58.6 dB(C)	59.0 dB(C)	57.8 dB(C)
Danish Environmental Protection Agency	14.5 dB	21.5 dB *	14.8 dB	15.0 dB	13.1 dB	16.1 dB	14.0 dB	18.0 dB *
Swedish National Board of Health and Welfare	14.1 dB	19.7 dB	15.9 dB	16.8 dB	15.5 dB	18.3 dB	16.0 dB	10.0 dB
* includes 5 dB "penalty"								

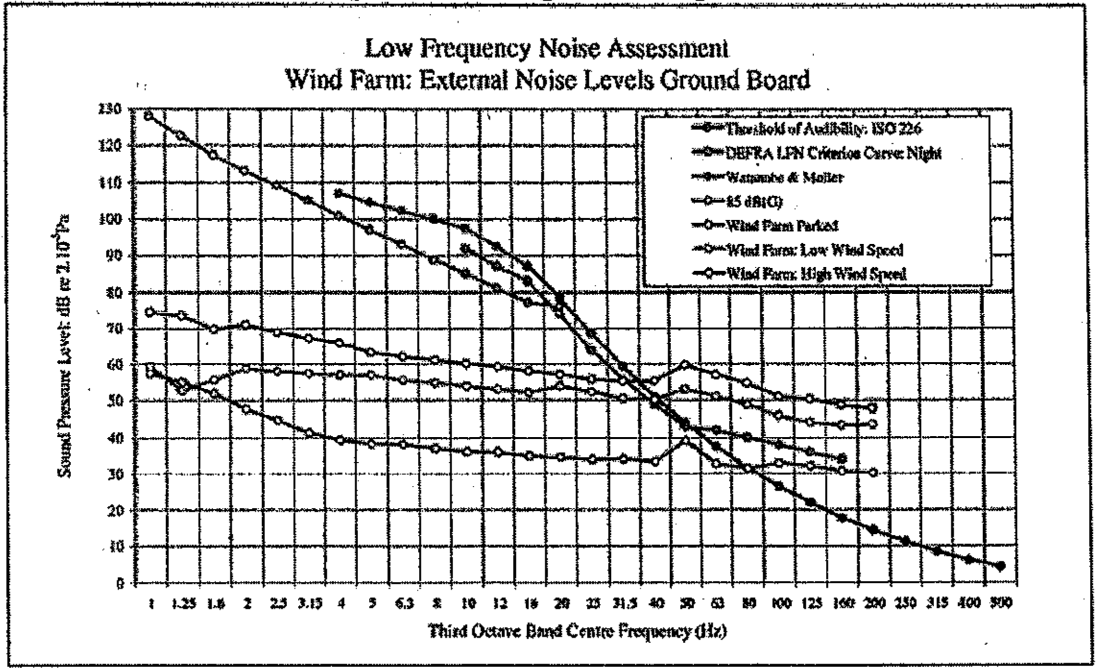
Noise adjusted to dB(lin), dB(A), dB(C) scales. Calculated exceedances of Danish and Swedish indoor criteria. (data from Danish Environmental Protection Agency, 2002)

In their noise guidance, the WHO (1999) recommends 30 dB(A) as a limit for "a good night's sleep". However, they also suggest that guidance for noise with predominating low frequencies be less than 30 dB(A).

3. Wind turbine sound measurements

Figure 8 shows examples of the SPLs at different frequencies from a representative wind turbine in the United Kingdom. Sound pressure level measurements are reported for a Nordex N-80 turbine at 200 meters (UK Department of Transport and Industry, 2006) when parked, at low wind speeds, and at high wind speeds. Figure 8 also includes, for reference, 3 sound threshold curves (ISO 226, Watanabe & Moller, 85 dB(G)) and the DEFRA Low Frequency Noise Criterion Curve (nighttime).

Figure 8: Low Frequency Noise from Wind Farm: Parked, Low Wind Speed, and High Wind Speed

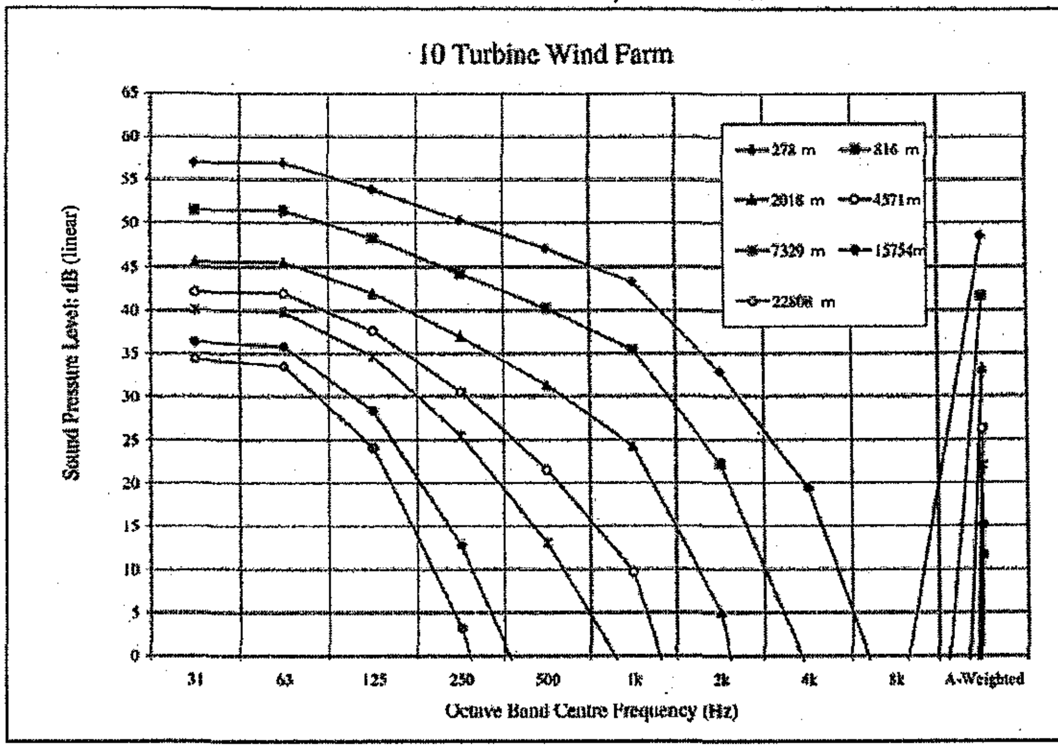


(UK Department of Transport and Industry, 2006)

In general, sound tends to propagate as if by spherical dispersion. This creates amplitude decay at a rate of about -6 dB per doubling of distance. However, low frequency noise from a wind turbine has been shown to follow more of a cylindrical decay at long distances, about -3 dB per doubling of distance in the downwind direction (Shepherd and Hubbard, 1991). This is thought to be the result of the lack of attenuation of low frequency sound waves by air and the atmospheric refraction of the low frequency sound waves over medium to long distances (Hawkins, 1987).

Figure 9 shows the calculated change in spectrum for a wind farm from 278 meters to 22,808 meters distant. As one moves away from the noise source, loudness at higher frequencies decreases more rapidly (and extinguishes faster) than at lower frequencies. Measurement of A-weighted decibels, shown at the right of the figure, obscures this finding.

Figure 9: Change in Noise Spectrum as Distance from Wind Farm Changes



(UK Department of Transport and Industry, 2006)

Thus, although noise from an upwind blade wind turbine is generally broad spectrum, without a tonal quality, high frequencies are efficiently attenuated by both the atmosphere, and by walls and windows of structures, as noted above. As a result, as one moves away from a wind turbine, the low frequency component of the noise becomes more pronounced.

Kamperman and James (2008) modeled indoor noise from outdoor wind turbine noise measurements, assuming a typical vinyl siding covered 2X4 wood frame construction. The wind turbine noise inside was calculated to be 5 dB less than the noise outside. Model data suggested that the sound of a single 2.5 MW wind turbine at 1000 feet will likely be heard in a house with the windows sealed. They note that models used for siting turbines often incorporate structure attenuation of 15dB. In addition, Kamperman and James demonstrate that sound from 10 2.5 MW turbines (acoustically) centered 2 km (1¼ mile) away and with the nearest turbine 1 mile away will only be 6.3 dB below the sound of a single turbine at 1000 feet (0.19 mile).

4. Wind turbine regulatory noise limits

Ramakrishnan (2007) has reported different noise criteria developed for wind farm planning. These criteria include common practices (if available) within each jurisdiction for estimating background SPLs, turbine SPLs, minimum setbacks and methods used to assess impacts. Reported US wind turbine noise criteria range from: ambient + 10 dB(A) where ambient is assumed to be 26 dB(A) (Oregon); to 55 dB(A) or "background" + 5 dB(A) (Michigan). European criteria range from 35 dB(A) to 45 dB(A), at the property. US setbacks range from 1.1 times the full height of the turbine (consenting) and 5 times the hub height (non-consenting; Pennsylvania); to 350 m (consenting) and 1000 m (non-consenting; Oregon). European minimum setbacks are not noted.

VI. Conclusions

Wind turbines generate a broad spectrum of low-intensity noise. At typical setback distances higher frequencies are attenuated. In addition, walls and windows of homes attenuate high frequencies, but their effect on low frequencies is limited. Low frequency noise is primarily a problem that may affect some people in their homes, especially at night. It is not generally a problem for businesses, public buildings, or for people outdoors.

The most common complaint in various studies of wind turbine effects on people is annoyance or an impact on quality of life. Sleeplessness and headache are the most common health complaints and are highly correlated (but not perfectly correlated) with annoyance complaints. Complaints are more likely when turbines are visible or when shadow flicker occurs. Most available evidence suggests that reported health effects are related to audible low frequency noise. Complaints appear to rise with increasing outside noise levels above 35 dB(A). It has been hypothesized that direct activation of the vestibular and autonomic nervous system may be responsible for less common complaints, but evidence is scant.

The Minnesota nighttime standard of 50 dB(A) not to be exceeded more than 50% of the time in a given hour, appears to underweight penetration of low frequency noise into dwellings. Different schemes for evaluating low frequency noise, and/or lower noise standards, have been developed in a number of countries.

For some projects, wind velocity for a wind turbine project is measured at 10 m and then modeled to the height of the rotor. These models may under-predict wind speed that will be encountered when the turbine is erected. Higher wind speed will result in noise exceeding model predictions.

Low frequency noise from a wind turbine is generally not easily perceived beyond ½ mile. However, if a turbine is subject to aerodynamic modulation because of shear caused by terrain (mountains, trees, buildings) or different wind conditions through the rotor plane, turbine noise may be heard at greater distances.

Unlike low frequency noise, shadow flicker can affect individuals outdoors as well as indoors, and may be noticeable inside any building. Flicker can be eliminated by placement of wind turbines outside of the path of the sun as viewed from areas of concern, or by appropriate setbacks.

Prediction of complaint likelihood during project planning depends on: 1) good noise modeling including characterization of potential sources of aerodynamic modulation noise and characterization of nighttime wind conditions and noise; 2) shadow flicker modeling; 3) visibility of the wind turbines; and 4) interests of nearby residents and community.

VII. Recommendations

To assure informed decisions:

- Wind turbine noise estimates should include cumulative impacts (40-50 dB(A) isopleths) of all wind turbines.
- Isopleths for dB(C) - dB(A) greater than 10 dB should also be determined to evaluate the low frequency noise component.
- Potential impacts from shadow flicker and turbine visibility should be evaluated.

Any noise criteria beyond current state standards used for placement of wind turbines should reflect priorities and attitudes of the community.

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Public Health Impacts

of

Wind Turbines

Prepared by:
Minnesota Department of Health
Environmental Health Division

In response to a request from:
Minnesota Department of Commerce
Office of Energy Security

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I. Introduction

In late February 2009 the Minnesota Department of Health (MDH) received a request from the Office of Energy Security (OES) in the Minnesota Department of Commerce, for a "white paper" evaluating possible health effects associated with low frequency vibrations and sound arising from large wind energy conversion systems (LWECS). The OES noted that there was a request for a Contested Case Hearing before the Minnesota Public Utilities Commission (PUC) on the proposed Bent Tree Wind Project in Freeborn County Minnesota; further, the OES had received a long comment letter from a citizen regarding a second project proposal, the Lakeswind Wind Power Plant in Clay, Becker and Ottertail Counties, Minnesota. This same commenter also wrote to the Commissioner of MDH to ask for an evaluation of health issues related to exposure to low frequency sound energy generated by wind turbines. The OES informed MDH that a white paper would have more general application and usefulness in guiding decision-making for future wind projects than a Contested Case Hearing on a particular project. (Note: A Contested Case Hearing is an evidentiary hearing before an Administrative Law Judge, and may be ordered by regulatory authorities, in this case the PUC, in order to make a determination on disputed issues of material fact. The OES advises the PUC on need and permitting issues related to large energy facilities.)

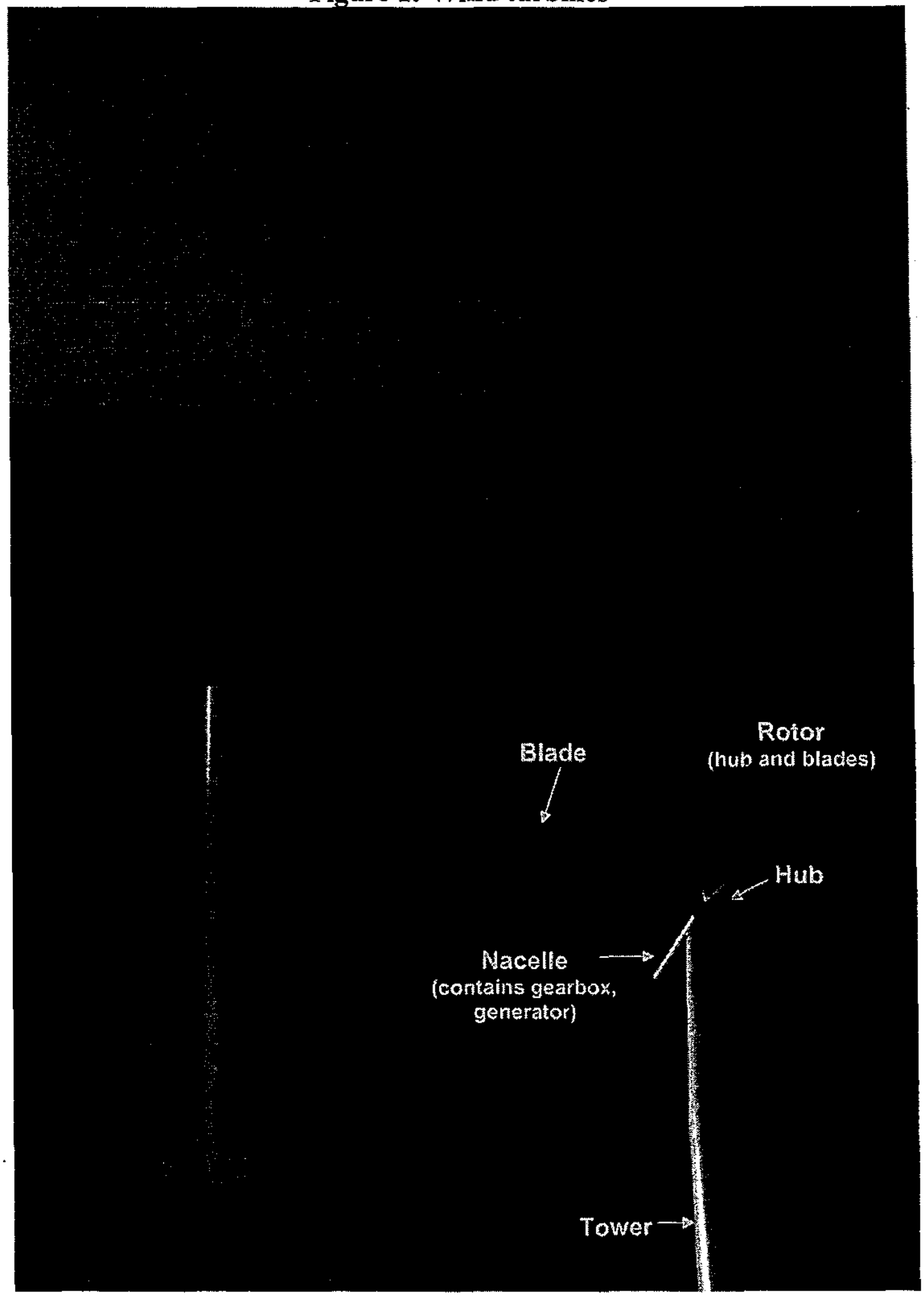
In early March 2009, MDH agreed to evaluate health impacts from wind turbine noise and low frequency vibrations. In discussion with OES, MDH also proposed to examine experiences and policies of other states and countries. MDH staff appeared at a hearing before the PUC on March 19, 2009, and explained the purpose and use of the health evaluation. The Commissioner replied to the citizen letter, affirming that MDH would perform the requested review.

A brief description of the two proposed wind power projects, and a brief discussion of health issues to be addressed in this report appear below.

A. Site Proposals

Wind turbines are huge and expensive machines requiring large capitol investment. Figure 1 shows some existing wind turbines in Minnesota. Large projects require control of extensive land area in order to optimize spacing of turbines to minimize turbulence at downwind turbines. Towers range up to 80 to 100 meters (260 to 325 feet), and blades can be up to 50 meters long (160 feet) (see Tetra Tech, 2008; WPL, 2008). Turbines are expected to be in place for 25-30 years.

Figure 1: Wind turbines



1. Bent Tree Wind Project in Freeborn County

This is a proposal by the Wisconsin Power and Light Company (WPL) for a 400 megawatt (MW) project in two phases of 200 MW each (requiring between 80 and 130 wind turbines). The cost of the first phase is estimated at $497 million. The project site area would occupy approximately 40 square miles located 4 miles north and west of the city of Albert Lea, approximately 95 miles south of Minneapolis (Figure 2) (WPL, 2008). The Project is a LWECS and a Certificate of Need (CON) from the PUC is required (*Minnesota Statutes 216B.243)*. The PUC uses the CON process to determine the basic type of facility (if any) to be constructed, the size of the facility, and when the project will be in service. The CON process involves a public hearing and preparation of an Environmental Report by the OES. The CON process generally takes a year, and is required before a facility can be permitted.

WPL is required to develop a site layout that optimizes wind resources. Accordingly, project developers are required to control areas at least 5 rotor diameters in the prevailing (north-south) wind directions (between about 1300 and 1700 feet for the 1.5 to 2.5 MW turbines under consideration for the project) and 3 rotor diameters in the crosswind (east-west) directions (between about 800 and 1000 feet). Thus, these are minimum setback distances from properties in the area for which easements have not been obtained. Further, noise rules promulgated by the Minnesota Pollution Control Agency (MPCA; *Minnesota Rules* Section 7030), specify a maximum nighttime noise in residential areas of 50 A-weighted decibels (dB(A). WPL has proposed a minimum setback of 1,000 feet from occupied structures in order to comply with the noise rule.

2. Noble Flat Hill Wind Park in Clay, Becker and Ottertail Counties

This is a LWECS proposed by Noble Flat Hill Windpark I (Noble), a subsidiary of Noble Environmental Power, based in Connecticut. The proposal is for a 201 MW project located 12 miles east of the City of Moorhead, about 230 miles northwest of Minneapolis (Figure 3) (Tetra Tech, 2008). The cost of the project is estimated to be between $382 million and $442 million. One hundred thirty-four GE 1.5 MW wind turbines are planned for an area of 11,000 acres (about 17 square miles); the site boundary encompasses approximately 20,000 acres. Setback distances of a minimum of 700 feet are planned to comply with the 50 dB(A) noise limit. However, rotor diameters will be 77 meters (250 feet). Therefore, setback distances in the prevailing wind direction of 1,300 feet are planned for properties where owners have not granted easements. Setbacks of 800 feet are planned in the crosswind direction.

Figure 2: Bent Tree Wind Project, Freeborn County

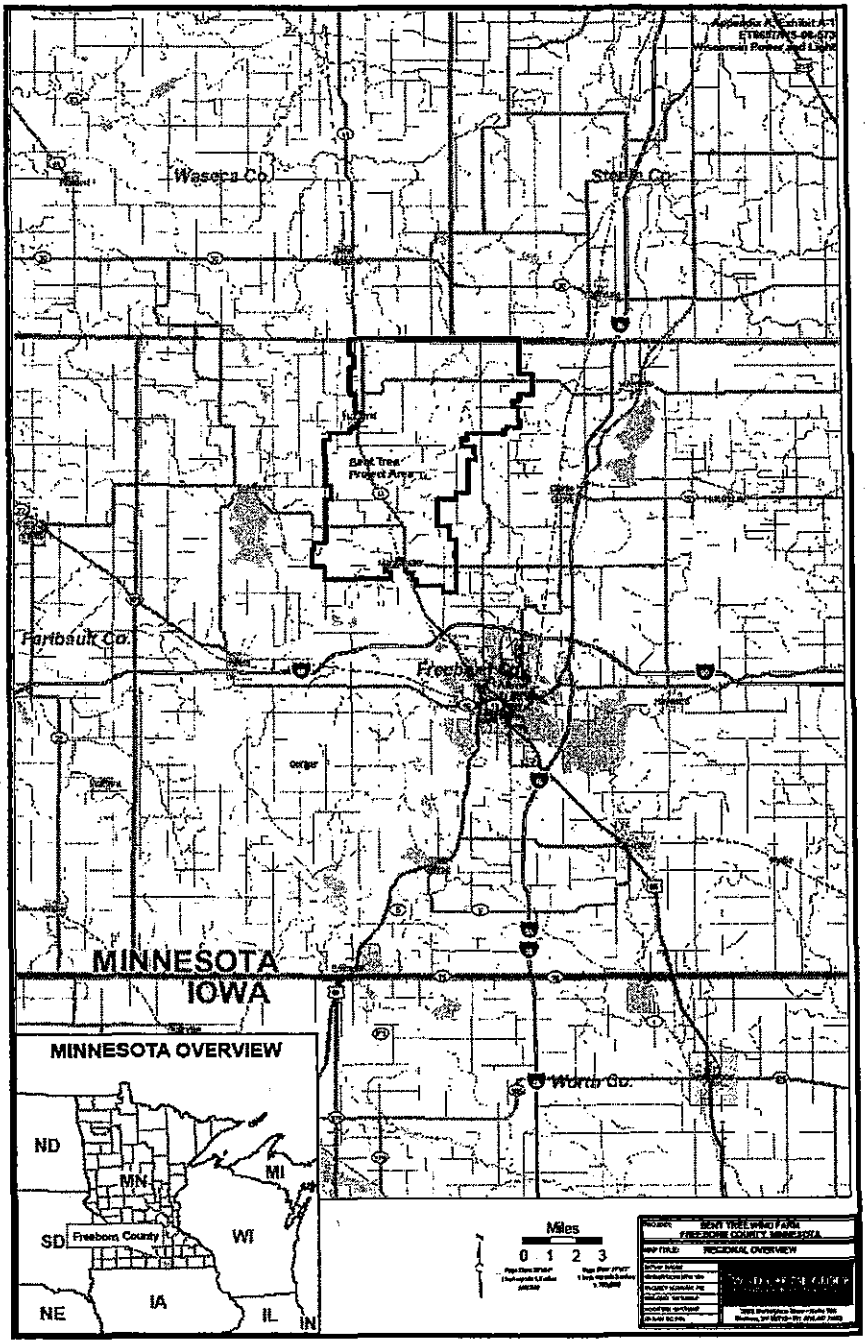
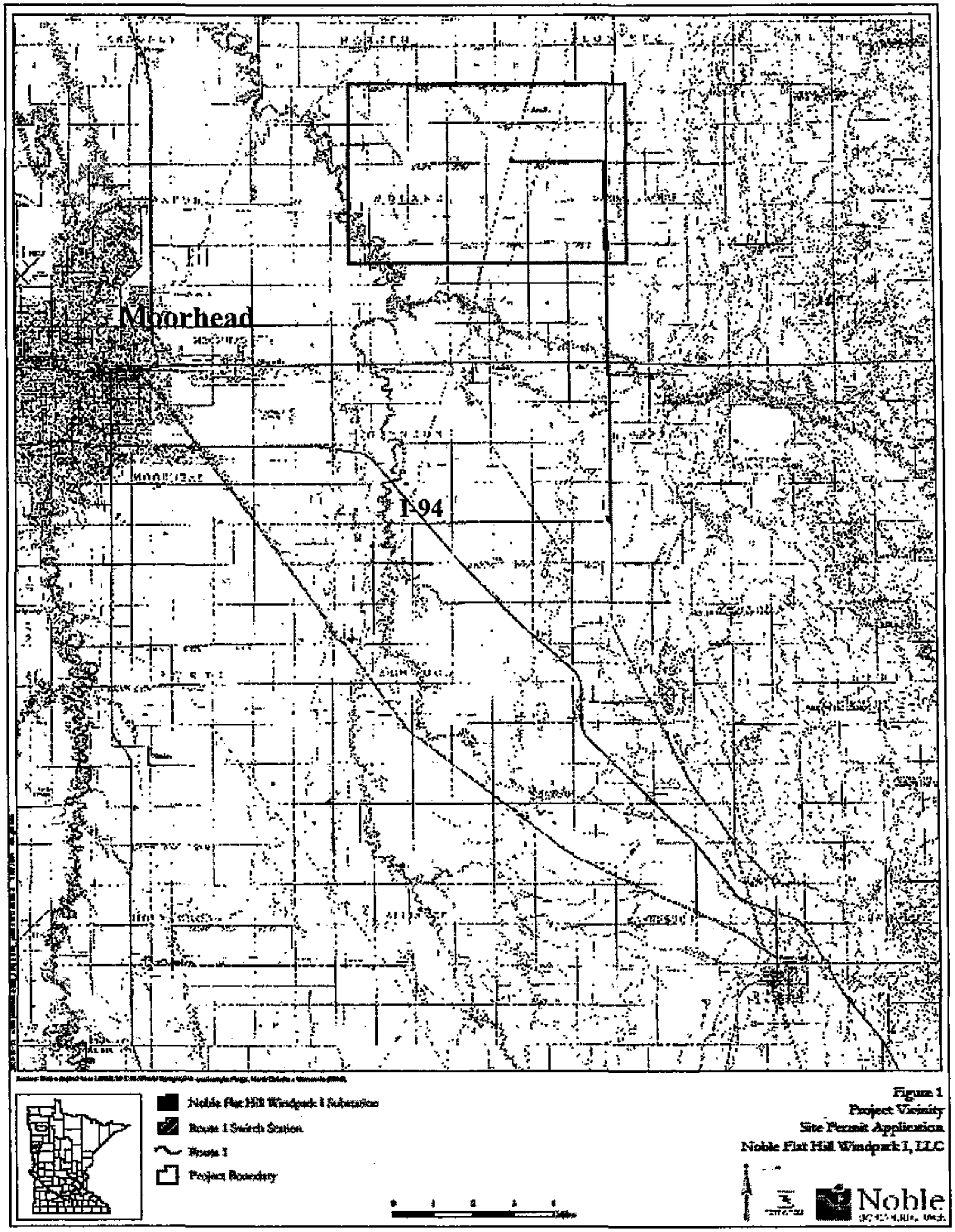


Figure 3: Noble Flat Hill Wind Park, Clay, Becker, Ottertail Counties



B. Health Issues

The National Research Council of the National Academies (NRC, 2007) has reviewed impacts of wind energy projects on human health and well-being. The NRC begins by observing that wind projects, just as other projects, create benefits and burdens, and that concern about impacts is natural when the source is near one's home. Further, the NRC notes that different people have different values and levels of sensitivity. Impacts noted by the NRC that may have the most effect on health include noise and low frequency vibration, and shadow flicker. While noise and vibration are the main focus of this paper, shadow flicker (casting of moving shadows on the ground as wind turbine blades rotate) will also be briefly discussed.

Noise originates from mechanical equipment inside the nacelles of the turbines (gears, generators, etc.) and from interaction of turbine blades with wind. Newer wind turbines generate minimal noise from mechanical equipment. The most problematic wind turbine noise is a broadband "whooshing" sound produced by interaction of turbine blades with the wind. Newer turbines have upwind rotor blades, minimizing low frequency "infrasound" (i.e., air pressure changes at frequencies below 20-100 Hz that are inaudible). However, the NRC notes that during quiet conditions at night, low frequency modulation of higher frequency sounds, such as are produced by turbine blades, is possible. The NRC also notes that effects of low frequency (infrasound) vibration (less than 20 Hz) on humans are not well understood, but have been asserted to disturb some people.

Finally, the NRC concludes that noise produced by wind turbines is generally not a major concern beyond a half mile. Issues raised by the NRC report and factors that may affect distances within which wind turbine noise may be problematic are discussed more extensively below.

II. Elementary Characteristics of Sensory Systems and Sound

A. Sensory Systems

1. Hearing

Sensory systems respond to a huge dynamic range of physical stimuli within a relatively narrow dynamic range of mechanical, chemical and/or neuronal (electrophysiological) output. Compression of the dynamic range is accomplished by systems that respond to logarithmic increases in intensity of physical stimuli with arithmetically increasing sensory responses. This general property is true for hearing, and has been recognized since at least the mid-19th century (see e.g., Woodworth and Schlosberg, 1964). "Loudness" is the sensory/perceptual correlate of the physical intensity of air pressure changes to which the electro-mechanical transducers in the ear and associated neuronal pathways are sensitive. Loudness increases as the logarithm of air pressure, and it is convenient to relate loudness to a reference air pressure (in dyne/cm^2 or pascals) in tenths of logarithmic units (decibels; dB). Further, the ear is sensitive to only a relatively narrow frequency range of air pressure changes: those between approximately 20 and 20,000 cycles per second or Herz (Hz). In fact, sensitivity varies within this range, so that the sound pressure level relative to a reference value that is audible in the middle of the range (near 1,000 Hz) is about 4 orders of magnitude smaller than it is at 20 Hz and about 2 orders of magnitude smaller than at 20,000 Hz (Fig. 3). Accordingly, measurements of loudness in dB generally employ filters to equalize the loudness of sounds at different frequencies or "pitch." To approximate the sensitivity of the ear, A-weighted filters weigh sound pressure changes at frequencies in the mid-range more than those at higher or lower frequencies. When an A-weighted filter is used, loudness is measured in dB(A). This is explained in greater detail in Section B below.

The ear accomplishes transduction of sound through a series of complex mechanisms (Guyton, 1991). Briefly, sound waves move the eardrum (tympanic membrane), which is in turn connected to 2 small bones (ossicles) in the middle ear (the malleus and incus). A muscle connected to the malleus keeps the tympanic membrane tensed, allowing efficient transmission to the malleus of vibrations on the membrane. Ossicle muscles can also relax tension and attenuate transmission. Relaxation of muscle tension on the tympanic membrane protects the ear from very loud sounds and also masks low frequency sounds, or much background noise. The malleus and incus move a third bone (stapes). The stapes in turn applies pressure to the fluid of the cochlea, a snail-shaped structure imbedded in temporal bone. The cochlea is a complex structure, but for present purposes it is sufficient to note that pressure changes or waves of different frequencies in cochlear fluid result in bending of specialized hair cells in regions of the cochlea most sensitive to different frequencies or pitch. Hair cells are directly connected to nerve fibers in the vestibulocochlear nerve (VIII cranial nerve).

Transmission of sound can also occur directly through bone to the cochlea. This is a very inefficient means of sound transmission, unless a device (e.g. a tuning fork or hearing aid) is directly applied to bone (Guyton, 1991).

2. Vestibular System

The vestibular system reacts to changes in head and body orientation in space, and is necessary for maintenance of equilibrium and postural reflexes, for performance of rapid and intricate body movements, and for stabilizing visual images (via the vestibulo-ocular reflex) as the direction of movement changes (Guyton, 1991).

The vestibular apparatus, like the cochlea, is imbedded in temporal bone, and also like the cochlea, hair cells, bathed in vestibular gels, react to pressure changes and transmit signals to nerve fibers in the vestibulocochlear nerve. Two organs, the utricle and saccule, called otolith organs, integrate information about the orientation of the head with respect to gravity. Otoliths are tiny stone-like crystals, embedded in the gels of the utricle and saccule, that float as the head changes position within the gravitational field. This movement is translated to hair cells. Three semi-circular canals, oriented at right angles to each other, detect head rotation. Stimulation of the vestibular apparatus is not directly detected, but results in activation of motor reflexes as noted above (Guyton, 1991).

Like the cochlea, the vestibular apparatus reacts to pressure changes at a range of frequencies; optimal frequencies are lower than for hearing. These pressure changes can be caused by body movements, or by direct bone conduction (as for hearing, above) when vibration is applied directly to the temporal bone (Todd et al., 2008). These investigators found maximal sensitivity at 100 Hz, with some sensitivity down to 12.5 Hz. The saccule, located in temporal bone just under the footplate of the stapes, is the most sound-sensitive of the vestibular organs (Halmagyi et al., 2004). It is known that brief loud clicks (90-95 dB) are detected by the vestibular system, even in deaf people. However, we do not know what the sensitivity of this system is through the entire range of sound stimuli.

While vestibular system activation is not directly felt, activation may give rise to a variety of sensations: vertigo, as the eye muscles make compensatory adjustments to rapid angular motion, and a variety of unpleasant sensations related to internal organs. In fact, the vestibular system interacts extensively with the "autonomic" nervous system, which regulates internal body organs (Balaban and Yates, 2004). Sensations and effects correlated with intense vestibular activation include nausea and vomiting and cardiac arrhythmia, blood pressure changes and breathing changes.

While these effects are induced by relatively intense stimulation, it is also true that A-weighted sound measurements attuned to auditory sensitivity, will underweight low frequencies for which the vestibular system is much more sensitive (Todd et al., 2008). Nevertheless, activation of the vestibular system *per se* obviously need not give rise to unpleasant sensations. It is not known what stimulus intensities are generally required for for autonomic activation at relatively low frequencies, and it is likely that there is considerable human variability and capacity to adapt to vestibular challenges.

B. Sound

1. Introduction

Sound is carried through air in compression waves of measurable frequency and amplitude. Sound can be tonal, predominating at a few frequencies, or it can contain a random mix of a broad range of frequencies and lack any tonal quality (white noise). Sound that is unwanted is called noise.

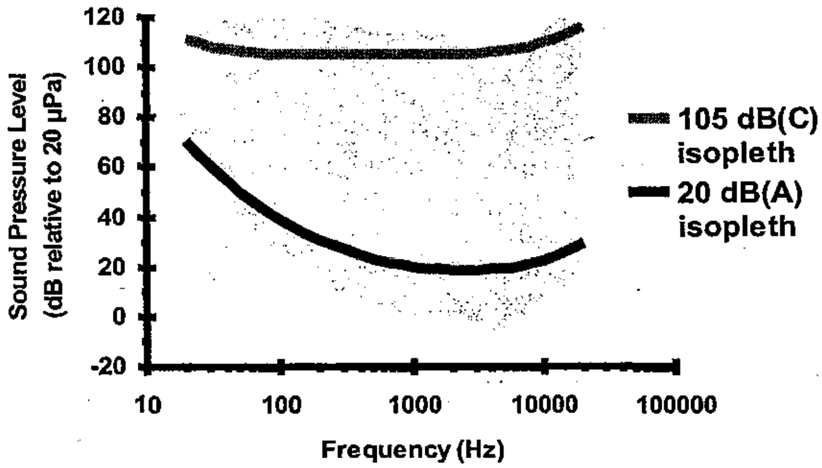
Audible Frequency Sound

Besides frequency sensitivity (between 20 and 20,000 Hz), humans are also sensitive to changes in the amplitude of the signal (compression waves) within this audible range of frequencies. Increasing amplitude, or increasing sound pressure, is perceived as increasing volume or loudness. The sound pressure level in air (SPL) is measured in micro Pascals (μPa). SPLs are typically converted in measuring instruments and reported as decibels (dB) which is a log scale, relative unit (see above). When used as the unit for sound, dBs are reported relative to a SPL of 20 μPa. Twenty μPa is used because it is the approximate threshold of human hearing sensitivity at about 1000 Hz. Decibels relative to 20 μPa are calculated from the following equation:

$$\text{Loudness (dB)} = \text{Log}((\text{SPL} / 20\ \mu\text{Pa})^2) * 10$$

Figure 4 shows the audible range of normal human hearing. Note that while the threshold sensitivity varies over the frequency range, at high SPLs sensitivity is relatively consistent over audible frequencies.

Figure 4: Audible Range of Human Hearing



Equivalence curves for different frequencies, when sound meter readings in dB are taken with A or C-weighting filters. (Adapted from EPD Hong Kong SAR, 2009)

Sub-Audible Frequency Sound

Sub-audible frequency sound is often called infrasound. It may be sensed by people, similar to audible sound, in the cochlear apparatus in the ear; it may be sensed by the vestibular system which is responsible for balance and physical equilibrium; or it may be sensed as vibration.

Resonance and modulation

Sound can be attenuated as it passes through a physical structure. However, because the wavelength of low frequency sound is very long (the wavelength of 40 Hz in air at sea level and room temperature is 8.6 meters or 28 ft), low frequencies are not effectively attenuated by walls and windows of most homes or vehicles. (For example, one can typically hear the bass, low frequency music from a neighboring car at a stoplight, but not the higher frequencies.) In fact, it is possible that there are rooms within buildings exposed to low frequency sound or noise where some frequencies may be amplified by resonance (e.g. ½ wavelength, ¼ wavelength) within the structure. In addition, low frequency sound can cause vibrations within a building at higher, more audible frequencies as well as throbbing or rumbling.

Sounds that we hear generally are a mixture of different frequencies. In most instances these frequencies are added together. However, if the source of the sound is not constant, but changes over time, the effect can be re-occurring pulses of sound or low frequency modulation of sound. This is the type of sound that occurs from a steam engine, a jack hammer, music and motor vehicle traffic. Rhythmic, low frequency pulsing of higher frequency noise (like the sound of an amplified heart beat) is one type of sound that can be caused by wind turbine blades under some conditions.

2. Human Response to Low Frequency Stimulation

There is no consensus whether sensitivity below 20 Hz is by a similar or different mechanism than sensitivity and hearing above 20 Hz (Reviewed by Møller and Pedersen, 2004). Possible mechanisms of sensation caused by low frequencies include bone conduction at the applied frequencies, as well as amplification of the base frequency and/or harmonics by the auditory apparatus (eardrum and ossicles) in the ear. Sensory thresholds are relatively continuous, suggesting (but not proving) a similar mechanism above and below 20 Hz. However, it is clear that cochlear sensitivity to infrasound (< 20 Hz) is considerably less than cochlear sensitivity to audible frequencies.

Møller and Pedersen (2004) reviewed human sensitivity at low and infrasonic frequencies. The following findings are of interest:

- When whole-body pressure-field sensitivity is compared with ear-only (earphone) sensitivity, the results are very similar. These data suggest that the threshold sensitivity for low frequency is through the ear and not vestibular.
- Some individuals have extraordinary sensitivity at low frequencies, up to 25 dB more sensitive than the presumed thresholds at some low frequencies.
- While population average sensitivity over the low frequency range is smooth, sound pressure thresholds of response for individuals do not vary smoothly but are inconsistent, with peaks and valleys or "microstructures". Therefore the sensitivity response of individuals to different low frequency stimulation may be difficult to predict.
- Studies of equal-loudness-levels demonstrate that as stimulus frequency decreases through the low frequencies, equal-loudness lines compress in the dB scale. (See Figure 4 as an example of the relatively small difference in auditory SPL range between soft and loud sound at low frequencies).
- The hearing threshold for pure tones is different than the hearing threshold for white noise at the same total sound pressure.

3. Sound Measurements

Sound measurements are taken by instruments that record sound pressure or the pressure of the compression wave in the air. Because the loudness of a sound to people is usually the primary interest in measuring sound, normalization schemes or filters have been applied to absolute measurements. dB(A) scaling of sound pressure measurements was intended to normalize readings to equal loudness over the audible range of frequencies at low loudness. For example, a 5,000 Hz (5 kHz) and 20 dB(A) tone is expected to have the same intensity or loudness as a 100 Hz, 20 dB(A) tone. However, note that the absolute sound pressures would be about 200 μPa and 2000 μPa, respectively, or about a difference of 20 dB (relative to 20 μPa), or as it is sometimes written 20 dB(linear).

Most sound is not a single tone, but is a mixture of frequencies within the audible range. A sound meter can add the total SPLs for all frequencies; in other words, the dB readings over the entire spectrum of audible sound can be added to give a single loudness metric. If sound is reported as A-weighted, or dB(A), it is a summation of the dB(A) scaled sound pressure from 20 Hz to 20 kHz.

In conjunction with the dB(A) scale, the dB(B) scale was developed to approximate equal loudness to people across audible frequencies at medium loudness, and dB(C) was developed to approximate equal-loudness for loud environments. Figure 4 shows isopleths for 20 dB(A) and 105 dB(C). While dB(A), dB(B), dB(C) were developed from empirical data at the middle frequencies, at the ends of the curves these scales were extrapolated, or sketched in, and are not based on experimental or observational data (Berglund et al., 1996). As a result, data in the low frequency range (and probably the highest audible frequencies as well) cannot be reliably interpreted using these scales. The World Health Organization (WHO, 1999) suggests that A-weighting noise that has a large low frequency component is not reliable assessment of loudness.

The source of the noise, or the noise signature, may be important in developing equal-loudness schemes at low frequencies. C-weighting has been recommended for artillery noise, but a linear, unweighted scale may be even better at predicting a reaction (Berglund et al., 1996). A linear or equal energy rating also appears to be the most effective predictor of reaction to low frequency noise in other situations, including blast noise from mining. The implication of the analysis presented by Berglund et al. (1996) is that annoyance from non-tonal noise should not be estimated from a dB(A) scale, but may be better evaluated using dB(C), or a linear non-transformed scale.

However, as will be discussed below, a number of schemes use a modified dB(A) scale to evaluate low frequency noise. These schemes differ from a typical use of the dB(A) scale by addressing a limited frequency range below 250 Hz, where auditory sensitivity is rapidly changing as a function of frequency (see Figure 4).

III. Exposures of Interest

A. Noise From Wind Turbines

1. Mechanical noise

Mechanical noise from a wind turbine is sound that originates in the generator, gearbox, yaw motors (that intermittently turn the nacelle and blades to face the wind), tower ventilation system and transformer. Generally, these sounds are controlled in newer wind turbines so that they are a fraction of the aerodynamic noise. Mechanical noise from the turbine or gearbox should only be heard above aerodynamic noise when they are not functioning properly.

2. Aerodynamic noise

Aerodynamic noise is caused by wind passing over the blade of the wind turbine. The tip of a 40-50 meter blade travels at speeds of over 140 miles per hour under normal operating conditions. As the wind passes over the moving blade, the blade interrupts the laminar flow of air, causing turbulence and noise. Current blade designs minimize the amount of turbulence and noise caused by wind, but it is not possible to eliminate turbulence or noise.

Aerodynamic noise from a wind turbine may be underestimated during planning. One source of error is that most meteorological wind speed measurements noted in wind farm literature are taken at 10 meters above the ground. Wind speed above this elevation, in the area of the wind turbine rotor, is then calculated using established modeling relationships. In one study (van den Berg, 2004) it was determined that the wind speeds at the hub at night were up to 2.6 times higher than modeled. Subsequently, it was found that noise levels were 15 dB higher than anticipated.

Unexpectedly high aerodynamic noise can also be caused by improper blade angle or improper alignment of the rotor to the wind. These are correctable and are usually adjusted during the turbine break-in period.

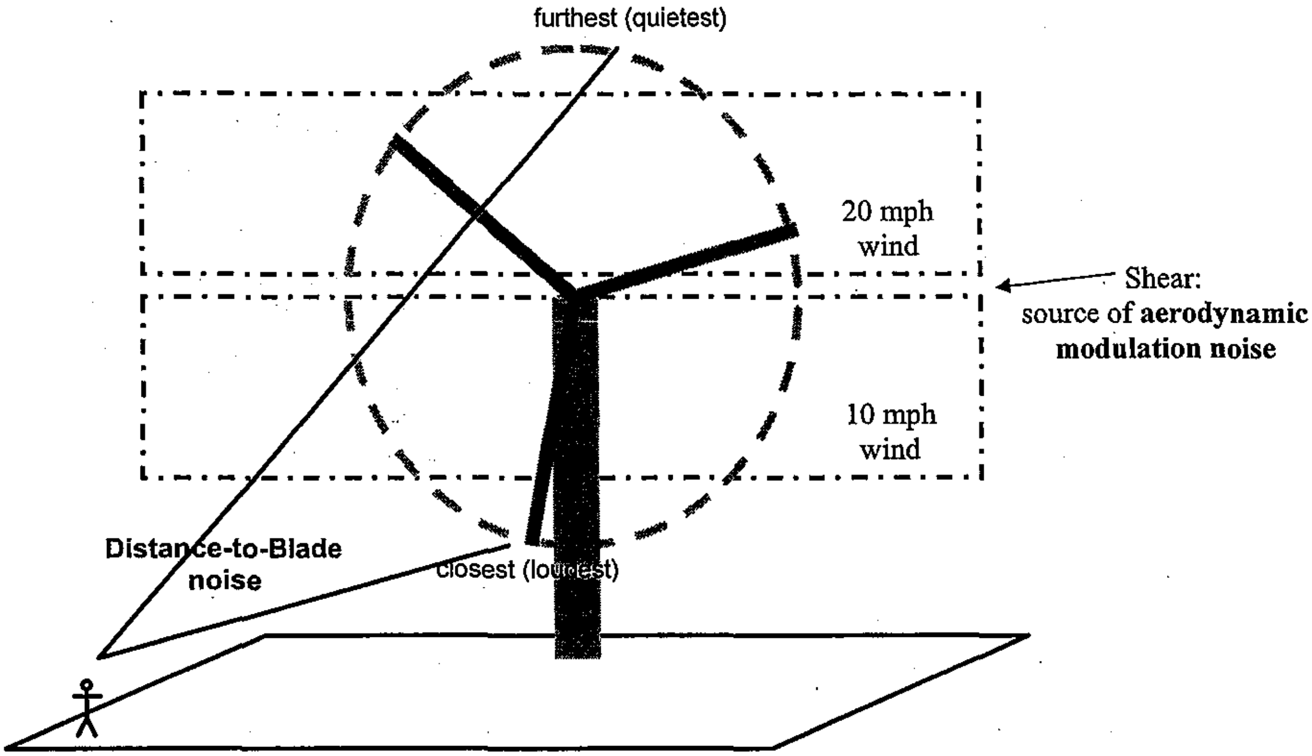
3. Modulation of aerodynamic noise

Rhythmic modulation of noise, especially low frequency noise, has been found to be more annoying than steady noise (Bradley, 1994; Holmberg et al., 1997). One form of rhythmic modulation of aerodynamic noise that can be noticeable very near to a wind turbine is a distance-to-blade effect. To a receptor on the ground in front of the wind turbine, the detected blade noise is loudest as the blade passes, and quietest when the blade is at the top of its rotation. For a modern 3-blade turbine, this distance-to-blade effect can cause a pulsing of the blade noise at about once per second (1 Hz). On the ground, about 500 feet directly downwind from the turbine, the distance-to-blade can cause a difference in sound pressure of about 2 dB between the *tip* of the blade at its farthest point and the *tip* of the blade at its nearest point (48 meter blades, 70 meter tower). Figure 5 demonstrates why the loudness of blade noise (aerodynamic noise) pulses as the distance-to-blade varies for individuals close to a turbine.

If the receptor is 500 feet from the turbine base, in line with the blade rotation or up to 60° off line, the difference in sound pressure from the *tip* of the blade at its farthest and nearest point can be about 4-5 dB, an audible difference. The tip travels faster than the rest of the blade and is closer to (and then farther away from) the receptor than other parts of the blade. As a result, noise from other parts of the blade will be modulated less than noise from the tip. Further, blade design can also affect the noise signature of a blade. The distance-to-blade effect diminishes as receptor distance increases because the relative difference in distance from the receptor to the top or to the bottom of the blade becomes smaller. Thus, moving away from the tower, distance-to-blade noise gradually appears to be more steady.

Another source of rhythmic modulation may occur if the wind through the rotor is not uniform. Blade angle, or pitch, is adjusted for different wind speeds to maximize power and to minimize noise. A blade angle that is not properly tuned to the wind speed (or wind direction) will make more noise than a properly tuned blade. Horizontal layers with different wind speeds or directions can form in the atmosphere. This wind condition is called shear. If the winds at the top and bottom of the blade rotation are different, blade noise will vary between the top and bottom of blade rotation, causing modulation of aerodynamic noise. This noise, associated with the blades passing through areas of different air-wind speeds, has been called aerodynamic modulation and is demonstrated in Figure 5.

Figure 5: Sources of noise modulation or pulsing



In some terrains and under some atmospheric conditions wind aloft, near the top of the wind turbine, can be moving faster than wind near the ground. Wind turbulence or even wakes from adjacent turbines can create non-uniform wind conditions as well. As a result of aerodynamic modulation a rhythmic noise pattern or pulsing will occur as each blade passes through areas with different wind speed. Furthermore, additional noise, or thumping, may occur as each blade passes through the transition between different wind speed (or wind direction) areas.

Wind shear caused by terrain or structures on the ground (e.g. trees, buildings) can be modeled relatively easily. Wind shear in areas of flat terrain is not as easily understood. During the daytime wind in the lower atmosphere is strongly affected by thermal convection which causes mixing of layers. Distinct layers do not easily form. However, in the nighttime the atmosphere can stabilize (vertically), and layers form. A paper by G.P. van den Berg (2008) included data from a study on wind shear at Cabauw, The Netherlands (flat terrain). Annual average wind speeds at different elevations above ground was reported. The annual average wind speed at noon was about 5.75 meters per second (m/s; approximately 12.9 miles per hour(mph)) at 20 m above ground, and about 7.6 m/s (17 mph) at 140 m. At midnight, the annual averages were about 4.3 m/s (9.6 mph) and 8.8 m/s (19.7 mph) for 20m and 140 m, respectively, above ground. The data show that while the average windspeed (between 20m and 140m) is very similar at noon and midnight at Cabauw, the windspeed difference between elevations during the day is much less than the difference at night (1.85 m/s (4.1 mph) and 4.5 m/s (10 mph), respectively). As a result one would expect that the blade angle can be better tuned to the wind speed during the daytime. Consequently, blade noise would be greater at night.

A number of reports have included discussion of aerodynamic modulation (van den Berg, 2005; UK Department of Transport and Industry, 2006; UK Department for Business Enterprise and Regulatory Reform, 2007; van den Berg, 2008). They suggest that aerodynamic modulation is typically underestimated when noise estimates are calculated. In addition, they suggest that detailed modeling of wind, terrain, land use and structures may be used to predict whether modulation of aerodynamic noise will be a problem at a proposed wind turbine site.

4. Wind farm noise

The noise from multiple turbines similarly distant from a residence can be noticeably louder than a lone turbine simply through the addition of multiple noise sources. Under steady wind conditions noise from a wind turbine farm may be greater than noise from the nearest turbine due to synchrony between noise from more than one turbine (van den Berg, 2005). Furthermore, if the dominant frequencies (including aerodynamic modulation) of different turbines vary by small amounts, an audible beat or dissonance may be heard when wind conditions are stable.

B. Shadow Flicker

Rhythmic light flicker from the blades of a wind turbine casting intermittent shadows has been reported to be annoying in many locations (NRC, 2007; Large Wind Turbine Citizens Committee, 2008). (Note: Flashing light at frequencies around 1 Hz is too slow to trigger an epileptic response.)

Modeling conducted by the Minnesota Department of Health suggests that a receptor 300 meters perpendicular to, and in the shadow of the blades of a wind turbine, can be in the flicker shadow of the rotating blade for almost 1½ hour a day. At this distance a blade may completely obscure the sun each time it passes between the receptor and the sun. With current wind turbine designs, flicker should not be an issue at distances over 10 rotational diameters (~1000 meters or 1 km (0.6 mi) for most current wind turbines). This distance has been recommended by the Wind Energy Handbook (Burton et al., 2001) as a minimum setback distance in directions that flicker may occur, and has been noted in the Bent Tree Permit Application (WPL, 2008).

Shadow flicker is a potential issue in the mornings and evenings, when turbine noise may be masked by ambient sounds. While low frequency noise is typically an issue indoors, shadow flicker can be an issue both indoors and outdoors when the sun is low in the sky. Therefore, shadow flicker may be an issue in locations other than the home.

Ireland recommends wind turbines setbacks of at least 300 meters from a road to decrease driver distraction (Michigan State University, 2004). The NRC (2007) recommends that shadow flicker is addressed during the preliminary planning stages of a wind turbine project.

IV. Impacts of Wind Turbine Noise

A. Potential Adverse Reaction to Sound

Human sensitivity to sound, especially to low frequency sound, is variable. Individuals have different ranges of frequency sensitivity to audible sound; different thresholds for each frequency of audible sound; different vestibular sensitivities and reactions to vestibular activation; and different sensitivity to vibration.

Further, sounds, such as repetitive but low intensity noise, can evoke different responses from individuals. People will exhibit variable levels of annoyance and tolerance for different frequencies. Some people can dismiss and ignore the signal, while for others, the signal will grow and become more apparent and unpleasant over time (Moreira and Bryan, 1972; Bryan and Tempest, 1973). These reactions may have little relationship to will or intent, and more to do with previous exposure history and personality.

Stress and annoyance from noise often do not correlate with loudness. This may suggest, in some circumstances, other factors impact an individual's reaction to noise. A number of reports, cited in Staples (1997), suggest that individuals with an interest in a project and individuals who have some control over an environmental noise are less likely to find a noise annoying or stressful.

Berglund et al. (1996) reviewed reported health effects from low frequency noise. Loud noise from any source can interfere with verbal communication and possibly with the development of language skills. Noise may also impact mental health. However, there are no studies that have looked specifically at the impact of low frequency noise on communication, development of language skills and mental health. Cardiovascular and endocrine effects have been demonstrated in studies that have looked at exposures to airplane and highway noise. In addition, possible effects of noise on performance and cognition have also been investigated, but these health studies have not generally looked at impacts specifically from low frequency noise. Noise has also been shown to impact sleep and sleep patterns, and one study demonstrated impacts from low frequency noise in the range of 72 to 85 dB(A) on chronic insomnia (Nagai et al., 1989 as reported in Berglund et al., 1996).

Case studies have suggested that health can be impacted by relatively low levels of low frequency noise. But it is difficult to draw general conclusions from case studies. Feldmann and Pitten (2004)) describe a family exposed during the winter to low frequency noise from a nearby heating plant. Reported health impacts were: "indisposition, decrease in performance, sleep disturbance, headache, ear pressure, crawl parästhesy [crawling, tingling or numbness sensation on the skin] or shortness of breath."

<u>*Annoyance, unpleasant sounds, and complaints*</u>

Reported health effects from low frequency stimulation are closely associated with annoyance from audible noise. "There is no reliable evidence that infrasounds below the hearing threshold produce physiological or psychological effects" (WHO, 1999). It has not been shown whether annoyance is a symptom or an accessory in the causation of health impacts from low frequency noise. Studies have been conducted on some aspects of low frequency noise that can cause annoyance.

Noise complaints are usually a reasonable measure of annoyance with low frequency environmental noise. Leventhall (2004) has reviewed noise complaints and offers the following conclusions:

> " The problems arose in quiet rural or suburban environments
> The noise was often close to inaudibility and heard by a minority of people
> The noise was typically audible indoors and not outdoors
> The noise was more audible at night than day
> The noise had a throb or rumble characteristic
> The main complaints came from the 55-70 years age group
> The complainants had normal hearing.
> Medical examination excluded tinnitus.
>
> " These are now recognised as classic descriptors of low frequency noise problems."

These observations are consistent with what we know about the propagation of low intensity, low frequency noise. Some people are more sensitive to low frequency noise. The difference, in dB, between soft (acceptable) and loud (annoying) noise is much less at low frequency (see Figure 4 audible range compression). Furthermore, during the daytime, and especially outdoors, annoying low frequency noise can be masked by high frequency noise.

The observation that "the noise was typically audible indoors and not outdoors" is not particularly intuitive. However, as noted in a previous section, low frequencies are not well attenuated when they pass through walls and windows. Higher frequencies (especially above 1000 Hz) can be efficiently attenuated by walls and windows. In addition, low frequency sounds may be amplified by resonance within rooms and halls of a building. Resonance is often characterized by a throbbing or a rumbling, which has also been associated with many low frequency noise complaints.

Low frequency noise, unlike higher frequency noise, can also be accompanied by shaking, vibration and rattling. In addition, throbbing and rumbling may be apparent in some low frequency noise. While these noise features may not be easily characterized, numerous studies have shown that their presence dramatically lowers tolerance for low frequency noise (Berglund et al., 1996).

As reviewed in Leventhall (2003), a study of industrial exposure to low frequency noise found that fluctuations in total noise averaged over 0.5, 1.0 and 2.0 seconds correlated with annoyance (Holmberg et al., 1997). This association was noted elsewhere and led (Broner and Leventhall, 1983) to propose a 3dB "penalty" be added to evaluations of annoyance in cases where low frequency noise fluctuated.

In another laboratory study with test subjects controlling loudness, 0.5 – 4 Hz modulation of low frequency noise was found to be more annoying than non-modulated low frequency noise. On average test subjects found modulated noise to be similarly annoying as a constant tone 12.9 dB louder (Bradley, 1994).

B. Studies of Wind Turbine Noise Impacts on People

1. Swedish Studies

Two studies in Sweden collected information by questionnaires from 341 and 754 individuals (representing response rates of 68% and 58%, respectively), and correlated responses to calculated exposure to noise from wind farms (Pedersen and Waye, 2004; Pedersen, 2007; Pedersen and Persson, 2007). Both studies showed that the number of respondents perceiving the noise from the wind turbines increased as the calculated noise levels at their homes increased from less than 32.5 dB(A) to greater than 40 dB(A). Annoyance appeared to correlate or trend with calculated noise levels. Combining the data from the two studies, when noise measurements were greater than 40 dB(A), about 50% of the people surveyed (22 of 45 people) reported annoyance. When noise measurements were between 35 and 40 dB(A) about 24% reported annoyance (67 of 276 people). Noise annoyance was more likely in areas that were rated as quiet and in areas where turbines were visible. In one of the studies, 64% respondents who reported noise annoyance also reported sleep disturbance; 15% of respondents reported sleep disturbance without annoyance.

2. United Kingdom Study

Moorhouse et al. (UK Department for Business Enterprise and Regulatory Reform, 2007) evaluated complaints about wind farms. They found that 27 of 133 operating wind farms in the UK received formal complaints between 1991 and 2007. There were a total of 53 complainants for 16 of the sites for which good records were available. The authors of the report considered that many complaints in the early years were for generator and gearbox noise. However, subjective analyses of reports about noise ("like a train that never gets there", "distant helicopter", "thumping", "thudding", "pulsating", "thumping", "rhythmical beating", and "beating") suggested that aerodynamic modulation was the likely cause of complaints at 4 wind farms. The complaints from 8 other wind farms may have had "marginal" association with aerodynamic modulation noise.

Four wind farms that generated complaints possibly associated with aerodynamic modulation were evaluated further. These wind farms were commissioned between 1999 and 2002. Wind direction, speed and times of complaints were associated for 2 of the sites and suggested that aerodynamic modulation noise may be a problem between 7% and 25% of the time. Complaints at 2 of the farms have stopped and at one farm steps to mitigate aerodynamic modulation (operational shutdown under certain meteorological conditions) have been instituted.

3. Netherlands Study

F. van den Berg et al. (2008) conducted a postal survey of a group selected from all residents in the Netherlands within 2.5 kilometers (km) of a wind turbine. In all, 725 residents responded (37%). Respondents were exposed to sound between 24 and 54 dB(A). The percentage of respondents annoyed by sound increased from 2% at levels of 30 dB(A) or less, up to 25% at between 40 and 45 dB. Annoyance decreased above 45 dB. Most residents exposed above 45 dB(A) reported economic benefits from the turbines. However, at greater than 45 dB(A) more respondents reported sleep interruption. Respondents tended to report more annoyance when they also noted a negative effect on landscape, and ability to see the turbines was strongly related to the probability of annoyance.

4. Case Reports

A number of un-reviewed reports have catalogued complaints of annoyance and some more severe health impacts associated with wind farms. These reports do not contain measurements of noise levels, and do not represent random samples of people living near wind turbines, so they cannot assess prevalence of complaints. They do generally show that in the people surveyed, complaints are more likely the closer people are to the turbines. The most common complaint is decreased quality of life, followed by sleep loss and headache. Complaints seem to be either from individuals with homes quite close to turbines, or individuals who live in areas subject to aerodynamic modulation and, possibly, enhanced sound propagation which can occur in hilly or mountainous terrain. In some of the cases described, people with noise complaints also mention aesthetic issues, concern for ecological effects, and shadow flicker concerns. Not all complaints are primarily about health.

Harry (2007) describes a meeting with a couple in Cornwall, U.K. who live 400 meters from a wind turbine, and complained of poor sleep, headaches, stress and anxiety. Harry subsequently investigated 42 people in various locations in the U.K. living between 300 meters and 2 kilometers (1000 feet to 1.2 miles) from the nearest wind turbine. The most frequent complaint (39 of 42 people) was that their quality of life was affected. Headaches were reported by 27 people and sleep disturbance by 28 people. Some people complained of palpitations, migraines, tinnitus, anxiety and depression. She also mentions correspondence and complaints from people in New Zealand, Australia, France, Germany, Netherlands and the U.S.

Phipps (2007) discusses a survey of 619 households living up to 10 kilometers (km; 6 miles) from wind farms in mountainous areas of New Zealand. Most respondents lived between 2 and 2.5 km from the turbines (over 350 households). Most respondents (519) said they could see the turbines from their homes, and 80% of these considered the turbines intrusive, and 73% considered them unattractive. Nine percent said they were affected by flicker. Over 50% of households located between 2 and 2.5 km and between 5 and 9.5 km reported being able to hear the turbines. In contrast, fewer people living between 3 and 4.5 km away could hear the turbines. Ninety-two households said that their quality of life was affected by turbine noise. Sixty-eight households reported sleep disturbances: 42 of the households reported occasional sleep disturbances, 21 reported frequent sleep disturbances and 5 reported sleep disturbances most of the time.

The Large Wind Turbine Citizens Committee for the Town of Union (2008) documents complaints from people living near wind turbines in Wisconsin communities and other places in the U.S. and U.K. Contained in this report is an older report prepared by the Wisconsin Public Service Corporation in 2001 in response to complaints in Lincoln County, Wisconsin. The report found essentially no exceedances of the 50 dB(A) requirement in the conditional use permit. The report did measure spectral data accumulated over very short intervals (1 minute) in 1/3 octave bands at several sites while the wind turbines were functioning, and it is of interest that at these sites the sound pressure level at the lower frequencies (below 125 Hz) were at or near 50 dB(A).

Pierpont (2009) postulates wind turbine syndrome, consisting of a constellation of symptoms including headache, tinnitus, ear pressure, vertigo, nausea, visual blurring, tachycardia, irritability, cognitive problems and panic episodes associated with sensations of internal pulsation. She studied 38 people in 10 families living between 1000 feet and slightly under 1 mile from newer wind turbines. She proposes that the mechanism for these effects is disturbance of balance due to "discordant" stimulation of the vestibular system, along with visceral sensations, sensations of vibration in the chest and other locations in the body, and stimulation of the visual system by moving shadows. Pierpont does report that her study subjects maintain that their problems are caused by noise and vibration, and the most common symptoms reported are sleep disturbances and headache. However, 16 of the people she studied report symptoms consistent with (but not necessarily caused by) disturbance of equilibrium.

V. Noise Assessment and Regulation

1. Minnesota noise regulation

The Minnesota Noise Pollution Control Rule is accessible online at: https://www.revisor.leg.state.mn.us/rules/?id=7030 . A summary of the Minnesota Pollution Control Agency (MPCA) noise guidance can be found online at: http://www.pca.state.mn.us/programs/noise.html . The MPCA standards require A-weighting measurements of noise; background noise must be at least 10 dB lower than the noise source being measured. Different standards are specified for day and night, as well as standards that may not be exceeded for more than 10 percent of the time during any hour (L10) and 50 percent of the time during any hour (L50). Household units, including farm houses, are Classification 1 land use. The following are the Class 1 noise limits:

Table 1: Minnesota Class 1 Land Use Noise Limits

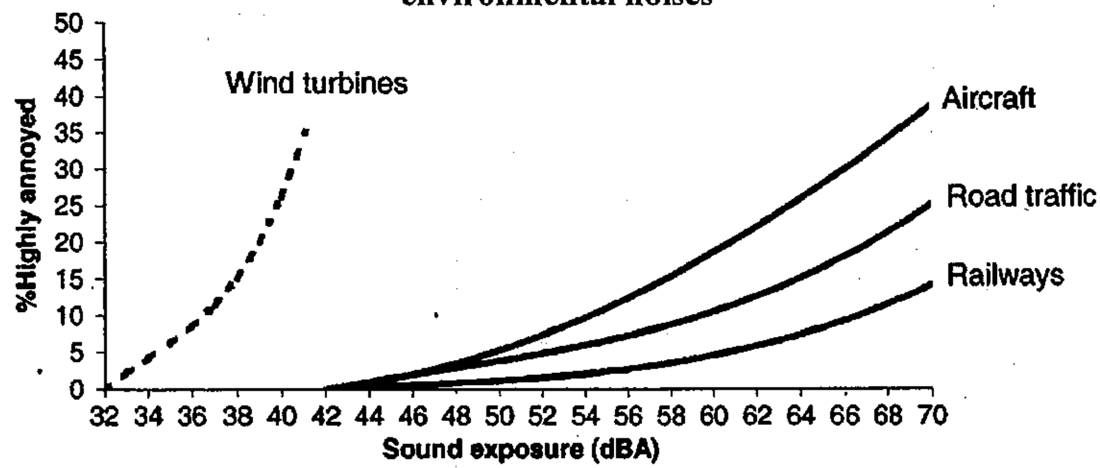
Daytime		Nighttime	
L50	L10	L50	L10
60 dB(A)	65 dB(A)	50 dB(A)	55 dB(A)

These noise limits are single number limits that rely on the measuring instrument to apply an A-weighting filter over the entire presumed audible spectrum of frequencies (20 Hz to 20 KHz) and then integrating that signal. The result is a single number that characterizes the audible spectrum noise intensity.

2. Low frequency noise assessment and regulation

Pedersen and Waye (2004) looked at the relationship between total dB(A) sound pressure and the annoyance of those who are environmentally exposed to noise from different sources. Figure 6 demonstrates the difficulty in using total dB(A) to evaluate annoyance. Note how lower noise levels (dB(A)) from wind turbines engenders annoyance similar to much higher levels of noise exposure from aircraft, road traffic and railroads. Sound impulsiveness, low frequency noise and persistence of the noise, as well as demographic characteristics may explain some of the difference.

Figure 6: Annoyance associated with exposure to different environmental noises



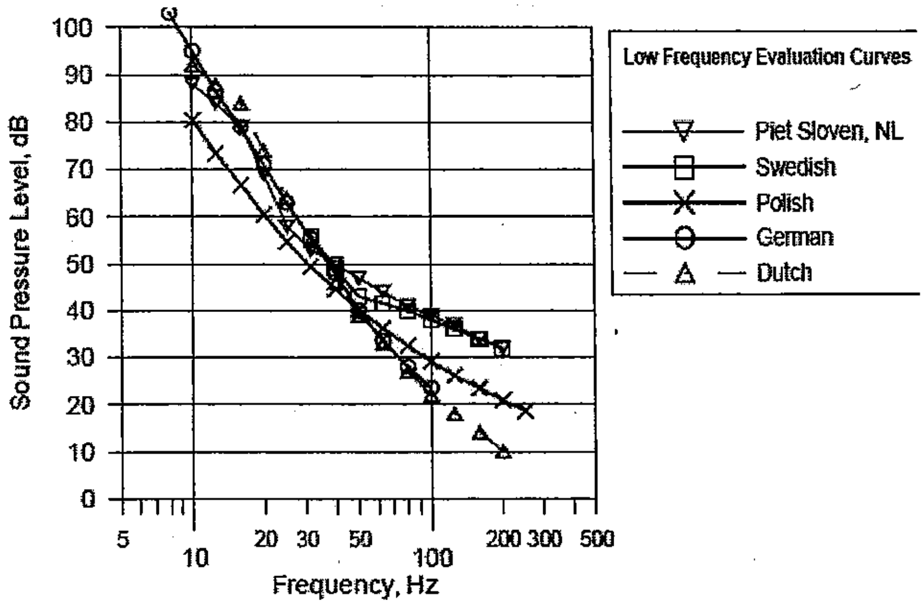
Reprinted with permission from Pedersen, E. and K.P. Waye (2004). Perception and annoyance due to wind turbine noise—a dose-response relationship. The Journal of the Acoustical Society of America 116: 3460. Copyright 2004, Acoustical Society of America.

Kjellberg et al. (1997) looked at the ability of different full spectrum weighting schemes to predict annoyance caused by low frequency audio noise. They found that dB(A) is the worst predictor of annoyance of available scales. However, if 6 dB ("penalty") is added to dB(A) when dB(C) – dB(A) is greater than 15 dB, about 71% of the predictions of annoyance are correct. It is important to remember that integrated, transformed measurements of SPL (e.g. dB(A), dB(C)) do not measure frequencies below 20 Hz. While people detect stimuli below 20 Hz, as discussed in above sections, these frequencies are not measured using an A-weighted or C-weighted meter.

The World Health Organization (WHO) recommends that if dB(C) is greater than 10 dB more than dB(A), the low frequency components of the noise may be important and should be evaluated separately. In addition, WHO says "[i]t should be noted that a large proportion of low-frequency components in noise may increase considerably the adverse effects on health." (WHO, 1999)

Many governments that regulate low frequency noise look at noise within bands of frequencies instead of summing the entire spectrum. A study by Poulsen and Mortensen (Danish Environmental Protection Agency, 2002) included a summary of low frequency noise guidelines. German, Swedish, Polish, and Dutch low frequency evaluation curves were compared (see Figure 7). While there are distinctions in how the evaluation curves are described, generally, these curves are sound pressure criterion levels for 1/3 octaves from about 8 Hz to 250 Hz. Exceedance in any 1/3 octave measurement suggests that the noise may be annoying. However, note that regulations associated with low frequency noise can be quite complex and the regulatory evaluations associated with individual curves can be somewhat different.

Figure 7: 1/3 Octave Sound Pressure Level Low frequency Noise Evaluation Curves



(Danish Environmental Protection Agency, 2002)

The Danish low frequency evaluation requires measuring noise indoors with windows closed; SPL measurements are obtained in 1/3 octave bands and transformed using the A-weighting algorithm for all frequencies between 10 and 160 Hz. These values are then summed into a single metric called $L_{pA,LF}$. A 5 dB "penalty" is added to any noise that is "impulsive". Danish regulations require that 20 dB $L_{pA,LF}$ is not exceeded during the evening and night, and that 25 dB $L_{pA,LF}$ is not exceeded during the day.

Swedish guidance recommends analyzing 1/3 octave bands between 31.5 and 200 Hz inside a home, and comparing the values to a Swedish assessment curve. The Swedish curve is equal to the United Kingdom (UK) Department of Environment, Food and Rural Affairs (DEFRA) low frequency noise criterion curve for overlapping frequencies (31.5 – 160 Hz).

The German "A-level" method sums the A-weighted equivalent levels of 1/3 octave bands that exceed the hearing threshold from 10 – 80 Hz. If the noise is not tonal, the measurements are added. The total cannot exceed 25 dB at night and 35 dB during the day. A frequency-dependent adjustment is applied if the noise is tonal.

In the Poulsen and Mortensen, Danish EPA study (2002), 18 individuals reported annoyance levels when they were exposed through earphones in a controlled environment to a wide range of low frequency environmental noises, all attenuated down to 35 dB, as depicted in Table 2. Noise was simulated as if being heard indoors, filtering out noise at higher frequencies and effectively eliminating all frequencies above 1600 Hz. Noise levels in 1/3 octave SPLs from 8 Hz to 1600 Hz were measured and low frequencies (below 250 Hz) were used to predict annoyance using 7 different methods (Danish, German A-level, German tonal, Swedish, Polish, Sloven, and C-level). Predictions of annoyance were compared with the subjective annoyance evaluations. Correlation coefficients for these analyses ranged from 0.64 to 0.94, with the best correlation in comparison with the Danish low frequency noise evaluation methods.

As would be expected, at 35 dB nominal (full spectrum) loudness, every low frequency noise source tested exceeded all of the regulatory standards noted in the Danish EPA report. Table 2 shows the Danish and Swedish regulatory exceedances of the different 35 dB nominal (full spectrum) noise.

Table 2: 35 dB(A) (nominal, 8 Hz-20KHz) Indoor Noise from Various Outdoor Environmental Sources

	Traffic Noise	Drop Forge	Gas Turbine	Fast Ferry	Steel Factory	Generator	Cooling Compressor	Discotheque
Noise	67.6 dB(lin)	71.1 dB(lin)	78.4 dB(lin)	64.5 dB(lin)	72.7 dB(lin)	60.2 dB(lin)	60.3 dB(lin)	67.0 dB(lin)
Noise ≥ 20 Hz	35.2 dB(A)	36.6 dB(A)	35.0 dB(A)	35.1 dB(A)	33.6 dB(A)	36.2 dB(A)	36.6 dB(A)	33.6 dB(A)
	62.9 dB(C)	67.3 dB(C)	73.7 dB(C)	61.7 dB(C)	66.0 dB(C)	58.6 dB(C)	59.0 dB(C)	57.8 dB(C)
Danish Environmental Protection Agency	14.5 dB	21.5 dB *	14.8 dB	15.0 dB	13.1 dB	16.1 dB	14.0 dB	18.0 dB *
Swedish National Board of Health and Welfare	14.1 dB	19.7 dB	15.9 dB	16.8 dB	15.5 dB	18.3 dB	16.0 dB	10.0 dB
* includes 5 dB "penalty"								

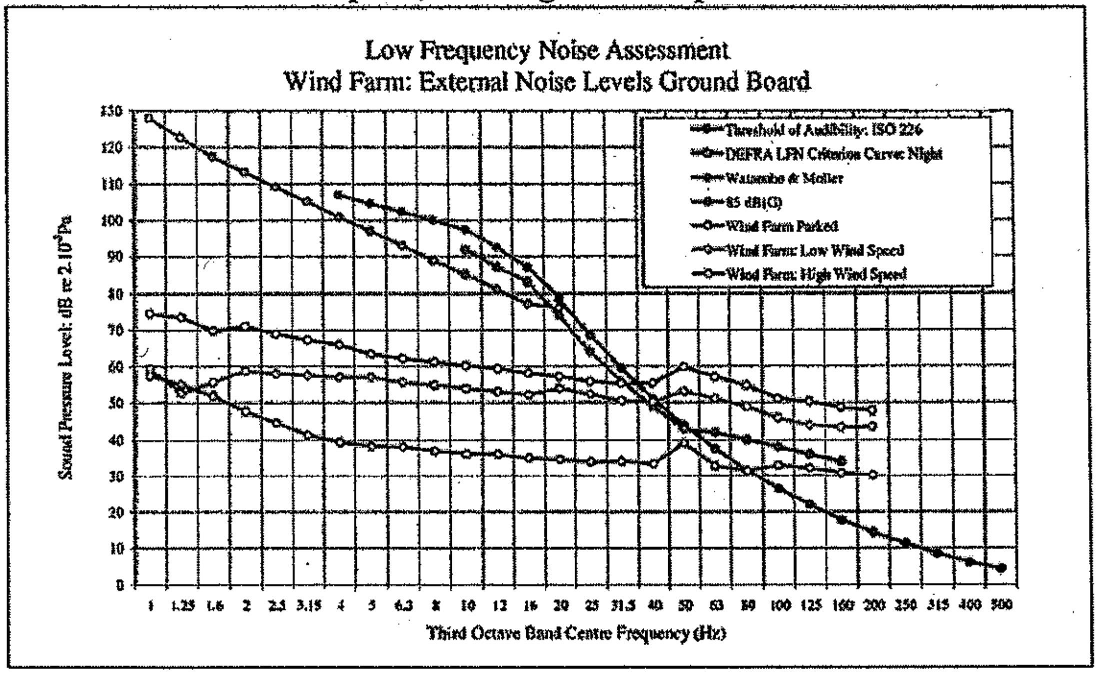
Noise adjusted to dB(lin), dB(A), dB(C) scales. Calculated exceedances of Danish and Swedish indoor criteria. (data from Danish Environmental Protection Agency, 2002)

In their noise guidance, the WHO (1999) recommends 30 dB(A) as a limit for "a good night's sleep". However, they also suggest that guidance for noise with predominating low frequencies be less than 30 dB(A).

3. Wind turbine sound measurements

Figure 8 shows examples of the SPLs at different frequencies from a representative wind turbine in the United Kingdom. Sound pressure level measurements are reported for a Nordex N-80 turbine at 200 meters (UK Department of Transport and Industry, 2006) when parked, at low wind speeds, and at high wind speeds. Figure 8 also includes, for reference, 3 sound threshold curves (ISO 226, Watanabe & Moller, 85 dB(G)) and the DEFRA Low Frequency Noise Criterion Curve (nighttime).

Figure 8: Low Frequency Noise from Wind Farm: Parked, Low Wind Speed, and High Wind Speed

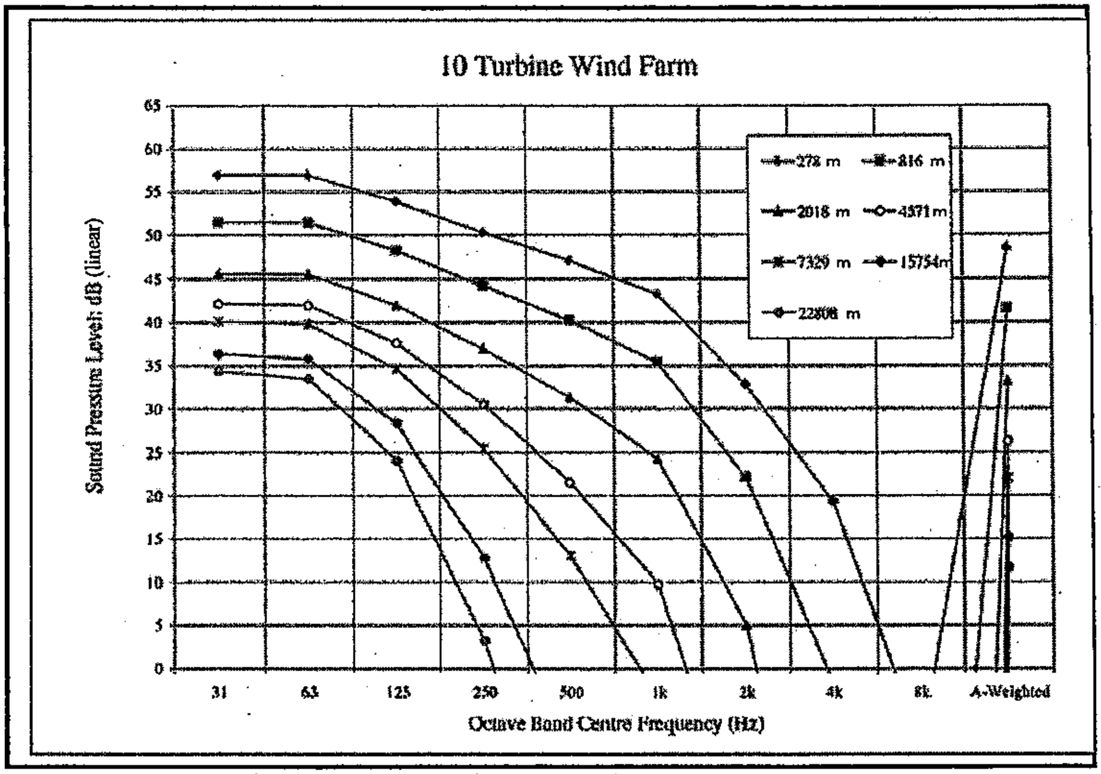


(UK Department of Transport and Industry, 2006)

In general, sound tends to propagate as if by spherical dispersion. This creates amplitude decay at a rate of about -6 dB per doubling of distance. However, low frequency noise from a wind turbine has been shown to follow more of a cylindrical decay at long distances, about -3 dB per doubling of distance in the downwind direction (Shepherd and Hubbard, 1991). This is thought to be the result of the lack of attenuation of low frequency sound waves by air and the atmospheric refraction of the low frequency sound waves over medium to long distances (Hawkins, 1987).

Figure 9 shows the calculated change in spectrum for a wind farm from 278 meters to 22,808 meters distant. As one moves away from the noise source, loudness at higher frequencies decreases more rapidly (and extinguishes faster) than at lower frequencies. Measurement of A-weighted decibels, shown at the right of the figure, obscures this finding.

Figure 9: Change in Noise Spectrum as Distance from Wind Farm Changes



(UK Department of Transport and Industry, 2006)

Thus, although noise from an upwind blade wind turbine is generally broad spectrum, without a tonal quality, high frequencies are efficiently attenuated by both the atmosphere, and by walls and windows of structures, as noted above. As a result, as one moves away from a wind turbine, the low frequency component of the noise becomes more pronounced.

Kamperman and James (2008) modeled indoor noise from outdoor wind turbine noise measurements, assuming a typical vinyl siding covered 2X4 wood frame construction. The wind turbine noise inside was calculated to be 5 dB less than the noise outside. Model data suggested that the sound of a single 2.5 MW wind turbine at 1000 feet will likely be heard in a house with the windows sealed. They note that models used for siting turbines often incorporate structure attenuation of 15dB. In addition, Kamperman and James demonstrate that sound from 10 2.5 MW turbines (acoustically) centered 2 km (1¼ mile) away and with the nearest turbine 1 mile away will only be 6.3 dB below the sound of a single turbine at 1000 feet (0.19 mile).

4. Wind turbine regulatory noise limits

Ramakrishnan (2007) has reported different noise criteria developed for wind farm planning. These criteria include common practices (if available) within each jurisdiction for estimating background SPLs, turbine SPLs, minimum setbacks and methods used to assess impacts. Reported US wind turbine noise criteria range from: ambient + 10 dB(A) where ambient is assumed to be 26 dB(A) (Oregon); to 55 dB(A) or "background" + 5 dB(A) (Michigan). European criteria range from 35 dB(A) to 45 dB(A), at the property. US setbacks range from 1.1 times the full height of the turbine (consenting) and 5 times the hub height (non-consenting; Pennsylvania); to 350 m (consenting) and 1000 m (non-consenting; Oregon). European minimum setbacks are not noted.

VI. Conclusions

Wind turbines generate a broad spectrum of low-intensity noise. At typical setback distances higher frequencies are attenuated. In addition, walls and windows of homes attenuate high frequencies, but their effect on low frequencies is limited. Low frequency noise is primarily a problem that may affect some people in their homes, especially at night. It is not generally a problem for businesses, public buildings, or for people outdoors.

The most common complaint in various studies of wind turbine effects on people is annoyance or an impact on quality of life. Sleeplessness and headache are the most common health complaints and are highly correlated (but not perfectly correlated) with annoyance complaints. Complaints are more likely when turbines are visible or when shadow flicker occurs. Most available evidence suggests that reported health effects are related to audible low frequency noise. Complaints appear to rise with increasing outside noise levels above 35 dB(A). It has been hypothesized that direct activation of the vestibular and autonomic nervous system may be responsible for less common complaints, but evidence is scant.

The Minnesota nighttime standard of 50 dB(A) not to be exceeded more than 50% of the time in a given hour, appears to underweight penetration of low frequency noise into dwellings. Different schemes for evaluating low frequency noise, and/or lower noise standards, have been developed in a number of countries.

For some projects, wind velocity for a wind turbine project is measured at 10 m and then modeled to the height of the rotor. These models may under-predict wind speed that will be encountered when the turbine is erected. Higher wind speed will result in noise exceeding model predictions.

Low frequency noise from a wind turbine is generally not easily perceived beyond ½ mile. However, if a turbine is subject to aerodynamic modulation because of shear caused by terrain (mountains, trees, buildings) or different wind conditions through the rotor plane, turbine noise may be heard at greater distances.

Unlike low frequency noise, shadow flicker can affect individuals outdoors as well as indoors, and may be noticeable inside any building. Flicker can be eliminated by placement of wind turbines outside of the path of the sun as viewed from areas of concern, or by appropriate setbacks.

Prediction of complaint likelihood during project planning depends on: 1) good noise modeling including characterization of potential sources of aerodynamic modulation noise and characterization of nighttime wind conditions and noise; 2) shadow flicker modeling; 3) visibility of the wind turbines; and 4) interests of nearby residents and community.

VII. Recommendations

To assure informed decisions:

- Wind turbine noise estimates should include cumulative impacts (40-50 dB(A) isopleths) of all wind turbines.
- Isopleths for dB(C) - dB(A) greater than 10 dB should also be determined to evaluate the low frequency noise component.
- Potential impacts from shadow flicker and turbine visibility should be evaluated.

Any noise criteria beyond current state standards used for placement of wind turbines should reflect priorities and attitudes of the community.

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Cyndi Apana

From: mailinglist@capitol.hawaii.gov
Sent: Monday, March 08, 2010 1:52 PM
To: EEPtestimony
Cc: choon@hawaii.rr.com
Subject: Testimony for SB2526 on 3/9/2010 9:30:00 AM

Bill No. SB2526

Date 3/8

Time 1352

Cat AF AS AX (B)

Type (1) 2 WI

Testimony for EEP/WLO 3/9/2010 9:30:00 AM SB2526

Conference room: 325
Testifier position: oppose
Testifier will be present: No
Submitted by: Choon James
Organization: Individual
Address: 56-1081 Kahuku, Hawaii 96717
Phone: 293 9111
E-mail: choon@hawaii.rr.com
Submitted on: 3/8/2010

Comments:
Testimony - SB 2526

Testimony for EEP/WLO 3/9/2010 9:30:00 AM SB2526 Conference room: 325

This is a very very important issue. You must consider the welfare and quality of life for affected residents and owners. The buffer zone has to be the most important factor to consider.

I oppose SB 2526 as the buffer zone is not sufficient enough to eliminate issues connected with this technology. These issues include; audible and visual impacts, industrial encroachment on residential and agricultural neighborhoods, and potential health and safety issues. A more acceptable distance of one half to one full mile should be considered as this may; increase public acceptance of large wind tower and turbines in other suitable sites, increase the margin of safety for residents living in close proximity to large 1 megawatt turbines and towers, lower adverse affects on health and wellness issues that may be detrimental to humans. Thank you for your consideration on this matter.

Choon James
56-1081 Kam Hwy
Kahuku, Hawaii 96717

Cyndi Apana

From: mailinglist@capitol.hawaii.gov
Sent: Monday, March 08, 2010 1:53 PM
To: EEPtestimony
Cc: tutorc@hotmail.com
Subject: Testimony for SB2526 on 3/9/2010 9:30:00 AM

Bill No. SB2526

Date 3/8

Time 1353

Cat AF AS AX B

Type 1 2 WI

Testimony for EEP/WLO 3/9/2010 9:30:00 AM SB2526

Conference room: 325
Testifier position: oppose
Testifier will be present: No
Submitted by: Cindy Tutor
Organization: Individual
Address: 55-488 Iosepa St. Laie, HI
Phone: 808-293-9413
E-mail: tutorc@hotmail.com
Submitted on: 3/8/2010

Comments:
I oppose SB 2526 as the buffer zone is not sufficient enough to eliminate issues connected with this technology. These issues include; audible and visual impacts, industrial encroachment on residential neighborhoods, and potential health and safety issues. A more acceptable distance of one half to one full mile should be considered as this may; increase public acceptance of large wind tower and turbines in other suitable sites, increase the margin of safety for residents living in close proximity to large 1 megawatt turbines and towers, lower adverse affects on health and wellness issues that may be detrimental to humans Thank you for your consideration on this matter.

Cyndi Apana

From: mailinglist@capitol.hawaii.gov
Sent: Monday, March 08, 2010 2:06 PM
To: EEPtestimony
Cc: mfeagai@byuh.edu
Subject: Testimony for SB2526 on 3/9/2010 9:30:00 AM

Bill No. SB 2526

Date 3/8

Time 1406

Cat AF AS AX (B)

Type (1) 2 WI

Testimony for EEP/WLO 3/9/2010 9:30:00 AM SB2526

Conference room: 325
Testifier position: oppose
Testifier will be present: No
Submitted by: Maria F. Feagai
Organization: Individual
Address: Iosepa St. B Laie, HI
Phone: (808) 293-5933
E-mail: mfeagai@byuh.edu
Submitted on: 3/8/2010

Comments:
Testimony - SB 2526

Testimony for EEP/WLO 3/9/2010 9:30:00 AM SB2526 Conference room: 325

I oppose SB 2526 as the buffer zone is not sufficient enough to eliminate issues connected with this technology. These issues include; audible and visual impacts, industrial encroachment on residential neighborhoods, and potential health and safety issues. A more acceptable distance of one half to one full mile should be considered as this may; increase public acceptance of large wind tower and turbines in other suitable sites, increase the margin of safety for residents living in close proximity to large 1 megawatt turbines and towers, lower adverse affects on health and wellness issues that may be detrimental to humans Thank you for your consideration on this matter.

Cyndi Apana

From: mailinglist@capitol.hawaii.gov
Sent: Monday, March 08, 2010 2:22 PM
To: EEPtestimony
Cc: rmakaiau@hawaii.rr.com
Subject: Testimony for SB2526 on 3/9/2010 9:30:00 AM

.ll No. SB2526

Date 3/8

Time 1422

Cat AF AS AX B

Type 1 2 WI

Testimony for EEP/WLO 3/9/2010 9:30:00 AM SB2526

Conference room: 325
Testifier position: oppose
Testifier will be present: No
Submitted by: Ralph K. Makaiau Jr.
Organization: Kahuku Community Association
Address: 56-134 Pualalea St. Kahuku, Oahu, Hawaii
Phone: (808) 478-6548
E-mail: rmakaiau@hawaii.rr.com
Submitted on: 3/8/2010

Comments:
The Kahuku Community Association, a wind farm project host community, opposes SB 2526. SB 2526 buffer zone is not sufficient enough to eliminate issues connected with wind turbine towers greater than 400 feet in height. This technology next to residentally zoned land with existing densily populated houses and homes amplify issues to include: audible and visual impacts, industrial encroachment on residential neighborhoods, and long term health and safety impacts.

A more acceptable minimum distance of one half mile to one mile should be considered when abutting residentially zoned land. Towers with lower heights and less adverse affects on health and safety may allow closer placement to residential dewelling subject to dewelling heights.

The Kahuku Community Association's Board supports renewable energy efforts, but not at the expense of our well being and has taken a position against four of the ten turbines due to proximity issues as proposed by Oahu Wind Power Partners LLC. The community is strongly against the four proposed sites. Again, please keep in mind that this is not an effort to oppose renewable energy. It is an effort to support responsible renewable energy in residentially zone districts.

Cyndi Apana

From: mailinglist@capitol.hawaii.gov
Sent: Monday, March 08, 2010 2:43 PM
To: EEPtestimony
Cc: macgregs@polynesia.com
Subject: Testimony for SB2526 on 3/9/2010 9:30:00 AM

Bill No. 2526

Date 3/8

Time 1443

Cat AF AS AX B

Type 1 2 WI

Testimony for EEP/WLO 3/9/2010 9:30:00 AM SB2526

Conference room: 325
Testifier position: oppose
Testifier will be present: No
Submitted by: SUSAN
Organization: Individual
Address: 55-484 PALEKANA ST LAIE, HI
Phone: 808-638-3705
E-mail: macgregs@polynesia.com
Submitted on: 3/8/2010

Comments:

Bill No. 2957

Date 3/8

800

AS AX B

PAHIO RESORTS 2 WI

Committee on Energy and Environmental Protection and
Committee on Water, Land, & Ocean Resources
Hearing
Tuesday, March 9, 2010 9:30 a.m.
Conference Room 325

Representative Hermina M. Morita, Chair and
Representative Ken Ito, Chair

Testimony on SB 2957, SD1 Relating to the Environment

Dear Chairs Morita, Ito and Members of the Committees:

My testimony is in SUPPORT of SB2957 SD1. My name is Lynn McCrory and I am the President of PAHIO Development, Inc. We are a locally owned and operated time share development company on the island of Kauai. I was a member of the Reinventing Government Task Force, and this was one of the concepts coming from the Task Force.

This bill provides a HRS Chapter 343 exemption for projects that protect, preserve, and enhance native species, native habitats, or native ecosystem functions. The concept is clear and the decision making authority resting with the Department of Land & Natural Resources provides the overview that is needed for allowing an exemption. The recommendation from the Task Force was to provide an "exemption" to Chapter 343 for examples such as installation of predator fencing or removal of rocks for safety issues. The addition of timeframes and a public period for review provides clarity.

The time and cost for both government staff and the private sector to complete an environmental assessment will be removed for specific nonimpact projects. This will result in a more efficient government and one that will continue to care for our fragile environment. I humbly ask for your consideration to SUPPORT SB2957 SD1. Mahalo!

Me ke aloha pumehana
With warm aloha,

PAHIO DEVELOPMENT, INC.

Lynn P. McCrory

Lynn P. McCrory
President

A Vacatic Ownership Company 3970 Wyllie Road, Princeville, Kauai, Hawaii 96722 Telephone 808/826/6549 Facsimile 808/826/6715

For the Protection of Hawaii's Native Wildlife

HAWAII AUDUBON SOCIETY

850 Richards Street, Suite 505, Honolulu, HI 96813-4709
Phone/Fax: (808) 528-1432; hiaudsoc@pixi.com
www.hawaiiaudubon.com

Bill No. SB 2957

March 9, 2010

Date 3/8

Time 1351

Cat AF AS AX B

Type 1 2 WI

Committee on Energy & Environmental Protection
Representative Hermina Morita, Chair
Representative Denny Coffman, Vice Chair

Committee on Water, Land, & Ocean Resources
Representative Ken Ito, Chair
Representative Sharon E. Har, Vice Chair

Thursday, February 18, 2010; 2:45 P.M., Conference Rm. 325

Re: SB2957, SD1 – Relating to the Environment

Testimony in Opposition

Chair's Morita and Ito and members of the joint committees. Thank you for the opportunity to provide testimony in opposition on SB2957, SD1, which if enacted would provide an exemption for projects that protect, preserve, and enhance the environment, land, or natural resources, under certain conditions.

The Hawaii Audubon Society was founded in 1939, and is the Hawaii's oldest conservation organization. For the last 71 years the Society's primary mission has been the protection of Hawaii's endemic birds, wildlife, native habitats, and aquatic resources. One of keys in protecting our Island's unique ecosystems is our environmental review process as outlined in HRS Chapter 343.

Although the environmental review process can be burdensome we believe it is a necessary process that ensures that there is systematic identification and evaluation of the potential impacts (effects) of proposed projects, programs, or policies on the ecological, cultural, and socioeconomic components on the environment.

We would note for the committees that our current environmental review process as outlined in the National Environmental Policy Act and HRS Chapter 343 already provides for exemption of certain projects that are deemed to have little or no impacts on the environment.

Since there are adequate statutory provisions in place that address this issue the Audubon Society would recommend that this bill be deferred.

Sincerely,

George Massengale, J.D.
Legislative Analyst

Printed on 100% Post-Consumer Recycled Paper

Cyndi Apana

From: mailinglist@capitol.hawaii.gov
Sent: Monday, March 08, 2010 2:00 PM
To: EEPtestimony
Cc: nicoleel@hawaii.edu
Subject: Testimony for SB2957 on 3/9/2010 9:00:00 AM

Bill No. SB2957

Date 3/8

Time 1400

Cat AF AS AX (B)

Type (1) 2 WI

Testimony for EEP 3/9/2010 9:00:00 AM SB2957

Conference room: 325
Testifier position: comments only
Testifier will be present: Yes
Submitted by: Nicole Lowen
Organization: UH Environmental Center
Address: 2500 Dole Street Honolulu, HI
Phone: 956-3974
E-mail: nicoleel@hawaii.edu
Submitted on: 3/8/2010

Comments:

Cyndi Apana

From: mailinglist@capitol.hawaii.gov
Sent: Monday, March 08, 2010 10:03 PM
To: EEPtestimony
Cc: harrybrown@hawaii.rr.com
Subject: Testimony for SB2526 on 3/9/2010 9:30:00 AM

Bill No. SB 2526

Date 3/8

Time 2203

Cat AF AS AX (B)

Type 1 (2) WI

Testimony for EEP/WLO 3/9/2010 9:30:00 AM SB2526

Conference room: 325
Testifier position: oppose
Testifier will be present: No
Submitted by: Harry, Donna & Kahiau Brown
Organization: Individual
Address: 56-306 Huehu St. Kahuku, HI 96731
Phone: 808 393-7767
E-mail: harrybrown@hawaii.rr.com
Submitted on: 3/8/2010

Comments:
We oppose SB 2526 because the distance is not sufficient to minimize the effects on health, sound disturbance and many other negative impacts on our very close community. Just the shaking, vibration and rumbling of military aircraft (even at night) who promised to keep distant from our housing has plagued us for years. There are many like ourselves who have special needs children and elderly (also a hospital connected to us) who will be adversely affected by this venture. Please move the wind farm back at least a mile and we will be more supportive. Respectfully submitted.

Cyndi Apana

From: mailinglist@capitol.hawaii.gov
Sent: Monday, March 08, 2010 10:15 PM
To: EEPtestimony
Cc: cpualoa@hotmail.com
Subject: Testimony for SB2526 on 3/9/2010 9:30:00 AM

Bill No. SB2526

Date 3/8

Time 2215

Cat AF AS AX (B)

Type 1 (2) WI

Testimony for EEP/WLO 3/9/2010 9:30:00 AM SB2526

Conference room: 325
Testifier position: oppose
Testifier will be present: No
Submitted by: Colleen
Organization: Individual
Address: 55-545 Naniloa Loop Laie HI
Phone: (808) 756-1855
E-mail: cpualoa@hotmail.com
Submitted on: 3/8/2010

Comments:
I oppose SB2526. This distance is insufficient and will effect the health and wefare of those living within those perimeters. The distance needs to be increased to 1 mile min. up to 10. I am a big advocate for alternative energy but it must be safe for the existing residence. Please so the responsible thing and kill this bill.

Cyndi Apana

From: mailinglist@capitol.hawaii.gov
Sent: Monday, March 08, 2010 10:47 PM
To: EEPtestimony
Cc: tutorc@gmail.com
Subject: Testimony for SB2526 on 3/9/2010 9:30:00 AM

Bill No. SB2526

Date 3/8

Time 2247

Cat AF AS AX B

Type 1 2 WI

Testimony for EEP/WLO 3/9/2010 9:30:00 AM SB2526

Conference room: 325
Testifier position: oppose
Testifier will be present: No
Submitted by: Cindy Fonoimoana Tutor
Organization: Individual
Address: 55-488 Iosepa St. Laie, HI
Phone: 808-293-9413
E-mail: tutorc@gmail.com
Submitted on: 3/8/2010

Comments:
Do not pass SB2526 without amending the setback requirement to a safer distance of at least 2 miles from the nearest residence. We do not want Kahuku to be known for the "Kahuku Disease" as the Australian city of Waubra is known for the "Waubra Disease". Citizens of Waubra are experiencing symptoms such as high blood pressure, headaches, irregular heartbeats, insomnia, mood swings due to poor sleep as a result of the recent installation of Wind Turbines near their community. Be responsible! Do not solve one problem by creating another.

Cyndi Apana

From: mailinglist@capitol.hawaii.gov
Sent: Monday, March 08, 2010 11:03 PM
To: EEPtestimony
Cc: tasiponder1@yahoo.com
Subject: Testimony for SB2526 on 3/9/2010 9:30:00 AM

Bill No. SB2526

Date 3/8

Time 2303

Cat-AF AS AX B

Type 1 2 WI

Testimony for EEP/WLO 3/9/2010 9:30:00 AM SB2526

Conference room: 325
Testifier position: oppose
Testifier will be present: Yes
Submitted by: Aliitasi Ponder
Organization: Individual
Address: Kahuku, HI
Phone:
E-mail: tasiponder1@yahoo.com
Submitted on: 3/8/2010

Comments:
Aloha,

I am a Kahuku resident. I testified when SB2526 was before the Senate.

We have gathered approximately 200 signatures of community members who feel the suggested set back distance of 1000 ft puts safety and health at risk and should be amended so that wind turbines can be no closer than 1/2 mile from residential housing. There is ample scientific and medical evidence available that substantiates why.

We are dismayed at the way a decision of such import is moving along without informing those immediately and directly impacted. As yet most of our community has no idea of the threat around the corner, or how every one of us could be affected. We respectfully ask that you slow down and include us; involve us in a decision-making process that could forever impact our livelihoods, mental, emotional, physical and financial health. That is Democracy.

At the last hearing it was mentioned that sound could end up being the criteria used in establishing a standard set back distance. But there are different ways to measure sound (dBA as compared to dBC) and often the more impact-felt low frequency sound is knowingly sidelined by fast-moving developers.

Therefore as a part of your deliberation process we ask that you please read a paper presented at The Institute of Noise Control Engineering (INCE) NOISE-CON 2008, July 28-31, 2008 to understand how sound criteria can be selectively used by developers in order to justify building turbines closer to communities than has been deemed safe by experts in the field. The paper stipulates how sound should instead be measured if we are to consider community health. The formal paper reviewed sound studies conducted by consultants for governments, the wind turbine owner, or the local residents for a number of sites with known health or annoyance problems. The purpose was to determine if a set of simple guidelines using dBA and dBC sound levels can serve as the 'safe' siting guidelines for noise and its effects on communities and people.

http://www.wind-watch.org/documents/simple-guidelines-for-siting-wind-turbines-to-prevent-health-risks/

http://www.wind-watch.org/documents/the-how-to-guide-to-criteria-for-siting-wind-turbines-to-prevent-health-risks-from-sound/

Here are some of the
Paper Highlights:

Excerpt #1.

"The review showed that some residents living as far as 3 km (two (2) miles) from a wind farm complain of sleep disturbance from the noise. Many residents living one-tenth this distance (300 m. or 1000 feet) from a wind farm are experiencing major sleep disruption and other serious medical problems from nighttime wind turbine noise. The peculiar acoustic characteristics of wind turbine noise immissions cause the sounds heard at the receiving properties to be more annoying and troublesome than the more familiar noise from traffic and industrial factories. Limits used for these other community noise sources do not appear to be appropriate for siting industrial wind turbines. The residents who are annoyed by wind turbine noise complain of the approximately one (1) second repetitive swoosh-boom-swoosh-boom sound of the turbine blades and "low frequency" noise."

Excerpt #2.

"How does wind turbine noise impact nearby residents? Initially, the most common problem is chronic sleep deprivation during nighttime. According to the medical research documents, this may develop into far more serious physical and psychological problems."

Excerpt #3.

"The simple fact that so many residents complain of low frequency noise from wind turbines is clear evidence that the single A-weighted (dBA) noise descriptor used in most jurisdictions for siting turbines is not adequate..."

"It is well known that dBC readings are more predictive of perceptual loudness than dBA readings if low frequency sounds are significant." (THIS is why wind developers prefer using the dBA readings!!)

Excerpt #4.

"We are proposing to use the commonly accepted dBA criteria that is based on the preexisting background sound levels plus a 5 dB allowance for the wind turbine's immissions (e.g. L90A+5) for the audible sounds from wind turbines. But, to address the lower frequencies that are not considered in A-weighted measurements, we are proposing to add limits based on dBC. The Proposed Sound Limits are presented in the text box at the end of this paper. For the current industrial grade wind turbines in the 1.5 to 3 MWatt range, the addition of the dBC requirement will result in an increased distance between wind turbines and the nearby residents."

There is a lot to consider in addition to our state's bottom line. We ask you take the time needed to weigh things carefully.

Mahalo,

Aliitasi Ponder