Letter sent to commissioners today along with two attachments

February 6, 2017

To the Commissioners and Planning Department of Lincoln County, SD;

Before I start I want to state that I will discuss some information later in this letter that does have documents on your website already but will attach them again with the letter I send to Planning and Zoning so they will be easier for you to access.

This letter is written with concern over the process that has been in motion for almost three years now regarding the ordinances involving wind energy as well as a project that is being developed for the largest industrial wind energy facility in our great state of South Dakota. The following are observations, concerns, facts, and opinions regarding this process.

The first observation, and one of great importance, is the question that has been asked of Commissioner King as well as some of those that sit on the Planning and Zoning Board. It has been asked as to how they came to the recommendations of a 1 mile setback and noise levels that they brought to the Commission. I don’t believe it is rocket science to understand where these recommendations came from. They have been exposed to countless hours of testimony as well as thousands of pages of documents that their recommendations were derived from. As a Commissioner or Planning Director one shouldn’t question as to where their recommendations came from. They had so much more exposure to testimony and the documents that were used in that testimony to understand and put together the entire puzzle. As Commissioners you have had very little time to listen and understand that. I do understand the limitations that have been placed on testimony, etc. What I don’t understand is how you expect to make a decision that is in the best interest of all of those in Lincoln County with the limited amount of understanding you are exposing yourself to. You need
to have some confidence in the recommendations that were sent to you. You cannot expect to put the puzzle together yourself unless you are willing to spend the time and effort that those on the Planning and Zoning Board did.

There was much testimony and from that testimony documents that were placed on your website. I understand it is difficult for you to understand the context of the documents without testimony. If you are not reading and understanding all of the documents that have been placed on your website you are not going to be able to put the puzzle pieces together. You do know where the documents come from. If you are wondering how this fits in you need to ask those who presented the documents. Yet, I have not heard of one call from any of you to understand any of this. You are serving the people, yet, don’t appear to have any desire to understand what the people are telling you. I am going to ask you a very direct question, are you reading all of the information that has been placed on your website over the last few years?

For myself, I can tell you that any information that was shared or quoted in testimony that I gave is on your website. That cannot be said for proponents of industrial wind. They have thrown out many names and documents that are not on your website. After doing some research myself I do have an understanding why that may be. Some of the names that have been spoken and the documents I was able to find really don’t have any relation to what we are discussing here in Lincoln County, as a matter of fact, some don’t appear to have anything at all to do with industrial wind energy siting. They are very good at attempting to give you a perception. That is what the wind energy lobby, aka Wind Energy Association members, and developers are getting paid to do. Yet, perception is not reality. When observing the actions and change in proposals from that which the Planning and Zoning Board gave you at times it appears that Mr. Brown and some of you may be swayed by this perception without understanding the reality. I am sure you are being lobbied hard by these industrial wind energy proponents that are attempting to convince you that they are showing you the entire puzzle when in reality they are only giving you a few pieces. You cannot forget that they are getting paid for this and that is their job while the majority of those in this county who have real concerns that are based on real facts have a job and family to take care of and aren’t going to be in your offices and at the courthouse every week to lobby you on their side of the story. When looking at the amount of reality that is out there and available I would say that we have many more pieces of the puzzle to give you and put together than that of the proponents of industrial wind, yet, they are very good at giving you a different perception.

A great example of this is the Massachusetts Wind Turbine Health Impact Study of 2012. In it the panel looked at 5 peer-reviewed research studies and came to very different conclusions than what the 5 original authors did. I have attached a review by Dr. Raymond Hartman that he presented to the Zoning Board of Charlestown, Rhode Island. In it he explains the many flaws of the Massachusetts study. I will just tell you that the reality of all 5 of the studies that this panel studied had conclusions of adverse health effects that this panel totally ignored. There is also a dose-response relationship in some of these peer-reviewed studies. With this comparison alone I have shown you 5 pieces to the puzzle that are peer-reviewed compared to 1 that wind proponents are continually referencing. This 1 review that they use appears to be very flawed and biased.

Another observation that can be made regarding the development of Industrial Wind is that the locations of these developments are changing. It no longer is being developed in wide open areas that there may only be one home among 10’s or even 100’s of turbines. It is moving into much more densely populated areas with the population not wanting or expecting this type of development. Due to this change it is very important to understand that ordinances will vary greatly from place to place due to not only population size but the expectations of that population. A setback of 1000 ft might work in some areas that are sparsely populated with farmers working with heavy machinery every day. That type of setback is not going to work in a place such as Lincoln County. We live in a county that is growing faster than most everywhere, not only in our State but in the Country. Those that are living in this County are not expecting this kind of Industrial expansion next to them and throughout the County. As a planning Director I would urge Mr. Brown not to cherry-pick
ordinances that may be given to him by wind developers or limit himself to only a few comparisons. He may look at one ordinance that has a setback of 2500 ft and the location next to it may have a setback of 1 mile. That is becoming very common with the variety of needs based on the population that is affected and the age of the ordinance. I would also make note that many of these ordinances have been made many years ago when population density was different and less facts were known about the negative affects Industrial Wind Turbines (IWT) have on the health, safety, and welfare of those who have to live among them. Again, a point that the wind proponents refuse to accept or tell you. Something that is left out of the perception they are attempting to give you.

As I near the end of this letter I would like to share some information from The Acoustic Ecology Institute (AEI) that was published by Jim Cummings in the Wind Farm Noise 2012 Science and Policy Overview. I have attached the entire document to the letter I have sent to Planning and Zoning. It should be noted that Jim Cummings has a very unique and broad look and understanding of industrial wind energy and its effects on the population as he is a member of the American Society of Acoustic Ecology, the American Wind Energy Association, and the Acoustical Society of America.

In this report he offers a reality check regarding wind turbine noise propagation. He states that the typical maps and images used from GE and the American Wind Energy Association (AWEA) are significantly different than reality. When he looked at a few projects that he had information on and the actual sound contour maps that were generated by consultants the difference between those project maps and that of GE and the AWEA was strikingly different. The results to get to 40dB was also significantly variable, even within the same project. The distances were anywhere from roughly a half of a mile to well over one mile. These results were also from ideal wind conditions that were steady with no changes in speed or turbulence.

He also noted that when looking at all of the community surveys that he has come across in an area where turbines are operating there is a consistency in the percentage of people annoyed with the noise that the turbines produce. Of those living within a half mile to a mile, roughly half of those within a half mile and 20-30% of those within a half mile to a mile report that noise is a problem for them. With setbacks in Lincoln County of less than 1 mile it would not be surprising to see 20-30%, and possibly up to 50%, of the population having a problem with noise according to his research of the literature. Due to what this reality is it may be the reason why many counties and towns across the Country are looking at setbacks of ¾ of a mile or greater to protect the health, safety, and welfare of those who have to live among them. We cannot miss the reality that living within a mile of IWTS is dramatically different than living a greater distance away. A great example that Jim Cummings gives in this report is the town of Freedom, Maine. He met with neighbors and wind proponents here and found a striking effect that living with wind turbines for a few years has had on them. This community has a very strong pro wind element to it and they are considering very different ranges and options regarding their wind ordinances. This pro wind component is recommending 4000 ft setbacks rather than the typical starting point of 1000-1750 ft.

In this 2012 review by AEI it appears that there is a middle ground of current setbacks being proposed and implemented of sound levels 35-45 dBA with a significant proportion of those at 40 dBA. Distance setbacks are variable with some as close as ½ mile but with some also at more than 1 mile. It would appear that a middle ground regarding distance would be somewhere between ¾-1 mile. With this information I would be so bold to say that the industry standard that developers are trying to sell is not the reality of what councils such as yourselves are proposing and implementing.

To close I would remind yourself of our current wind ordinance and its intent. Section 12.02 A states that the intent of regulations for WECs is to encourage the development of alternative sources of energy while protecting the health, safety, and welfare of the public. I interpret this as saying that we will develop alternative energy sources but not at the expense of the people of Lincoln County. I would also remind you
that there are two sources of wind energy, personal and industrial WECs. At this time we are only addressing industrial WECs.

According to reality it would appear that setbacks of less than 1 mile would be placing 20-30%, and up to 50%, of the public at risk of the harm of annoyance, noise, stress, and sleep disturbance. In my opinion, and I urge that it is yours too, that is unacceptable.

Thank you for your service and the time you spend reading my correspondence.

If you have any questions or concerns please don’t hesitate to contact me.

David Brouwer
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Beresford, SD
Statement of Dr. Raymond S. Hartman  
Presented to the Zoning Board of Charlestown, Rhode Island

Critique of the Massachusetts Department of Environmental Planning (DEP)  
“Wind Turbine Health Impact Study,  

June 5, 2013

Executive Summary

I have been asked by a group of residents of Charlestown, Rhode Island to review the report submitted in January, 2012 to the Massachusetts Department of Environmental Planning (DEP) by an “Independent Expert Panel” to assess the health impacts of Industrial Wind Turbines (IWTs). Having done so, I conclude that the purported “independent expert panel” was not independent. It was no more “expert” than scientists whose research was dismissed or marginalized by the Panel. The Panel and its staff conducted no independent primary scientific research, even though it recognizes how such research should be conducted and it had ample opportunity to sample nearby, highly relevant, Industrial Wind Turbine (IWT) installations in the Commonwealth and in New England. It dismisses or marginalizes a significant body of research conducted by scientists with credentials as good as, or better than, the credentials of the Panel members. Instead, the Panel relies upon a very limited number of research articles and after doing so comes to very strong conclusions. That in itself is questionable scientific practice. More importantly, the Panel misstates the full context of the research upon which it relies.

I conclude, therefore, that the Wind Turbine Health Impact Study conducted by the Independent Expert Panel and presented to the Massachusetts DEP in January 2012 is biased, inaccurate and a fairly transparent mischaracterization of the existing scientific research. It cannot be relied upon to support the contention that IWTs have no impact upon the health and well-being of neighboring residents. The report has little scientific merit.

My testimony proceeds as follows. In Section I, I introduce my qualifications to put forward this analysis. In Section II, I summarize my conclusions. In Section III, I present in greater detail, the research finding of the research papers upon which the Panel relies. I demonstrate that these research papers find adverse health impacts and nuanced conclusions about how IWTs impact human health and well-being. This discussion
demonstrates that the Panel’s reliance upon them as proof that IWTs have no adverse health impacts is a gross mischaracterization.

I. QUALIFICATIONS

1. My name is Raymond S. Hartman. I am Director and President of Greylock McKinnon Associates (GMA), a consulting and litigation support firm located in Cambridge, Massachusetts.

2. I am a mathematical economist specializing in microeconomics, econometric and statistical modeling and the study of industrial organization. I have taught economics, conducted economic and econometric research and provided consulting in my areas of specialization for forty years. I taught economics as an Assistant Professor and Associate Professor within the Department of Economics at Boston University over the period 1977-1988. I taught economics as a Visiting Associate Professor and member of the Visiting Faculty at the School of Law, Boalt Hall, University of California at Berkeley over the period 1988-1993. I was a member of the research faculty at MIT over the period 1977-1982, during which time I conducted research in energy markets for the United States Department of Energy. During the same time, I declined the offer of a Visiting Assistant Professorship within the Department of Applied Economics at MIT. Over the entire period since 1971, I have consulted to federal and state governmental bodies, private corporations, law firms, consulting companies, research organizations and international lending organizations. I have been a research referee for a variety of academic journals. I am the author of more than 100 refereed journal articles, book chapters and research/consulting reports.

3. Over the last 35 years, I have submitted oral and written testimony before United States federal and state courts of law and regulatory commissions. I have submitted testimony to international arbitration panels, international governments and the World Bank. My testimony as an expert witness has addressed anticompetitive behavior, fraudulent pricing schemes, merger efficiencies, breach of contract, employment discrimination, patent infringement, class certification, adverse health impacts of particular technologies and products, and the estimation of damages in a variety of markets and industries including, but not limited to, the pharmaceutical industry, the health care services industry, the electric power industry, the banking industry, the copper industry, the defense industry, the cable TV industry, the tobacco industry, the electrical and mechanical carbon products industry, the medical devices industry, the automobile industry, and the construction industry. My testimony has been upheld by federal appellate courts.
4. My two primary areas of specialty are the economics of energy markets and the economics of the markets for health-care services, health-care devices and pharmaceuticals.

5. Over the last thirty-five years, I have submitted testimony, conducted research and/or consulted on a variety of matters of litigation or policy evaluation addressing energy markets and the environmental impacts of alternative energy proposals. I have focused on the markets for electric power and natural gas specifically. My consulting and/or litigation assignments have all included quantitative modeling. I have designed and implemented models for load forecasting, evaluation of conservation and load management programs, econometric cost analysis, analysis of revenue requirements and rate-making, analysis of value of service reliability, the analysis of mergers and acquisitions, analysis of industry restructuring, analysis of manipulation of spot and future prices in energy markets, and analysis of contract damages arising from DOE’s Standard Contract regarding storage of spent nuclear fuel waste. In these assignments, I consulted or testified for such clients as Arizona Public Service, the Pacific Gas and Electric Company, the Southern California Edison Company, the Southern California Gas Company, the San Diego Gas and Electric Company, Portland General Electric Company, Bonneville Power Administration, General Public Utilities, Northeast Utilities, Niagara Mohawk Power Corporation, the Delmarva Power Corporation, Florida Power Corporation, Sithe Energies, the California Energy Commission and Public Utilities Commission, the Missouri Public Service Commission, the Rhode Island Division of Public Utilities, the Attorney General of the State of Massachusetts, the Electric Power Research Institute, the Gas Research Institute, the U.S. Department of Energy, the U.S. Department of Justice, the World Bank, and the governments of Indonesia and Thailand.

6. The work that I performed for the Rhode Island Division of Public Utilities and the Attorney General of the State of Massachusetts was undertaken and submitted in 1995-1996. It addressed the economic impacts of restructuring electric markets in New England. Much of that restructuring provides the basis through which alternative energy producers, such as large-scale industrial wind turbine installations and solar photovoltaic installations, are allowed to integrate into the grid.

7. One of my earliest consultations in energy markets was for the United States Department of Energy. Over 1977-1982, as a member of the MIT research faculty, I studied the market feasibility of alternative energy sources, most particularly solar photovoltaic installations. Most recently, over the last five to ten years, I have testified numerous times before the United States Court of Federal Claims on behalf of the DOJ and DOE relating to damages regarding storage of nuclear waste.
Over the last twenty years, I have analyzed and/or submitted testimony in approximately 100 matters of litigation in a variety of health-care, pharmaceutical and medical device industries. The cases most frequently involved antitrust allegations of market foreclosure and economic injury. My testimony in these matters addressed market definition, product competition, antitrust violations, class certification, unlawful promotion (under RICO) and/or consumer protection laws, and/or damage estimation. My CV provides a more complete presentation of my testimony.

Indeed, I regularly have testified as an expert witness on behalf of the Massachusetts Attorney General’s office in a variety of matters, including the 1995-1998 tobacco litigation (the result of which the Commonwealth received billions of dollars in settlement from “Big Tobacco”); litigation against large drug companies for defrauding the Massachusetts Medicaid program (2008-2011); the restructuring of the electric power industry (1990s), mentioned above; and a variety of public utility rate cases (2000s).

I received a bachelor’s degree in economics (magna cum laude) from Princeton University in 1969. I received a master’s degree in economics from MIT in 1971 and a Ph.D. in economics from MIT in 1977. My Curriculum Vita is attached to provide specific and recent biographical and professional information (see Attachment A.1). The recent cases in which I have submitted testimony at deposition and trial are provided in Attachment A.2. I have waived any compensation in this matter.

In rendering my opinions, I have relied upon the materials reasonably relied on by experts in my field in forming opinions and drawing inferences on subjects such as these.

II. MY ASSIGNMENT AND SUMMARY OF MY CONCLUSIONS

A. Assignment

I have been asked by a group of residents of Charlestown, Rhode Island to review and critique the “Wind Turbine Health Impact Study” (hereafter the Health Impact Study), a report put forward in January 2012 by the panel convened by Governor Deval Patrick and Commissioner Kimmel of the Massachusetts DEP.\(^1\) The stated goal of the research of this Study was to identify whether, and quantify the extent to which, Industrial Wind Turbine Installations (IWTs) have adverse health impacts upon neighboring residents.

\(^1\) I note that I am neither for nor against the use of IWTs in all situations. I feel that each siting needs to be evaluated both from a health perspective and from an economic perspective before IWTs should be installed. It is clear from the research that there are health issues in siting IWTs in residential and rural areas and that many of these sites are not economically efficient for IWT sites.
13. I am quite familiar with this study. I reviewed and critiqued it during January-February of 2012, at the request of my neighbors in my home town of Shelburne Falls, Massachusetts. I presented my report to the residents of Shelburne Falls. I also submitted written testimony before the DEP hearing concerning the results of the report.

14. I have reviewed and responded to reports like this in excess of 100 times over my career, as an expert witness and as a peer-reviewing academic research referee.

B. Conclusions

15. The Health Impact Report fails to rise to the level of reliable scientific research. In matters of litigation, research or testimony that does not reflect, or indeed violates, standard scientific practices is excluded from the record as Junk Science. As noted above, I have submitted many pieces of testimony over the last 35 years. My testimony has never been excluded as Junk Science. I find that the Health Impact Study is Junk Science. As Table 1 summarizes, there are major flaws with the Health Impact Study. I further discuss these below in this section and elaborate on the final flaw in Section III.

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<th>TABLE 1</th>
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<td><strong>MAJOR FLAWS OF THE HEALTH IMPACT STUDY</strong></td>
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| The Panel who authored the Study was not independent. |
| The Panel who authored the Study is no more expert than the many scientists whose research the Panel peremptorily dismissed. |
| The research design of the Panel is fatally flawed. |
| The Panel failed to implement the appropriate statistical methods to test for the occurrence of IWT-induced adverse health effects. |
| The Panel failed to use readily available and most relevant data for experimental sites in New England. |
| The Panel cherry picked 5 research studies and ignored countless others. |
| The Panel failed to fully report the findings of the limited number of articles upon which it did rely. A more complete reading of these articles reveals scientific findings of adverse health effects. |

16. The Health Impact Study would be excluded for the following reasons.
a) The “Independent Expert Panel” was not independent.

While the group of academics empanelled to conduct the research was designated as “Independent,” they were not. In complex litigation, courts at times appoint an “Independent Expert” to the Court, to assist the Judge and/or jury to understand the complex technical issues involved. Such Independent Experts are scrupulously vetted, so that they are acceptable to both parties of the dispute – the Defendants and the Plaintiffs (and the attorneys). The Independent Expert must not “have a dog in the fight;” he/she must not have prior preferences for the positions or arguments of one side. If the Independent Expert has any financial or ideological preference for the arguments of one group of adverse litigations, that Expert will simply not be Independent, either consciously or sub-consciously. If an Independent Expert is found to have such prejudices, he or she will be impeached – excluded from serving as a consulting expert.

Several “experts” on the Expert Panel have pro-wind-industry connections. For one important example, I understand that Dr. James Manwell’s Wind Energy Center is heavily involved with the industry and is heavily funded by the Commonwealth. I believe that it is therefore impossible for him to offer a neutral opinion on the health effects of industrial wind turbine installations. Likewise, the Panel was appointed by representatives of the Commonwealth of Massachusetts, which has an obvious infatuation with wind energy. Such a panel cannot be relied upon for impartial scientific judgment. It would certainly be challenged in a legal setting.

I find that many of the Panel members are advocates of Wind Energy. As a result, I find that their report is an exercise in advocacy. It is not science.

b) The “Independent Expert Panel” is no more expert than the many scientists whose research the Panel peremptorily dismisses.

The Health Impact Report cites, but improperly dismisses or marginalizes, research that contradicts the Report’s findings. This research has been conducted by qualified scientists no less expert than members of the Panel. This dismissal or marginalization violates standard scientific practices. It is unacceptable. For one example, the Health Impact Report dismisses the research and work conducted by Dr. Nina Pierpont, a physician and PhD biologist, whose credentials are as good or better than those of almost all the members of the “Independent Expert Panel.”

2 Dr. Nina Pierpont has an undergraduate degree (with honors) from Yale University; an MD from Johns Hopkins University; and a PhD in Population Biology/Behavioral Ecology from Princeton University. Therefore, she is well qualified to diagnose medical problems; she is trained to design and implement statistical models of causality of environmentally induced illness.
Indeed, the design of the research experiment conducted by Dr. Pierpont is exactly the design blessed, but not implemented, by the Independent Expert Panel – a “Before-and-After” study.

c) The research design of the Independent Expert Panel is fatally flawed.

The research design of the Independent Expert Panel was to conduct no primary research of its own. Instead, it reviewed a variety of research efforts; incorrectly dismissed most of that research, particularly research that found adverse health effects; and cherry-picked five peer-reviewed articles out of hundreds, which could have been given equal weight. The Panel bases its conclusions importantly upon these 5 articles, even though these studies were conducted in Europe and New Zealand, where the geographical characteristics, the size of the IWTs and wind assets are distinctly different than those found for proposed IWTs in New England.

d) The Panel recognized the appropriate statistical methods to test for the occurrence of IWT-induced adverse health effects but failed to implement them for the readily-available and the most-relevant experimental sites.

The Panel explicitly recognizes the need for the best statistical method – pooling time series and cross-sectional data. Since the Panel should be most interested in the possible impacts of IWTs upon neighboring residents in Massachusetts and similar New England states, it could have implemented such research where it mattered and where data was readily available – at the many IWT sites in Massachusetts, New York and New England generally. Inexplicably, the Panel did not conduct such research. Indeed, it ignored the considerable problems arising at such sites. As a matter of public-policy research design and implementation, this is unacceptable.

e) After conducting no research of its own; and after cherry-picking 5 articles to support its “research;” the Panel further fails to fully report the findings of the articles upon which it relies. A more complete reading of these articles reveals scientific findings of adverse health effects. This mischaracterization of the

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3 See the Wind Turbine Health Impact Study, pp. 17 & 21, where the Panel discusses the limitations of cross-sectional data analysis to deal with temporal effects. Pooling time-series and cross-sectional data is the statistical modeling method designed to address that concern.

4 I understand that, as of January 2012, the ISO-NE seasonal-claimed capability spreadsheet identifies the following IWT sites which could have been used for “Before-and-After” studies: 19 IWT projects in Massachusetts; 9 IWT projects in Maine, including Mars Hill which is outside the ISO-NE area and so is not listed on the ISO's spreadsheet; 3 IWT projects in Rhode Island; 2 IWT projects in New Hampshire; and 2 IWT projects in Vermont.
research upon which it relies is dishonest and renders the conclusions of the Health Impact Study completely without merit.

I develop this final criticism in more detail in Section III.

III. ANALYSIS

17. In this Section I focus specifically on the five articles relied upon by the “Independent Expert Panel.” I summarize, and quote at some length, the findings of the research developed by these articles. I demonstrate how the Panel failed to report important evidence contained therein, evidence that contradicts the Panel’s interpretation.

18. The five articles reflect research performed by acousticians. Acoustical studies generally gather survey information from the people who are being impacted, either through a time-series or cross-sectional survey. The acousticians hypothesize a dose-response model, relating doses of noise to responses in the surveyed sample of respondents. A time-series survey allows for measurement before and after the installation of the IWT; as such they provide a very precise measure of the change in health status induced by the IWT, which may be the only real change introduced into the survey experiment. Cross-sectional analysis allows for assessing the responses and impacts of survey respondents at a given point in time, where the survey respondents differ from one another in, among other things, personal attributes, attitudes toward IWTs, and most importantly, proximity to the noise dosage (the IWTs). Dose-response

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5 Specifically the following:

- E. Pedersen and P. Larsman, “The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines,” *Journal of Environmental Psychology*, 28, 2008, pp. 379-389. Note that this article was only briefly mentioned in the Study.

I note that I excerpt considerable portions of the articles without using quotation marks, since the articles speak well for themselves and there is no need for me to rephrase what has been well-said. In some places, I do use quotes, when the excerpting is exact and the point important.

Since the publication of the January 2012 DEP study, there have been additional publications and studies identifying the adverse health effects of noise exposure. See, for example, M. Nissenbaum, J. Aramini and C. Hanning, “Effects of industrial wind turbine noise on sleep and health,” *Noise Health*, 14(60), September-October 2012, pp. 237-43.
will differ by these attributes and those differences allow for identifying the single impact of the noise and its proximity upon the survey respondents. Both time-series and cross-sectional survey information and analyses are standard quantitative methods. A time-series cross-sectional study is an even better hybrid of the two approaches.

19. After dismissing or marginalizing, incorrectly, much research that is valid and relevant, the Panel states (in bold in the original) the following conclusions:

- “[T]here is limited evidence suggesting an association between exposure to wind turbines and annoyance.”
- “[T]here is insufficient evidence to determine whether there is an association between noise from wind turbines and annoyance independent from the effects of seeing a wind turbine and vice versa.”
- “[T]here is limited evidence suggesting an association between noise from wind turbines and sleep disruption and that further study would quantify precise sound levels from wind turbines that disrupt sleep.”
- “[T]he weight of the evidence suggests no association between noise from wind turbines and measures of psychological distress or mental health problems.”

20. The five IWT dose-response statistical analyses relied upon by the Panel do not support such strong conclusions. I discuss below each of the studies relied upon and show that the Panel has mischaracterized each of the studies and omitted key findings from those studies.


21. This paper summarizes a cross-sectional study conducted in Sweden. Residents exposed to varying A-weighted sound pressure levels (SPL) from wind turbines were surveyed in five areas totaling 22 km² comprising 16 wind turbines and 627 households. The survey was conducted in May and June 2000.

22. While the purpose of the study was to measure a dose-response relationship between IWTs and adverse health impacts, that purpose was appropriately masked in the questionnaire, which addressed a variety of perceived advantages and/or disadvantages to living in the rural countryside where there also happened to be one or several proximate

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6 Wind Turbine Health Impact Report, p 28.
When asked about the IWTs, respondents were asked to describe their level of perception and annoyance related to the wind turbine sounds they could hear, using verbal descriptors of sound and perceptual characteristics. Respondents were asked questions about their normal sleep habits: quality of sleep, whether sleep was disturbed by any noise source, and whether they normally slept with the window open. The turbines were relatively small by today’s standards – about 160 feet tall.\footnote{The purpose of the survey was not framed as feelings towards IWTs. The survey was designed and implemented as if it were assessing rural living generally. The questionnaire consisted of questions on living conditions, reaction to possible sources of annoyance in the living environment, sensitivity to environmental factors, health and wellbeing. The inclusion of responses to IWTs was embedded in the survey, as if IWTs were just one more aspect of rural living about which the respondents might have some feelings. Perception of and annoyance with wind turbine noise were assessed together with other environmental stressors. “The survey method is well established and has been used in several previous studies exploring annoyance due to community noise” (e.g., E. Ohrstrom, “Longitudinal surveys on effects of changes in road traffic noise-annoyance, activity disturbances, and psycho-social well-being,” Journal of the Acoustical Society of America, 145, 2004, pp. 719-729), p. 3467.}

“A statistically significant dose–response relationship was found, showing higher proportion of people reporting perception and annoyance than expected from the present dose–response relationships for transportation noise.”\footnote{P. 3460. Dose-response relationships between doses of alternative transportation noise and the response of annoyance were well studied before IWTs became a relevant technology. Three well-known examples include H. Miedema and H. Vos (“Exposure-response relationships for transportation noise,” Journal of the Acoustical Society of America, 104, 1998, pp. 3432-3445 and “Demographic and attitudinal factors that modify annoyance from transportation noise,” Journal of the Acoustical Society of America, 105, 1999, pp. 3336-3344) and H. Miedema and C. Oudshoorn (“Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals,” Environmental Health Perspectives, 109, 2001, pp. 409-416). The source of Figure 1 below is Figure 3 in Pedersen and Waye (2004). The link between continual annoyance and the adverse health effects has become clearer over the past 15 years.}

As shown in Figure 1 below, this dose-response relationship is expressed as the proportion of nearby residents “highly annoyed” by the dose of noise (measured in dBA, A-weighted decibels\textsuperscript{10}). The percentage of the population highly annoyed was positive at much lower dBA (32.5) than other forms of transportation noise (aircraft, road traffic and railways; which begin at 42 dBA). The percentage of the population highly annoyed increased much more rapidly than other forms of transportation, reaching 35-40\% at 40-42 dBA, that is, before the other forms of noise (even aircraft at airports) even register annoyance. One can conclude that, for some reason, the proportions of respondents annoyed by wind turbine

\footnote{The authors note that it is possible that A-weighted SPL (sound pressure levels in decibels) do not fully capture the noises that cause annoyance. They note different sound properties (likely low frequency infrasound, measured in Hertz, rather decibels) not fully described by the equivalent A-weighted level, are of importance for perception and annoyance for wind turbine noise. Support for such a hypothesis was given in a previous experimental study where reported perception and annoyance for five recorded wind turbine noises were different, although the equivalent A-weighted SPL were the same (K. Persson Waye and E. Ohrstrom, “Psycho-acoustic characters of relevance for annoyance of wind turbine noise,” Journal of Sound and Vibration, 250, 2002, pp. 65-73).}
noise are higher than for other community noise sources at the same A-weighted SPL and that the proportion annoyed increases more rapidly. No respondent self-reported being annoyed at sound categories below 32.5 dBA, but at sound category 37.5–40.0 dBA, “20% of the 40 respondents living within this exposure were very annoyed and above 40 dBA, 36% of the 25 respondents.”¹¹

24. “When adding the subjective factor of attitude to visual impact as an independent variable, the influence of the noise exposure decreased, but was still statistically significant.”¹² Almost all respondents (93%) could see one or more wind turbines from their dwelling or garden, so visibility was not the determining factor.

Figure 1
Dose-Response Relationships – % Population Highly Annoyed (y-axis)
Given Level of Noise (dBA)

25. The authors speculate that the high prevalence of noise annoyance could be due to the intrusive characteristics of the aerodynamic sound. The verbal descriptors of sound characteristics related to the aerodynamic sounds of swishing, whistling, pulsating/throbbing, and resounding were reported to be most annoying. “Most respondents who were annoyed by wind turbine noise stated that they were annoyed often, i.e., every day or almost every day. The high occurrence of noise annoyance indicates that the noise intrudes on people’s daily life. The survey was performed during May and June when people could be expected to spend time outdoors, and the results

¹¹ P. 3464.
¹² P. 3465.
therefore reflect the period that is expected to be most sensitive for annoyance due to wind turbine noise. … Some of the respondents also stated that they were disturbed in their sleep by wind turbine noise, and the proportions seemed to increase with higher SPL.”

26. It should be noted that a rather high proportion, 50%, of respondents self-reported as being rather or very sensitive to noise. Other field studies in Sweden on annoyance due to road traffic noise in urban areas have found a lower proportion of noise-sensitive persons. The difference likely reflects some preference of living environment, indicating that noise sensitive individuals prefer a more rural surrounding or that people living in areas with low background noise levels might develop a higher sensitivity to noise. The difference might suggest erecting IWTs in noisy urban areas with much higher ambient background noise.

27. One can conclude the following from this paper:

- There was a substantial proportion of the population that was annoyed or highly annoyed by IWT sounds.
- To those that are annoyed, the annoyance occurs every day, every hour the turbines are running. This annoyance is not some simple irritation; it is annoyance that affects mood, well being and health.
- Approximately 25% of the surveyed respondents experienced sleep interruption. As we shall see in the next several papers I review, this effect is common to all surveys. Sleep deprivation is a documented cause of a variety of physical and psychological diseases. Many disease states begin with poor or interrupted sleep. Most modern technologies which create noise and annoyance are noisy during the day but the noise ceases at night, giving those living nearby the night time to sleep, relax and recover from the adverse physical and psychological responses to noise. IWTs are unique in that they are noisy day and night. Those adversely affected do not have a quiet night to sleep and recover. Indeed, some studies find that the noise is worse at night, since the ambient noise is reduced and the relative noises of the IWTs are that much greater. The adverse effects of sleep deprivation and annoyance are cumulative.

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13 P. 3468. Recently, acousticians have hypothesized that low-frequency infrasound is more annoying indoors rather than outdoors. I do not address that issue here.

28. The paper extends the survey research and policy modeling reported in their (2004) paper discussed above. The objectives were the same. As above, the authors implemented a cross-sectional survey in Sweden. 1,309 questionnaires were sent out; the response rate was 57.6%; that is, there were 754 respondents. The design of the survey and survey instrument was almost identical to that used in the (2004) paper.

29. The survey population (hence the number of respondents) were grouped into 7 groups. The *average* distance for each group to the nearest IWT ranged from a low of 1,984 feet to a high of 3,326 feet. These are fairly long set-backs compared to some siting practices. The average A-weighted noise level (SPL) for all but one group ranged from 31.4 – 35, which is fairly quiet, as noted in Figure 1 above. One group had an average noise level > 35 (38.2 dBA, with a standard deviation of 4.7).

30. The analytic results, conclusions and main messages from the paper are the following.

- “The odds of perceiving wind turbine noise increased with increasing SPL [sound pressure levels – measured in dBA], … [and] [t]he odds of being annoyed by wind turbine noise also increased with increasing SPLs.” … “Dose-response relationships at noise levels as low as these have not earlier been derived.”

- “[N]oise annoyance was associated with sleep quality and negative emotions.” Of those respondents who were annoyed by wind turbine noise, 36% reported that their sleep was disturbed by a noise source. This is compared with 9% among those not noise-annoyed. Respondents who were annoyed by wind turbine noise felt more tired and tense in the morning. They also felt resigned (29%), violated (23%), strained (19%) and tired (19%) when thinking about wind turbines to a statistically significantly higher degree compared with those who were not annoyed. These feelings were not related to self-reported health status.

- “Perception and annoyance were associated with terrain and urbanization.” “Living in a rural environment, in comparison with a suburban area, increases the risk of perceiving and being annoyed by sound from nearby wind turbines.” “Annoyance was associated with both objective and subjective factors of wind turbine visibility, and was further associated with lowered sleep quality and

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14 P. 482, Table 1.

15 Pp. 480, 484 and 485. I have woven a variety of quotes together from these pages.
negative emotions” which “could lead to hindrance of human restoration.” This, together with reduced restoration possibilities may adversely affect health.”

- “There is a need to take the unique environment into account when planning a new wind farm so that adverse health effects are avoided.”

31. The results of this study, as well as the previous one by these authors, demonstrate that greater annoyance, lower sleep quality, lower levels of “human restoration” from sleep, and negative emotions are related to increasing IWT noise.


32. This paper combines the survey data sets from the two Pedersen and Waye articles (2004, 2007) discussed above. The authors develop a more nuanced multi-equation model which tests for the measured impact of noise (audible and inaudible) upon respondents’ propensity toward being annoyed and the simultaneous relationship between annoyance and attitudes toward the visibility of the turbines.

33. Citing a 1995 research effort, the paper’s first sentence notes that “[c]ommunity noise is an increasing environmental problem known to cause adverse health effects.” Pedersen and Larsman continue, citing the previous two Pedersen and Waye articles, “Wind turbines are new sources of community noise and their impact on people living nearby are as yet only partly known. … Dose–response relationships between A-weighted sound pressure levels (SPLs) and noise annoyance with wind turbine noise were verified in these studies, even though the noise levels from wind turbines were low, typically being below 40 A-weighted decibel (dB(A)) outside the dwellings of respondents.”

34. They ask the question: Why are people annoyed by IWTs at much lower dBA than other forms of community noise (See Figure 1 above)? In trying to answer this question, they noted perhaps the visual impact of the wind turbines interacted with the response to turbine noise. Respondents living in the proximity of wind turbines talked primarily about the noise, but also about the spoiled view and the constant movement of the rotor blades always attracting the eyes. This has since been labeled “flicker” and is claimed to be an adverse effect, much like living with a strobe light going on continuously, when the sun is at the right angle to catch the spinning of the blades. In any case, they specified a model to quantify the visual impact of the IWTs upon a

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16 Quotes in this paragraph are from p. 380.
respondent’s “Visual Attitude.” They then attempted to differentiate the impacts of “Visual Attitude” from the impacts of the noise itself, hypothesizing that people were measured as being more sensitive to IWT noise at lower dBA because they could also see the looming behemoth of an IWT and suffer from its flicker, in addition to the noise.

35. As they talked with the survey respondents, they found that an adverse response to IWT noise was **positively correlated with noise** (A-weighted SPL); **positively correlated with negative general attitudes** toward IWTs; and **positively correlated with Visual Attitude toward the specific local IWT** they could see. However, correlation is not causation. The problem with the modeling effort is that all of the proposed factors are correlated and it is unclear what causes what. Even when the authors allow all three factors to have an independent effect on annoyance, **noise still had a positive and statistically significant effect.** This is remarkable, as a statistical result, since the three variables are quite collinear. It is well known that when such multi-collinearity exists, it is difficult to identify with statistical precision the independent effects of the multi-collinear variables.

36. Unfortunately, their model and data are incapable of distinguishing causality from correlation. Do all three factors have independent effects? Or does one factor cause annoyance and the other factor? For example, if I live very close to an IWT and it looms mightily above my home and I am suffering from the adverse effects of the noise I hear and feel (for the sub-audible range), I will certainly have a negative Visual Attitude toward the proximate IWT; I will certainly see the IWT clearly (line-of-sight improves noise dispersion); I will certainly develop generally negative attitudes toward IWTs. So, if true, it is the noise itself that causes the other two attitudes to be more negative; which in turn can be found to have a measurable effect on annoyance. When all three variables are included in a regression, they may appear to display separate effects, and the measured effect of each will be less than if the entire effect was due to, and recognized as due to, the adverse response to noise (audible and inaudible).

37. The authors understand this: “The **proposed model was based on theoretical assumptions about causality and on the assumption that attitude towards the source influences noise annoyance.**” However, we cannot exclude the possibility that the causality is directed the opposite way so that annoyance causes a negative attitude towards the source. Being annoyed by wind turbine noise in the home environment could initiate a negative attitude towards wind turbines. There may also be a feedback loop between these variables.” **After considering these possibilities of correlation and correlation,**

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17 Specifically, one may just hate IWTs altogether, for whatever reason. In that case, one’s general negative general attitude will certainly cause one to have a negative Visual Attitude to the specific IWT one sees and will predispose one to be annoyed by the noises heard. In that case, the negative general attitude is the main causal factor.
causation, the authors conclude that “noise immission [sic] levels are possibly still the best predictor of noise annoyance.”


38. These authors begin their 2009 paper stating:19

“Community noise is recognized as an environmental stressor, causing nuisance, decreased wellbeing, and possibly non-auditory adverse effects on health. The main sources of community noise are transportation and industry. Air transport is the most annoying of the dominant means of transport. … Increasing awareness of the adverse effects of noise has led to noise management recommendations, including [World Health Organization – WHO] guideline values to limit health effects in various situations and action plans for reducing noise and preserving quietness, all with the aim of decreasing the overall noise load. Noise impact is quantified based on the relationship between noise dose and response, the latter measured as the proportion of the public annoyed or highly annoyed by noise from a specified source.”

“Wind turbines are a new source of community noise to which relatively few people have yet been exposed. The number of exposed people is growing, as in many countries the number of wind turbines is rapidly increasing. The need for guidelines for maximum exposure to wind turbine noise is urgent: While not unnecessarily curbing the development of new wind farms, it is also important to avoid possible adverse health effects.”

39. As do the previous 3 papers, this paper estimates and finds a statistically significant positive dose-response relationship between $A$-weighted sound pressure levels and reported perception of and annoyance from the noise in a 2007 field study in The Netherlands in which 725 respondents participated. The same survey questionnaire used in the Swedish studies was used here. As in Pedersen and Waye (2004; Figure 1 above), wind turbine noise was found more annoying than transportation noise or industrial noise at comparable levels, possibly due to specific sound properties such as a “swishing” quality, temporal variability, and lack of nighttime abatement, which of course causes

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18 Quotes in this paragraph are from p. 388.

19 P. 634.
sleep disruption. “Response to wind turbine noise was similar to that found in Sweden so the dose-response relationship should be generalizable.”

40. They note that there have been only a few studies measuring IWT dose-response relationships, which have found the following evidence. The sizes and heights of IWTs have increased over time; this is important since the evidence suggests that annoyance and sleep disorders increase with the size of the IWTs. Wind turbines differ in several respects from other sources of community noise. Specifically, modern IWTs mainly emit noise from turbulence at the trailing edge of the rotor blades. The turbine sound varies with the wind speed at hub height and varies rhythmically and more rapidly as the sound is amplitude-modulated, due to the variation in wind speed. Amplitude-modulated sound is more easily perceived than is constant-level sound and has been found to be more annoying. This is particularly true when turbines are placed in open rural areas with low levels of background sound.

41. The authors find the following analytic results.

- The degree of perception and annoyance increased with increasing sound level, for both outdoor and indoor annoyance. The proportion of respondents who were annoyed (rather or very) by the sound increased with increasing sound level up to 40–45 dB(A).
- The proportions of respondents annoyed by wind turbine noise were comparable to the previous Swedish studies. However, “this study found a stronger relationship between immission [sic] levels of wind turbine noise and annoyance than the … Swedish studies,” which may be due to the larger wind turbines included in the present study. Higher towers push the rotors to heights with stronger winds, increasing the time a wind turbine operates and increasing differences between emission levels and the background ambient sound levels, especially at night.
- The probability of being annoyed by wind turbine sound was higher if wind turbines were visible rather than not. Again, since the annoying audible and inaudible sounds produced by IWTs will increase with line-of-sight prevalence, this finding is not surprising.

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20 P. 634.
21 See p. 635 which cites a European study carried out in Denmark, The Netherlands and Germany in 1993; a complementary Danish study carried out in 1994; and the Swedish studies discussed in Sections III. A-C above.
22 See Figure 2 on p. 640. Also see p. 642 and Sections III.A-III.C above.
23 P. 642.
Figure 2
Proportion of Respondents Annoyed (a) and Very Annoyed (b) by IWT Noise Compared to the Noise from Road Traffic, Aircraft and Railways (Miedema and Oudshoorn (2001) and from Industry and Shunting Yards (Miedema and Vos (2004))

- Figure 2 above presents the proportion of respondents annoyed and highly annoyed with wind turbine noise above 35 dBA and below 55 dB(A). It is larger than the proportion annoyed with noise levels from all other noise sources except
railroad shunting yards, at comparable Lden. Shunting yards are rail yards in which trains and train cars are moved back and forth; connected, disconnected and reconnected; at random intervals; creating significant time-variant noise. The percentage of people “annoyed” or “very annoyed” with noise created at shunting yards is significantly higher than railway noise itself.

- “… the relatively high annoyance with shunting yard noise has partly been explained by the impulsive nature of some yard activities.” Wind turbine sound also varies unpredictably in level within a relatively short time span, i.e., minutes to hours. It can be postulated that it could be even more important that neither type of noise ceases at night. In contrast, in areas with traffic noise and/or industrial noise, background levels usually return to lower levels at night, allowing residents to restore themselves psycho-physiologically. A large proportion of respondents in the present study reported hearing wind turbine sound more clearly at night, an observation supported by previous findings. … Taken together, this implies that nighttime conditions should be treated as crucial in recommendations for wind turbine noise limits.”


42. This paper reports on the analysis of a 2010 cross-sectional survey conducted in New Zealand under the guise of a “Well-being and Neighbourhood Survey,” named to mask the true intent of the study. That intent was to analyze and measure the health-related quality of life (HRQOL) of individuals residing in the proximity of a wind farm relative to those individuals residing in a demographically matched area sufficiently displaced from wind turbines (the control group). The survey was in principle similar to the surveys discussed in the previous 4 papers. However, in designing the survey instrument, the authors considered a variety of outcome measures to assess the noise impacts including annoyance (used above), sleep disturbance, cardiovascular disease, cortisol levels and the subjective appraisal of health-related quality of life (HRQOL). The HRQOL is a concept that measures general well-being and well-being in the

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24 This is a reproduction of their Figure 3, p. 641. Lden is a dBA-based noise exposure level (den=day-evening-night) metric that has been found most appropriate for these analyses; see p. 634.


26 P. 642.

27 Samples were drawn from two demographically matched areas differing only in their distances from a wind farm in the Makara Valley, a coastal area 10 km west of New Zealand’s capital city, Wellington.
physical, psychological, and social domains. Because changes in HRQOL are expected to closely co-vary with changes in health, the World Health Organization (WHO) recommends the use of HRQOL measures as an outcome variable.\textsuperscript{28}

43. Statistically significant differences were found in some HRQOL scores, with residents living within 2 km of a turbine installation reporting lower overall quality of life, physical quality of life, and environmental quality of life. Those exposed to turbine noise also reported significantly lower sleep quality, and rated their environment as less restful.

44. The authors conclude the following:\textsuperscript{29}

- “Our data suggest that wind farm noise can negatively impact facets of HRQOL.”
- A large proportion of respondents from the turbine group identified turbine noise as a problem and rated it to be extremely annoying. The authors state that “\textit{It should be noted that, in contemporary medicine, annoyance exists as a precise technical term describing a mental state characterized by distress and aversion, which if maintained, can lead to a deterioration of health and well-being}. A Swedish study [Pedersen and Waye (2007)] reported that, for respondents who were annoyed by wind turbine noise, feelings of resignation, violation, strain, and fatigue were statistically greater than for respondents not annoyed by turbine noise.”
- “We also observed lower sleep satisfaction in the turbine group than in the comparison group, a finding which is consistent with previous research. One study directly related to wind turbine noise reported that 16\% of respondents experiencing 35 dB(A) or more of noise suffered sleep disturbances due to turbine noise [Pedersen and Waye (2004)]. Another study investigating the effects of wind turbine noise on sleep showed that 36\% of respondents who were annoyed at wind turbine noise also reported that they suffered disturbed sleep (versus 9\% of those not annoyed). A case-study approach examining exposure to turbine noise likewise identified turbine noise as an agent of sleep disturbance [a study for the WHO]. In relation to turbine noise levels, one study reported that even at the lowest noise levels (~25 dB(A)), 20\% of respondents reported disturbed sleep at least one night per month, and that interrupted sleep and difficulty in returning to sleep increased with calculated noise level. Demonstrably, our data have also captured the effects of wind turbine noise on sleep, reinforcing previous studies.

\textsuperscript{28} The authors cite scientific evidence linking community noise to health problems. The WHO reports that chronic noise-induced annoyance and sleep disturbance can compromise health and HRQOL (see p. 334 for the citations).

\textsuperscript{29} Pp. 333, 337-338.
suggesting that the acoustic characteristics of turbine noise are well suited to disturb the sleep of exposed individuals.”

IV. Summary and Conclusions

45. I conclude the following.

a) The “Independent Expert Panel” convened by the Mass DEP and the Governor was not independent. This fact alone is enough to disqualify it as a source of unbiased objective scientific opinion. Given the background of the participants and their advocacy connections to Big Wind, this Panel has produced a document designed to be advocacy, not science.

b) The “Independent Expert Panel” was not sufficiently expert to peremptorily dismiss or marginalize existing research performed by experts in their relevant areas, research which contradicts the findings of the Panel. The qualifications of the Panel members are certainly no better and in many cases worse than the qualifications of the scientists whose work they dismiss. This dismissal appears to be nothing less than eliminating inconvenient truths about the adverse health impacts of IWTs.

c) The “Independent Expert Panel” conducted no independent scientific research, even though many sample populations for estimating dose-response models in a before-and-after context were available to it. These sites include IWTs being erected or having been erected in Massachusetts and New England generally. Since the dispersion and potential adverse impacts of noise from IWTs are influenced by the topography and the ambient noise levels of the local areas in which they are sited, these local sites provide better estimates of potential adverse health impacts than sites in Europe and New Zealand. Indeed, at many of the sites at which IWTs already have been erected, there have been substantial adverse impacts. If the Governor and the Mass DEP are actually concerned

30 A complete set of references is found on pp. 337-338.

31 The advocates of IWTs like to dismiss reports of adverse effects as a “nocebo effect;” that is, an adverse effect that is imagined by the reporting residents. This dismissal is nonsense. As the articles relied upon by the Expert Panel (and many dismissed by the Panel), industrial noises have adverse impacts on the quality of life and health. Go ask someone living near Logan airport whether their sleep is disturbed or they are annoyed by incoming and outgoing jets. That is why there are timing restrictions on the operation of Logan Airport.

I note that the research relied upon by the Panel finds that local residents report IWT noise much more annoying and a much greater sleep disrupter than air traffic. Does the Panel expect us to believe that jet noise and IWT noise are all imagined by local residents? Apparently they do.

32 For examples, Falmouth, Fairhaven, Vinalhaven and now Hoosac.
about adverse impacts of IWTs, they should be paying closer attention to these sites and pause their aggressive efforts to get IWTs sited, until these adverse effects are better understood. I see no evidence of that occurring.

d) The Panel comes to some very strong conclusions which are simply contradicted by the research they cite as reliable. They are certainly contradicted by the research they improperly dismiss. In sum, the Panel’s unsupported conclusions, presented in ¶ 19, are that there is limited evidence that IWTs annoy neighbors; that the annoyance may really be due to seeing the IWTs rather than the noise they make; there is limited evidence that IWTs cause sleep disruption; and there is no evidence that the noise emission from IWTs have adverse health effects.

46. If the results of this Wind Turbine Health Impact Study were not given such widespread credence, these assertions would be comical, given the evidentiary record. Unfortunately, public policy affecting peoples’ lives is being determined based upon these conclusions. Most of the research that the Panel dismissed contradicted the Panel’s assertions. Their dismissal of this research is unacceptable as a matter of scientific procedure. However, even the research that the Panel allowed to be introduced contradicts their conclusions. I have developed this fact above in Section III.

47. Had the Panel not misrepresented the conclusions of the five studies they cite, the Panel’s conclusions would have been similar to those of the studies cited. In this Summary, I reiterate just a few of these findings which are in stark contrast to those unsupported findings of the Panel:33

- “A statistically significant dose–response relationship was found, showing higher proportion of people reporting perception and annoyance than expected from the present dose–response relationships for transportation noise.”34

- The percentage of the population highly annoyed increased much more rapidly than other forms of transportation, reaching 35-40% at 40-42 dBA, that is, before the other forms of noise (even aircraft at airports) even register annoyance.35 One can conclude that, for some reason, the proportions of respondents annoyed by wind turbine noise are higher than for other community noise sources at the same A-weighted SPL and that the proportion annoyed increases more rapidly.

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33 The following include direct quotes (which are in quotation marks), some paraphrasing, or description of figures.

34 See Section III.A above.

35 This is a description of Figure 1 above.
At sound category 37.5–40.0 dBA, “20% of the 40 respondents living within this exposure were very annoyed and above 40 dBA, 36% of the 25 respondents.”

- “When adding the subjective factor of attitude to visual impact as an independent variable, the influence of the noise exposure decreased, but was still statistically significant.”

- “Most respondents who were annoyed by wind turbine noise stated that they were annoyed often, i.e., every day or almost every day. The noise intrudes on people’s daily life.” Some of the respondents also stated that they were disturbed in their sleep by wind turbine noise, and the proportions seemed to increase with higher SPL.

- “[N]oise annoyance was associated with sleep quality and negative emotions.” Of those respondents who were annoyed by wind turbine noise, 36% reported that their sleep was disturbed by a noise source. Respondents who were annoyed by wind turbine noise felt more tired and tense in the morning. They also felt resigned (29%), violated (23%), strained (19%) and tired (19%) when thinking about wind turbines to a statistically significantly higher degree compared with those who were not annoyed.

- “Annoyance was associated with ... lowered sleep quality and negative emotions” which could “lead to hindrance of human restoration.” This, together with reduced restoration possibilities may adversely affect health.

- “[C]ommunity noise is an increasing environmental problem known to cause adverse health effects.”

- After considering the possibility that noise, visibility of IWTs and attitudes toward IWTs may be correlated and together act to determine the stated adverse impacts of noise, the authors conclude that “noise immission [sic] levels are possibly still the best predictor of noise annoyance.”

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36 See Section III.A above.
37 Ibid.
38 Ibid.
39 See Section III.B above.
40 Ibid.
41 See Section III.C above.
42 Ibid.
“Community noise is recognized as an environmental stressor, causing nuisance, decreased wellbeing, and possibly non-auditory adverse effects on health.”

- The main sources of community noise are transportation and industry. Air transport is the most annoying of the dominant means of transport.
- IWT noise is found to be considerably more intrusive and annoying than air transport.
- The proportion of respondents annoyed and highly annoyed with wind turbine noise above 35 dBA and below 55 dB(A) is larger than the proportion annoyed with noise levels from all other noise sources except railroad shunting yards, at comparable Lden. Shunting yards are rail yards in which trains and train cars are moved back and forth; connected, disconnected and reconnected; at random intervals; creating significant time-variant noise. The percentage of people “annoyed” or “very annoyed” with noise created at shunting yards is significantly higher than railway noise itself.
- “… the relatively high annoyance with shunting yard noise has partly been explained by the impulsive nature of some yard activities. Wind turbine sound also varies unpredictably in level within a relatively short time span, i.e., minutes to hours. … It can be postulated that it could be even more important that neither type of noise ceases at night. In contrast, in areas with traffic noise and/or industrial noise, background levels usually return to lower levels at night, allowing residents to restore themselves psycho-physiologically. A large proportion of respondents in the present study reported hearing wind turbine sound more clearly at night, an observation supported by previous findings. … Taken together, this implies that nighttime conditions should be treated as crucial in recommendations for wind turbine noise limits.”

- Increasing awareness of the adverse effects of noise has led to noise management recommendations, including [World Health Organization – WHO, 2000] guideline values to limit health effects in various situations and action plans for reducing noise and preserving quietness. …Wind turbines are a new source of community noise to which relatively few people have yet been exposed.”

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43 See Section III.D above for this bullet and its sub-bullets.
44 This sub-bullet is an explanation of Figure 2 above in Section III.D.
45 See Section III.D above.
• The proportions of respondents annoyed by wind turbine noise were compared with similar data from two previous Swedish studies. However, “this study found a stronger relationship between immission [sic] levels of wind turbine noise and annoyance than the Swedish studies,” which may be due to the larger wind turbines included in the present study.46

• The probability of being annoyed by wind turbine sound was higher if wind turbines were visible rather than not. Since the annoying audible and inaudible sounds produced by IWTs will increase with line-of-sight prevalence, this finding is not surprising.47

• A large proportion of respondents from the turbine group identified turbine noise as a problem and rated it to be extremely annoying. The authors state that “It should be noted that, in contemporary medicine, annoyance exists as a precise technical term describing a mental state characterized by distress and aversion, which if maintained, can lead to a deterioration of health and well-being. A Swedish study reported that, for respondents who were annoyed by wind turbine noise, feelings of resignation, violation, strain, and fatigue were statistically greater than for respondents not annoyed by turbine noise.”48

• “We also observed lower sleep satisfaction in the turbine group than in the comparison group, a finding which is consistent with previous research.” “Demonstrably, our data have also captured the effects of wind turbine noise on sleep, reinforcing previous studies suggesting that the acoustic characteristics of turbine noise are well suited to disturb the sleep of exposed individuals.”49

Raymond S. Hartman
June 3, 2013

46 Ibid.
47 Ibid.
48 See Section III.E above.
49 Ibid.
Attachment A.1
Raymond S. Hartman  
*Curriculum Vitae*

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**DEGREES**

B.A. (MAGNA CUM LAUDE) Princeton University 1969  
M.S. Massachusetts Institute of Technology 1971  
Ph.D. Massachusetts Institute of Technology 1977

**Ph.D. DISSERTATION**

An Oligopolistic Pricing Model of the U.S. Copper Industry (MIT, 1977)

**HONORS, SCHOLARSHIPS, AND FELLOWSHIPS**

- 1969-71 National Science Foundation Fellowship to MIT  
- 1965-69 Alfred P. Sloan Scholarship to Princeton  
- 1969 Woodrow Wilson Fellowship Honorable Mention  
- 1965 National Merit Scholarship Finalist

**RESEARCH AND TEACHING INTERESTS**

Econometrics/Statistics  
The Economics of Regulated Industries  
Energy and Environmental Economics  
Microeconomics  
Industrial Organization  
Law and Economics
POSITIONS

1970     Research Staff, Board of Governors, Federal Reserve Board, Washington, DC
1972-1992  Consultant and Staff Economist, Arthur D. Little, Inc.
1977-1984  Research Faculty, Massachusetts Institute of Technology
1977-1983  Assistant Professor, Department of Economics, Boston University
1983-1989  Associate Professor, Department of Economics, Boston University
1983-1988  Principal & Academic Principal, The Analysis Group
1988-1993  Visiting Associate Professor/Visiting Faculty, Boalt School of Law, University of California, Berkeley
1995-1996  Vice President, Charles River Associates
1996-1999  Senior Consultant, Charles River Associates
1996-2000  Director, Cambridge Economics, Inc.
2000-2004  Special Consultant, Lexecon Inc.
1997-2000  Director and President, Greylock McKinnon Associates

OTHER PROFESSIONAL ACTIVITIES


PAPERS APPEARING IN OR BEING SUBMITTED FOR PUBLICATION IN REFEREED JOURNALS AND BOOKS


Contributions of economic forecasting articles to the popular press, such as *Management Forum* and *Nations Business*

**PAPERS IN PROGRESS**

"Welfare Measures in Discrete Choice Markets"

“The Nature of Pharmaceutical Competition and the Implications for Antitrust Analysis under the Hatch-Waxman Act,” with Richard Frank

**CONFERENCE PAPERS AND PRESENTATIONS**


Comments on "Econometric Models of Choice and Utilization of Energy-Using Durables" by D.


Comments and discussion on "Efficient Postal Discounts" by John Panzar and "Efficient Component Pricing for Postal Service: It Ain't That Efficient!" by Michael Crew and Paul Kleindorfer -- both papers


MASSACHUSETTS INSTITUTE OF TECHNOLOGY (MIT); ANALYSIS GROUP, INC., (AG); LAW AND ECONOMICS CONSULTING GROUP (LECG); AND ARTHUR D. LITTLE, INC., (ADL) REPORTS

MIT Related


MIT Residential Energy Demand Group, Aggregate Pooled Data Utilized and/or Developed for Residential Energy Demand, MIT Energy Laboratory Working Paper, #MIT-EL-79-047, August 1979.

MIT Energy Laboratory, Assessment of the Appropriate Methods of Incorporating Appliance Engineering Analyses and Data into Residential End-Use Demand Models, Report to the Electric Power Research Institute, Number EA 4146, 1982.


R. Hartman and P. Spinney, Incentive Regulation for the Restructured Electric Power Industry in Massachusetts, MIT School of Engineering, Laboratory for Electromagnetic and Electronic Systems, LEES

**AG Related**


**LECG Related**


**ADL Related**


ADL, Tourism in Maryland: Analysis and Recommendations, Report to the Maryland Department of Economic and Community Development, 1972.


ADL, Tourism in San Diego: Its Economic, Fiscal and Environmental Impacts, Report to the City of San
Diego, November 1974.


**UNPUBLISHED WORKING PAPERS**


"The Use of Hedonic Analysis in Defining and Measuring Market Size: The Extension of the Merger Guidelines to Heterogeneous Products," Working Paper No. 91-12, Program in Law and Economics. School of Law, Boalt Hall

EXPERIENCE IN CONSULTING AND EXPERT TESTIMONY

Overview of Qualifications

Dr. Hartman is an economist specializing in microeconomics, econometrics and the study of industrial organization. Microeconomics is the science used to analyze and characterize the behavior of groups of consumers and producers that constitute markets. Econometrics is a science that makes use of mathematics and statistics to measure and quantify economic behavior and economic phenomena in markets. The study of industrial organization makes use of both microeconomic theory and econometrics. It focuses upon the structure, conduct and performance of the participants (consumers and producing firms) in markets and industries, for the purposes of predicting behavior and addressing such policy issues as antitrust, regulation and industrial policy.

He has taught economics, conducted economic research and provided economic consulting in his areas of specialization for thirty-five years. He taught economics as an Assistant Professor and Associate Professor within the Department of Economics at Boston University over the period 1977-1988. He taught economics as a Visiting Associate Professor and member of the Visiting Faculty at the School of Law, Boalt Hall, University of California at Berkeley over the period 1988-1993. He was a member of the research faculty at MIT over the period 1977-1982, during which time he conducted research in energy markets for the United States Department of Energy. During the same time, he declined the offer of a Visiting Assistant Professorship within the Department of Applied Economics at MIT, and instead lectured on a selective basis. Since 1971, he has consulted to federal and state governmental bodies, private corporations, law firms, consulting companies, research organizations and international lending organizations. He has been and continues to be a research referee for a variety of academic journals, including the top academic journals in the country. He is the author of more than 100 refereed journal articles, book chapters and research/consulting reports.

He has submitted oral and written testimony before federal and state courts of law and regulatory commissions. His testimony as an expert witness has addressed anticompetitive behavior, merger efficiencies, breach of contract, employment discrimination, patent infringement, class certification and the estimation of damages in a variety of markets and industries including, but not limited to, the pharmaceutical industry, the health care services industry, the electric power industry, the banking industry, the agrochemical industry, the copper industry, the defense industry, the cable TV industry, the tobacco industry, the electrical and mechanical carbon products industry, the medical devices industry and the construction industry. He has consulted to counsel on litigation matters in a broader array of markets. While his experience has been broadly-based across industries, two industries/markets have been primary subjects of substantial consulting, research and litigation support.

Experience in Energy Markets and Regulated Industries

Since 1977, Dr. Hartman’s expertise and experience have involved regulated industries generally and the markets for electric power and natural gas specifically. His consulting and/or litigation assignments
have included load forecasting, evaluation of conservation and load management programs, econometric cost analysis, analysis of revenue requirements and rate-making, analysis of value of service reliability, the analysis of mergers and acquisitions, analysis of industry restructuring, analysis of manipulation of spot and future prices in energy markets, and analysis of contract damages arising from DOE’s partial breach of the Standard Contract regarding storage of spent nuclear fuel waste. In these assignments, Dr. Hartman has consulted for such clients as Arizona Public Service, the Pacific Gas and Electric Company, the Southern California Edison Company, the Southern California Gas Company, the San Diego Gas and Electric Company, Portland General Electric Company, Bonneville Power Administration, General Public Utilities, Northeast Utilities, Niagara Mohawk Power Corporation, the Delmarva Power Corporation, Florida Power Corporation, Sithe Energies, the California Energy Commission and Public Utilities Commission, the Missouri Public Service Commission, the Rhode Island Division of Public Utilities, the Attorney General of the State of Massachusetts, the Electric Power Research Institute, the Gas Research Institute, the U.S. Department of Energy, the U.S. Department of Justice, the World Bank, and the governments of Indonesia and Thailand. He has consulted for a number of other clients whose identity must remain confidential. Over the last five years, he has testified numerous times before the United States Court of Federal Claims on behalf of the DOJ and DOE with regard to damages caused by DOE’s partial breach of the Standard Contract.

Experience in Health Care and Pharmaceutical Markets

Over the past 15 years, Dr. Hartman has participated as testifying or consulting expert in a wide array of matters related to health-care markets generally and, more specifically, markets for medical devices and pharmaceutical products. For examples, working with a team of health care experts, he submitted written testimony assessing and measuring the impacts of smoking on Medicaid health care costs in the Commonwealth of Massachusetts. He submitted testimony analyzing the competitive impacts upon and damages to a class of dental laboratories caused by the restrictive dealer practices of a dominant U.S. manufacturer of medical prostheses - false teeth. He consulted to the group of wholesaler defendants in the Brand-Name Prescription Drugs Antitrust Litigation, addressing issues of wholesaler pricing across classes of trade. He consulted to and/or submitted testimony for counsel to manufacturers of cardiovascular stents, related cardiovascular devices and generic drugs in a variety of patent infringement matters, addressing such issues as competition, market definition, liability, market penetration of new products and economic damages arising from patent infringement. He consulted for one group of private plaintiffs in the antitrust matter regarding the prescription drugs lorazepam & clorazepate and for the Federal Trade Commission in the matter of Hoechst Marion Roussel, Inc., Carderma Capital L.P. and Andrx Corporation concerning antitrust claims involving the prescription drug Cardizem CD. That consultation addressed issues of market definition, product competition, class certification and damage estimation. He consulted to counsel on the matter of damages to the class of direct purchasers of the prescription drugs Taxol and Flonase. He consulted to counsel and/or submitted testimony on the matter of damages to classes of indirect end-payer purchasers of the prescription drugs K-Dur, Augmentin, Wellbutrin, Zyprexa, Bextra, Celebrex, Tricor, Nexium, Estratest, Lotrel, Ketek, Flonase and Vioxx. He submitted testimony addressing class certification, liability and/or damages for the class of end-payer purchasers in antitrust, state consumer protection or RICO litigation concerning the prescription drugs Hytrin, BuSpar, Relafen, Lupron, Premarin, Ditropan, the hormone replacement therapy Estratest, Cipro in the states of New York and California and in the United States, K-Dur, Neurontin in the United States and Pennsylvania, and Risperdal in the State of Louisiana. In the MDL AWP litigation, he submitted testimony in support of the certification of to the class of end-payer purchasers of those pharmaceutical products produced by AstraZeneca, the Bristol-Myers Squibb Group, the Johnson & Johnson Group, the GlaxoSmithKline Group and the Schering Plough Group that were alleged to have been the subject of a
scheme to fraudulently inflate their Average Wholesale Price (AWP); he subsequently submitted and presented at trial testimony supporting findings of causation, liability and the calculation of damages for those end-payer groups for which class certification was granted and upheld at the appellate level. He has consulted to and/or submitted testimony for the Offices of the Attorneys General for the states of Massachusetts, Texas, New York, Connecticut, Montana and Nevada in analogous matters. He submitted testimony addressing class certification, liability, damages and settlement allocation in the MDL litigation, New England Carpenters Health Benefits Fund, et al. Plaintiffs, v. First Databank, Inc., a Missouri Corporation and McKesson Corporation, a Delaware Corporation, Defendants, in which violations of U.S. RICO and state consumer protection statutes were allegedly violated. He submitted similar testimony addressing and calculating the economic damages of these alleged activities upon the Medicaid agency and other governmental agencies of several specific states. He submitted testimony regarding class certification in the MDL matter alleging ERISA violations, In re Express Scripts, Inc., PBM Litigation. He has consulted to drug companies on related matters when they have arisen in a patent litigation context. His testimony has been the basis for the certification of class in a variety of these matters. His testimony has been the basis for approval supporting settlement agreements in a variety of these and other pharmaceutical matters.

He has provided testimony and/or white papers for counsel used in arbitration for a hospital seeking to revoke surgical privileges for an allegedly incompetent thoracic surgeon and for an insurance company that alleged physicians were overcharging for services provided under Medicare.

Specific Assignments

1972-1975: In consultation with Arthur D. Little, Inc., Dr. Hartman developed economic impact models to assess the effects of environmental regulations upon the U.S. pollution abatement equipment industry and upon a particular U.S. copper smelting company.

1972-1975: In consultation with Arthur D. Little, Inc., Dr. Hartman developed economic models to assess the regional macroeconomic and industrial impacts of alternative strategies to promote tourism-related industries. The models were used in the United States by the states of Maryland and Maine and for the Philadelphia Bicentennial Commission. Internationally, the models were used by the Ministry of Planning of Mexico to assess the national and regional importance of tourism coming into Acapulco.

1976-1977: Consultation with Arthur D. Little, Inc. for the U.S. Environmental Protection Agency. The effort involved the design, estimation and implementation of an econometric simulation model that was used to assess the impact of pollution abatement legislation on the U.S. copper industry. The model was designed to incorporate engineering cost estimates attributable to the abatement legislation while accounting for the noncompetitive pricing behavior in the industry. The model was used to evaluate and revise proposed abatement legislation. This analysis was the basis for Dr. Hartman's Ph.D. dissertation and several of his publications.

1977-1982: Working as the testifying expert, Dr. Hartman analyzed the presence of a price-fixing conspiracy among the major U.S. copper producers during the 1970's. His testimony addressed issues of liability and developed a model of damages. See


Deposition for United States District Court, Southern District of New York for Reading Industries, Inc., et al. (Plaintiffs) against Kennecott Copper Corporation, et al. (Defendants), 17 Civ. 1736

Testifying expert for the class of all individuals who employed the services of members of Massachusetts Furniture and Piano Movers Association. The analysis developed an econometric model to assist in certifying the class and measuring the damages common to that class. See Affidavit to United States District Court for the District of Massachusetts in the Matter of Kenett Corporation et al v. Massachusetts Furniture and Piano Movers Association Inc. et al, May 1984, Civil Action No. 82-140-Z.

In consultation with the U. S. Postal Service, Dr. Hartman identified appropriate econometric methods for analysis of the determinants of Postal Service costs. The particular methods he suggested were "hedonic" cost techniques, which are specifically designed to account for the fact that both increased levels of production and improved product attributes increase costs. The techniques assisted the Postal Service in quantification of the cost impacts of the attributes of service quality for alternative classes of service. For example, the techniques allowed for estimation of the differential cost impacts of alternative service priorities, size and weight attributes of the various classes of mail.

He later applied these techniques for a group of second class mailers. The analysis was introduced before the Postal Service Commission to assess whether proposed postal rate changes reflected actual costs.

The development of econometrically-based strategic planning models, which allow for estimation of the effects on corporate profits of alternative product design and pricing strategies. The models allow for examining specific design strategies by explicitly incorporating detailed product attributes. The models were developed for Westin Hotels and Shell Oil. The Westin models have been implemented into an interactive PC tool that facilitates pricing decisions at the front desk.

For analysis presented before the International Trade Commission, Dr. Hartman helped develop and estimate a model to evaluate the domestic effects of importation of certain synthetic aramid fibers. The analysis was used in adjudicating an international patent infringement complaint.

Dr. Hartman participated in an analysis of one of the nation's largest mutual funds. The study was undertaken as part of a class action alleging inappropriate management fees. The study assessed competition in the money market mutual fund industry. It measured investors' sensitivity to changes in yield and to the level of services provided. It also statistically identified the determinants of the costs of providing mutual fund services.

The development for GTE Laboratories of econometric demand models for analysis and measurement of the determinants of demand for telecommunications services. The models explicitly address the separate customer decisions to subscribe to one of several telecommunications carriers and the demand for telecommunications services, conditional upon the subscription decision. The analysis was employed by GTE to assist their subsidiary, GTE Sprint, in the design of marketable services, where the services were differentiated by tariff, perceived service quality, provider reputation, and specialized customer services. The analysis is summarized in the paper...

1985-Present: Dr. Hartman has performed a variety of economic damage analyses in cases of personal injury, wrongful injury and wrongful death. He has worked for both plaintiff and defendant. He was last deposed in such matters in 1995.


1986-1987: Working for the class of owners of selected General Motors' X Cars and VW Rabbits, Dr. Hartman specified and estimated econometric models that assisted in the certification of class and estimation of class damages. The damages flowed directly from allegedly-concealed design flaws in these automobiles. The methods are described in


1986-1987: Development of damage models for litigation in high technology industries. The models were developed in several cases. One involved alleged patent infringement by a major Japanese semiconductor firm, and the second involved market foreclosure of a domestic minicomputer emulator. In these efforts, Dr. Hartman developed econometric models to estimate the market potential, absent the violation, for the particular product foreclosed or whose patent was infringed. The methods are described generically in


1987: Analysis of the competitive effects of relaxing the restrictions on the Bell Regional Operating Companies regarding their vertical extension upstream into equipment manufacture and downstream into the provision of selected telecommunication services. The study was introduced before Judge Greene in the triennial review of the divestiture of the Bell operating companies from AT&T.

1987-1988: For a major gas utility, participation in analysis of the economic effects arising if bypass of an existing pipeline were allowed by state and federal regulation. The analysis developed methods for assessing when competitive bypass is socially desirable. The analysis also developed and used an econometric model to simulate the effects of bypass on demand and prices.

1988: Analysis of the competitive effects the acquisition of trade secrets through the predatory hiring of a competitor's essential labor force. See

Analysis submitted in testimony in the case *Universal Analytics Inc. v. MacNeil Schwendler, Corp.*

1988-1989: As part of their proposed acquisition of Public Service of New Hampshire, Dr. Hartman was retained by Northeast Utilities, Inc. to develop and estimate load forecasting models. The models were used to assess the demand implications of alternative rate assumptions proposed as part of the acquisition.
The forecasts were introduced as part of Northeast Utilities' filings before the bankruptcy court, the state public utility commissions, the SEC and the FERC.

1989: As part of major antitrust litigation against the leading vendors of airline computer reservation systems, Dr. Hartman helped develop liability analysis and models for the estimation of damages.

1989: As a proposed testifying expert for Parnelli Jones, Inc., Dr. Hartman analyzed the antitrust implications of Firestone's retail trade practices, particularly alleged vertical and horizontal restraints of trade. He designed damage models for the alleged violations.

1989 - 2000: Dr. Hartman performed the market analyses required for Hart-Scott-Rodino applications and second requests supporting mergers and acquisitions in a variety of industries, including specialty chemicals, airlines, health care and medical diagnostic products, and energy products and services.

1989-1990: Dr. Hartman participated as a principal investigator and testifying expert for the Division of Rate Payer Advocates of the California Public Utility Commission in an analysis of the economic and legal implications of the proposed merger between Southern California Edison Company and San Diego Gas and Electric Company. Dr. Hartman's responsibilities included overall study design, econometric analysis of scale and scope economies arising with the merger, and analysis of efficiencies purportedly arising with the coordination of the demand-side management programs of the two utilities. His direct and surrebuttal testimony is found in

California Public Utilities Commission, Division of Rate Payer Advocates, Report on the Proposed Merger of the Southern California Edison Company and the San Diego Gas and Electric Company, Volume V, Chapter II, Application 88-12-035, February, 1990, Exhibit 10,500; and


1989-1990: Working with Arthur D. Little, Inc., Dr. Hartman participated as a principal investigator and testifying expert in a merger study for several small New England utilities within Nepool. Dr. Hartman designed and implemented a statistical study of returns to scale and scope in the industry. Using the statistical results, Dr. Hartman developed opinions regarding the efficiency effects of the proposed merger. His analysis appears as an independent Appendix to


1990: Working for a group of commodity futures exchanges, Dr. Hartman participated as Principal Investigator in a critical review of a statistical and econometric study performed by the Commodity Futures Trading Commission. The CFTC study was developed to assess the effects of dual trading on commodity futures markets, in order to implement proposed regulations curtailing such trading.

1990: Working with Barakat and Chamberlin, Inc., Dr. Hartman developed a Ramsey pricing model for Arizona Public Service Corporation. The Ramsey pricing model was used to develop and
explore alternative rate strategies for a variety of residential, commercial and industrial market segments. The analysis was submitted in formal rate hearings.

1990-1992: Working with the Technology Research Center of Arthur D. Little, Inc. for the United States Postal Service, Dr. Hartman specified and estimated econometric models to analyze the determinants of productivity for the largest 120 post offices in the United States. The econometric models are being used to identify the most and least productive offices, with the purpose of learning from the performance of the most productive offices in order to improve the performance of the least productive offices. The models are being used to design and implement incentive regulation mechanisms to increase productivity across post offices.

A second set of econometric models have been specified and estimated to quantify the effects of the attributes of alternative postal services and rate classes upon total postal service costs. The results of this analysis are being used to design postal rates for alternative classes of service which reflect the real costs of providing the services. The analysis and its results will be introduced into the postal rate hearings.

1990-1997: Working with the World Bank, Dr. Hartman has specified and is estimating a set of econometric models to measure both the level and types of pollutants emitted by United States plants and establishments and the costs of abating those pollutants. The models identify and quantify, at the plant level, the relationship between the emission of approximately 300 pollutants and the scale of production, the types of technology used, the age and characteristics of the plant and equipment used, the extent to which abatement equipment has been installed, and the costs (capital and operating) of abating alternative pollutants.

The models will be used in the following ways in developing countries and Eastern European countries: to assist the countries to predict and assess the environmental implications of reliance upon certain technologies and industries in development; to assess the effectiveness of alternative regulatory methods for abating pollution, including effluent standards, effluent taxes, effluent licenses, technology standards, effluent banks, and alternative property right schemes; to implement incentive regulation mechanisms to better stimulate abatement compliance; and to identify and prioritize those industries that can abate certain pollutants at least cost.

As part of this effort, Dr. Hartman has also designed a specific incentive regulation system for pollution abatement compliance in Indonesia. The system is based upon the most recent theory in regulated incentive mechanisms. The system will ultimately evolve into an effluent bank or a system of effluent fees. If the effort is successful, it will form the basis for environmental institutions in other developing countries. In the process of designing this system, he has reviewed the institutional and statutory basis for environmental policy in Indonesia.

Also as part of this work, Dr. Hartman is in the process of designing the institutional and statutory structures for Environmental Protection Agencies in a variety of developing countries. The institutional structures will be designed to articulate and implement pollution abatement policies that are informed by the econometric modeling described above.

1991: Dr. Hartman participated as a principal investigator and testifying expert for the Missouri Public Service Commission in a critical analysis of the proposed merger between Kansas Power and Light Company and Kansas Gas and Electric Company. Dr. Hartman's responsibilities included overall study design, analysis of scale and scope economies arising with the merger, analysis of unanticipated transitional cost arising with the merger and an econometric event study of the stock market's response to the merger. His testimony appears in

1991: Working for the Resolution Trust Corporation in its litigation against Michael Milken and Drexel Burnham Lambert Inc., Dr. Hartman developed data and econometric models to measure the size of the relevant antitrust markets dominated by Drexel and to estimate the size of the economic damages produced by Drexel's alleged monopolization of those markets.

1991-1992: Working for the Indonesian government and the United States Agency for International Development, Dr. Hartman critically reviewed the structure of the Indonesian electric power industry and the institutions regulating that industry. The purpose of the analysis was to assist the government with privatizing their energy industries. His analysis focused upon the following: developing better data and models for predicting demand and supply; identifying and implementing more efficient industrial structures; and developing better regulatory regimes.

1992: Working for the World Bank, Dr. Hartman designed methods to measure and compare the social value of the environmental effects of alternative development projects, at the microeconomic and macroeconomic levels. His analysis focused upon standard and contingent valuation survey approaches and their use in econometric settings.

1992-1993: Working for the World Bank in Bangkok, Dr. Hartman characterized and critically analyzed the environmental effects of Thailand's energy use patterns. He focused upon the use and production of electric power, petroleum, coal and natural gas. He developed recommendations for environmental policy changes that included, but were not limited to, fuel taxes, effluent standards, technology standards, and privatization of environmental monitoring within a "bubble" policy approach.

1992-1993: Working for a biomedical company (a producer of vascular grafts) in an antitrust situation, Dr. Hartman designed and implemented survey techniques and econometric models to measure the size of the relevant markets and market power within those markets.

1992-1993: In a proceeding before the International Trade Commission, Dr. Hartman critiqued ITC econometric methods used for estimating elasticities of demand, supply and substitution among domestic and imported products. His focus was selected steel products. He formulated and estimated alternative models and methods to improve the existing estimates. He developed presentation materials for the Commission and testified before the Commission. His testimony is included in

LECG, Petitioners' Economic Testimony in the Matter of Certain Carbon Steel Flat Products, Final Hearing before the United States International Trade Commission, June 29-30, 1993; and


1992-1997: Working for the World Bank, Dr. Hartman has designed and is currently implementing a set of regional econometric/engineering models that accurately portray and predict the economic, environmental, infrastructural and socio-demographic effects of large-scale, World-Bank-funded infrastructural projects. The models combine input-output and econometric methods.

Given the Bank experience that many of their financially-sponsored projects create significant
unanticipated environmental effects, the models are designed to be broad and comprehensive enough to incorporate and predict all important effects. The models systematically characterize the relationship between resource-based economic growth and the regional environment in which that growth occurs.

The models are currently being implemented for assessing project developments in the Carajas region of the Brazilian Amazonian rain forest, which is a large, dynamic and ecologically sensitive frontier area. The methods implemented for Brazil will be generalized for analysis of economic growth in ecologically similar areas, such as the Lake Baikal region of the former Soviet Union.

1993-1994: Working for the Commonwealth of the Northern Mariana Islands, Dr. Hartman developed and presented testimony rebutting a complaint by the United States Department of Justice that the Public School System of the Commonwealth practiced employment discrimination against teachers of Filipino and native Carolinian origin. Dr. Hartman's testimony examined both hiring and compensation practices. His testimony included hedonic regression analysis of the market for public school teachers in the islands. This analysis measured how teacher attributes and qualifications determined teacher salaries and hiring. The results of the analysis indicated that salary differentials resulted from differences in teacher qualifications rather than discrimination.

1993-Present: Working either as the testifying expert or supporting other testifying experts, Dr. Hartman has participated in a variety of patent infringement cases. He has developed, supported and estimated alternative theories and measures of damages for manufacturers of coaxial cable, a variety of alternative medical devices and several generic drug manufacturers.

1993-1998: Working as the testifying expert, Dr. Hartman developed models estimating the damages to the business of a construction general contractor that were caused by the malicious prosecution of the contractor's insurance company.

1994: Working for the United States Wheat Associates in a proceeding before the ITC, Dr. Hartman designed and implemented an econometric study to assess and quantify the extent to which Canadian Wheat Board imports into the U.S. undersold domestic supplies and thereby materially interfered with the United States Department of Agriculture Wheat Program. The econometric study was hedonic. The study measured how non-price attributes are valued in U.S. wheat markets. The non-price attributes analyzed included such things as protein content, shipment defects, moisture content and a number of end-use performance characteristics. Having measured the value of these attributes in U.S. markets, the analysis indicated how the Canadian Wheat Board fixed import prices below market levels, given the attributes of the imported wheat.

1994: Working as a testifying expert for Gallo Wines in a proceeding before the ITC, Dr. Hartman designed and implemented a statistical study of the US wine industry that analyzed the impacts of Chilean wine imports upon the domestic industry that would result from the inclusion of Chile in a Free Trade Agreement with the US.

1994: Working as a testifying expert for an insurer of a member of the Asbestos Claims Facility and Center for Claims Resolution, Dr. Hartman developed a statistical analysis estimating alternative indemnification liabilities expected under the Settlement Share Analysis of the Center for Claims Resolution and under the tort system. The results were used to make strategic decisions regarding the desirability of participating in the Class Action Settlement relative to litigating the claims.

1994: Working for several regional Bell Operating companies, Dr. Hartman has developed models and survey procedures to analyze and quantify the determinants of demand for local services, long-distance
services and PCS services. The models quantify how consumers respond to and select among alternative carriers who differentiate their services by performance attributes and vendor reputation. The models also estimate the level of service demand, conditional upon the selection of service vendor. The models are being used to quantify the nature of competition among local carriers and long-distance carriers in the Intralata market. The models are also being used to help develop bidding strategies for specific RBOCs as they participate in the FCC auctions for the PCS spectra.

1995: Working as a testifying expert for a group of independent television stations and program producers, Dr. Hartman developed an econometric analysis of the impacts of the Prime Time Access Rule (PTAR) upon the economic performance of independent television stations. The analysis was submitted to the Federal Communications Commissions as part of their consideration of the repeal of the Rule. Dr. Hartman's analysis proved that PTAR had a strong, statistically significant effect upon the economic performance of these stations, and that its repeal would adversely impact them.

His testimony is included in


1995: Working for a big six accounting firm, Dr. Hartman designed and implemented a hedonic regression analysis to calculate transfer prices under the comparable uncontrolled price (CUP) method. The analysis is discussed in


1995-1996: Working as the testifying expert for a major high tech firm in New England, Dr. Hartman has developed rebuttal and affirmative testimony to rebut claims of age discrimination in the termination of a group of employees over forty. His rebuttal testimony involved critically reviewing statistical analyses purporting to demonstrate disparate treatment and disparate impact. His affirmative testimony has involved designing and implementing econometric models to identify and estimate those factors actually determining the compensation and termination decisions of the defendant.

1995-1996: Working as the testifying expert for the Office of Attorney General of the State of Massachusetts, Dr. Hartman has analyzed and helped develop the State's positions on the following issues: restructuring the electric utility industry in Massachusetts and New England; regulating those entities in the restructured industry that will remain subject to regulation; and valuing those assets that may be stranded as a result of restructuring. As part of the effort, Dr. Hartman also critically reviewed the restructuring proposals of the largest utilities in the state. His testimony appears in


1995-1996: Working as the testifying expert, Dr. Hartman represented Florida Power Corporation in a contract dispute with Independent Power Producers. His analysis and testimony focused upon issues of damages incurred as a result of a breach of contract.
1995-1999:  Working with a team of economists, Dr. Hartman represented the group of wholesalers in the retail prescription drug price fixing conspiracy case. His efforts included industry analysis and participation in cross examination of plaintiffs' experts.

1996:  Working as the testifying expert for the Division of Public Utilities of the State of Rhode Island, Dr. Hartman has analyzed and helped develop the State's positions on restructuring the electric utility industry in Rhode Island and New England, for both the State's Public Utilities Commission and the FERC. As part of the effort, Dr. Hartman also critically reviewed the restructuring proposals of some of the utilities in the state. His testimony appears in


1996:  Working with a team of engineering firms, an international investment banking firm, a big six accounting firm and several national law firms, Dr. Hartman developed models of demand, supply and futures markets in restructured electric power markets to assist a major industry participant in evaluating specific alternative acquisition strategies.

1996:  Working with a team of economists developing evidence for presentation before the High Court of New Zealand, Dr. Hartman critically reviewed and rebutted a variety of econometric analyses of natural gas markets and more broadly-defined energy markets in New Zealand. These analyses were used to determine the size of antitrust markets for a variety of energy products.

1996:  Dr. Hartman was retained by a major mid-west utility to critically review and rebut analyses and evidence presented before the FERC and the relevant State Commissions concerning the competitive impacts of the proposed Primergy merger.

1996-2003:  Working as the testifying expert, Dr. Hartman analyzed the employment practices and procedures of the Florida Power Corporation during a reduction in force, to assess the validity of a complaint that those practices and procedures resulted in a pattern of age discrimination. In his testimony, Dr. Hartman implemented a variety of statistical and econometric analyses to address and quantify claims of disparate impact and disparate treatment.

1996-1997:  Working for US Airways with a team of economists, Dr. Hartman specified and estimated a variety of econometric consumer choice models to measure customer preferences for the services of alternative air carriers in a cross section of US-European origin-destination markets. The models were used to evaluate the economic impacts of both the proposed alliance between American Airlines and British Airways and alternative proposals to condition that alliance.

1996-1997:  Working as the testifying expert, Dr. Hartman represented a major national retail pharmaceuticals wholesaler in litigation brought by a regional distributor alleging monopolization of wholesale services to distinct classes of trade. His analysis addressed market definition, the analysis of competition generally and analysis of the competitive impact of specific contractual arrangements.

1997:  Working with a team of experts, Dr. Hartman analyzed economic impacts of the construction of the Warrior Run Cogeneration plant which was under construction in Western Maryland and was contracted to sell power to Allegheny Power System's (APS) Maryland subsidiary, Potomac Edison.
1997: Working as the testifying expert for the Office of Ratepayer Advocates of the California Public Utilities Commission, Dr. Hartman critically reviewed the efficiencies estimated by Applicants to be induced by the proposed merger of Pacific Enterprises and Enova Corporation.

1997: Working with a team of economists, Dr. Hartman prepared affirmative and rebuttal testimony in a breach of contract matter in the pharmaceutical industry arbitrated before the International Chamber of Commerce.

1997-2000: Working as the testifying expert, Dr. Hartman developed analysis supporting certification of class and estimation of damages for the class of purchasers of thermal fax paper in the US over the period 1990-1992 who were damaged as a result of a price fixing conspiracy by major suppliers.

1998: Working as the testifying expert, Dr. Hartman analyzed the employment practices, procedures and personnel data of the Florida Power Corporation, in general and in particular, to assess the validity of a complaint that a specific employee had been subjected to racial discrimination.

1998-1999: Working with a team of economists for the Office of the Attorney General of the State of Massachusetts, Dr. Hartman developed and implemented econometric models to analyze and measure the health care costs arising under the Medicaid program that have been attributable to smoking. The analysis appears in the following documents:

- David M. Cutler, _et al._, *The Impact of Smoking on Medicaid Spending in Massachusetts: 1970-1998 - Results From The Inclusive Approach for Adults*, July 1, 1998;

Drawing upon these efforts, Dr. Hartman worked with the same team of experts to analyze the economic impacts of the Master Settlement Agreement and to present their findings to the Tobacco Fee Arbitration Panel.

1999: Working as one of two testifying experts for the Office of the Attorney General of the Commonwealth of Massachusetts, Dr. Hartman critically analyzed potential rate increases relevant to Joint Petitions introduced by both Eastern Enterprises/Colonial Gas Company and Boston Edison/Commonwealth Energy Systems. His testimony appears as

1999-2000: Dr. Hartman was retained by a group of industrial purchasers of copper to develop and implement methods and models to assess liability and measure damages in the matter involving the manipulation of the spot and future prices of copper on the London Metals Exchange by Sumitomo Corporation and Yasuo Hamanaka over the period 1987-1996.

1999-Present: Dr. Hartman consulted with counsel and the testifying expert in the development of data and models needed to certify class and measure damages in a price fixing case involving the manufacturer (Mylan) of generic clorazepate and lorazepam.

1999-2001: Working as the testifying expert, Dr. Hartman analyzed liability arising from a variety of restrictive dealer arrangements implemented by Dentsply International Inc., a U.S. manufacturer of artificial teeth, to foreclose entry by rival manufacturers from the US dental-laboratory dealer network. Dr. Hartman developed and implemented methods to measure damages to the class of dental laboratories that purchased artificial teeth from Dentsply at prices above the competitive prices that would have obtained absent the restrictive dealer arrangements.

1999-2000: Working with a team of economists for the Federal Trade Commission, Dr. Hartman analyzed the pro-competitive and anti-competitive nature of settlement agreements between generic and pioneer drug manufacturers resolving patent infringement litigation arising from certification under Paragraph IV of the Hatch Waxman Act (Drug Price Competition and Patent Term Restoration Act). Particular settlements analyzed include the settlement between Abbott Laboratories and Geneva Pharmaceuticals regarding the drug Hytrin and the settlement between Hoechst Marion Roussel (Aventis) and Andrx Corporation regarding the drug Cardizem.

1999-2000: Working as the testifying expert for the class of purchasers of Nine West shoes, Dr. Hartman was asked to analyze liability and measure damages arising from an alleged conspiracy to raise and maintain the prices of women’s shoes manufactured by the Nine West Group Inc. and sold by a variety of general merchandise retailers through their upscale retail department stores. The defendants in the case included Nine West Group Inc., Federated Department Stores, Inc., Dayton Hudson Corporation, Lord and Taylor, Nordstrom, Inc., May Department Stores, Macy’s, Bloomingdale’s, Inc., and other general merchandise retailers.

2000: Working with the testifying expert, Dr. Hartman assisted in the analysis and estimation of economic damages to a Class defined as all smokers with 20-pack years each of whom contracted lung cancer which was substantially contributed to by cigarette smoking.

2000: Working with a team of economists, Dr. Hartman developed econometric models to analyze and measure the impacts of subject imports, non-subject imports and factor price changes upon the prices of structural steel beams during the period 1998-1999. The work was presented before the International Trade Commission.

2001: Working with a team of economists, Dr. Hartman developed econometric models to analyze and measure the impacts of subject imports, non-subject imports and factor price changes upon the prices of structural steel beams and during 2000. He also developed econometric models to analyze and measure the impacts of subject imports, non-subject imports and factor price changes upon the prices of cold rolled and hot rolled steel during the Period of Inquiry of 1997-1999. Both efforts were presented before the International Trade Commission.

2001-2004: Working as the testifying expert, Dr. Hartman developed and submitted testimony in support

2001-Present: Working as consultant and testifying expert, Dr. Hartman has been retained by counsel to the classes of indirect or direct purchasers of a variety of branded pharmaceuticals (including but not limited to Augmentin, Bextra, Cipro (New York, California, U.S.), BuSpar, Celebrex, Vioxx, K-Dur, Taxol, Lupron, Relafen, Paxil, Neurontin, Remeron, Ditropan, Tamoxifen, Premarin, Wellbutrin and Zyprexa) to analyze and submit testimony dealing with class certification, liability, market definition, damage calculations and settlement allocations arising from violations of the Hatch Waxman Act (Drug Price Competition and Patent Term Restoration Act), related state-specific unfair competition statutes and the RICO Act.

Dr. Hartman’s testimony in this area has been relied upon (and cited thereto) for certification of end-payer consumer classes in the following matters:


- **In re Cipro Cases I and II**, D043543 (JCCP Nos. 4154, 4220), Court of Appeal, Fourth Appellate District, Division One, State of California [Decision affirming class certification not titled but marked as "Not to Be Published in Official Reports," Filed 7/21/04]

- **In re Relafen Antitrust Litigation**, United States District Court, District of Massachusetts, Master File No. 01-12239-WGY [Memorandum granting certification for an exemplar class, May 12, 2004]

- **In re Pharmaceutical Industry Average Wholesale Price Litigation**, United States District Court for the District of Massachusetts, MDL, No. 1456, Civil Action: 01-CV-12257-PBS.


Dr. Hartman’s testimony has been relied upon (and cited as necessary) for approval of proposed settlement allocations in the following matters:

- **In re: Lupron® Marketing and Sales Practices Litigation**, United States District Court, District of Massachusetts, MDL No. 1430, Master File No. 01-CV-10861-RGS [Memorandum and Order Approving Settlement and Certifying the Class, May 12, 2005]

- **HIP Health Plan of Florida, Inc., On Behalf of Itself and All Others Similarly Situated v. Bristol-Myers Squibb Co. and American Bioscience**, Case Number 1:01CV01295, United States District Court for the District of Columbia

- **In re Buspirone Antitrust Litigation**, MDL No. 1413, United States District Court for
the Southern District of New York

- **In re Relafen Antitrust Litigation**, United States District Court, District of Massachusetts, Master File No. 01-CV-12222-WGY
- **In re Remeron Antitrust Litigation**, United States District Court, District of New Jersey, Master Docket No. 02-CV-2007

2001: Working as consultant to counsel for various U.S. steel producers, Dr. Hartman worked with a team of economists to develop econometric models to analyze and measure the impacts of imports, demand and factor price changes upon the prices of domestically produced carbon steel flat products and carbon steel long products in the Section 201 hearings before the International Trade Commission. Dr. Hartman testified before the ITC in the hearings. The Commission decided in favor of most of the products subject to these analyses.

2001: Working as consultant to counsel for Nucor Steel Corporation, Dr. Hartman worked with a team of economists to develop econometric models to analyze and measure the impacts of imports, demand and factor price changes upon the prices of domestically produced carbon steel cold rolled products for preliminary hearings before the International Trade Commission.

2001-2002: Consulting to counsel for the Plaintiff Class, Dr. Hartman analyzed the targeting of youth by cigarette advertisements in the matter *in re Devin Daniels, et. al., v. Philip Morris Companies, Inc., et. al.*, Case Number 719446, coordinated with JCCP 4042.

2001-2003: Working as testifying expert, Dr. Hartman developed and presented statistical evidence analyzing the relative performance of a particular cardiovascular surgeon litigating the fact that his surgical privileges had been revoked as a result of incompetent surgical performance and results. He testified before an arbitration panel in the matter.

2003: Working as the testifying expert for Defendants, Dr. Hartman submitted testimony analyzing the allegation of racial discrimination on the part of Wells Fargo Home Mortgage, Inc. and Norwest Mortgage, Inc.

2003: Working as a consulting expert to counsel for the class of purchasers of graphite electrodes, Dr. Hartman developed econometric models to assess the impact of alleged antitrust violations.

2003: Working as a consulting expert for counsel to the class of direct purchasers, Dr. Hartman reviewed materials in a matter regarding antitrust allegations concerning the manufacture and sale of microcrystalline cellulose in the United States.

2003: Working as a consulting expert to counsel for a large electrical generation company, Dr. Hartman developed economic and econometric models to analyze the allegation that this electrical generation company participated in a conspiracy to manipulate prices of power sold in California.

2003: Working as the testifying expert, Dr. Hartman submitted testimony which analyzed and calculated the economic impacts and damages to the U.S. growers and quota holders of flue-cured and burley tobacco leaf caused by a price-fixing conspiracy among the major U.S. tobacco leaf buyers and cigarette manufacturers. The $1.4 billion settlement ultimately reached in the matter was the second highest antitrust settlement in history.
2004: Working as the consulting expert for the United States Department of Justice, Dr. Hartman critically analyzed the calculation of the economic damages borne by an electric power generation utility as a result of the breach of the Standard Contract with the U.S. Department of Energy to remove spent nuclear fuel in 1998. Dr. Hartman’s analysis included a critical review and rebuttal of the models and data put forward by the utility’s experts in the calculation of damages; the development and presentation of alternative and improved models and corrected data to more accurately calculate damages; a critical review of econometric analyses put forward by one of the utility’s experts; and a review of the economics of re-licensing existing nuclear generating facilities.

2004: Working as the testifying expert, Dr. Hartman submitted testimony in support of the certification of the class of purchasers of electrical carbon products who have been alleged to have been impacted and injured economically as a result of a price-fixing customer-allocation conspiracy of the major suppliers of such products in the United States.

2004-Present: Working as the testifying expert, Dr. Hartman submitted testimony in deposition and at trial in support of the certification of the class of end payer purchasers of those pharmaceutical products produced by AstraZeneca, the Bristol Myers Squibb Group, the Johnson and Johnson Group, the Glaxo-Smith-Kline Group and the Schering Plough Group that were subject to an alleged scheme to fraudulently inflate their Average Wholesale Price (AWP), thereby fraudulently inflating the reimbursement rates paid by the Class members for those pharmaceuticals when their reimbursement rates were formulaically related to the AWP. Dr. Hartman developed, implemented and presented at trial a theory of causation and under that theory calculated damages to the relevant indirect purchaser classes. The District Court and Appellate Court found in favor of Plaintiffs. Dr. Hartman has consulted and continues to consult and/or submit testimony on appeals and on related litigation undertaken by the Offices of the Attorneys General for the Medicaid Agencies of the states of New York, Connecticut, Arizona, Nevada, Montana, Texas, Pennsylvania and the Commonwealth of Massachusetts.

2004-2005: Working as a consulting expert to counsel for a major electricity and gas utility holding company, Dr. Hartman developed models to evaluate allegations of affiliate abuse by the regulated gas distribution entities and the trading entities of the holding company. The alleged abuses concerned spot and forward gas markets in California.

2005: Working as the testifying expert for the United States Department of Justice, Dr. Hartman developed models to critically analyze the cost submissions to the U.S. Court of Federal Claims by the TVA for monetary damages alleged to have resulted from partial breach by the U.S. Department of Energy of the Standard Contract to remove spent nuclear fuel from TVA beginning in 2002. Dr. Hartman’s analysis included a critical review and rebuttal of the models, data and cost analyses put forward by the utility and the development and implementation of alternative and improved models and corrected data to more accurately calculate costs attributable to the alleged partial breach.

2005-2007: Working again as the testifying expert for the United States Department of Justice, Dr. Hartman developed models to critically analyze the cost submissions to the U.S. Court of Federal Claims by the Systems Fuel Inc., a subsidiary of Entergy, for monetary damages alleged to have resulted from partial breach by the U.S. Department of Energy of the Standard Contract to remove spent nuclear fuel from SFI facilities in Mississippi and Arkansas. Dr. Hartman’s analysis has included a critical review and rebuttal of the SFI models, data and cost analyses put forward by the utilities and the development and implementation of alternative and improved models and corrected data to more accurately calculate costs attributable to the alleged partial breach.

2005-2010: Working as one of two testifying experts, Dr. Hartman submitted testimony calculating
monetary damages caused by the allegedly fraudulent promotion of the drug Neurontin for indications that were not approved by the FDA (off-label promotion). As part of his analysis, he consulted on the estimation of the econometric models calculating those prescriptions induced by the off-label promotion. His testimony has been submitted in the MDL and Pennsylvania matters. He has testified at trial in this matter.

2006: Working as the testifying witness for counsel to the named plaintiffs and the class, Dr. Hartman submitted testimony in support of certification of the Indirect Purchasers of the drug Ditropan.

2006-Present: Working as the testifying expert, Dr. Hartman has submitted testimony supporting class certification, liability and calculating damages resulting from an alleged conspiracy between McKesson and First Data Bank to inflate prices paid for a broad spectrum of brand name drugs by manipulating the list prices of those drugs (AWPs and WACs). Once class was certified and damages calculated, Dr. Hartman submitted testimony analyzing and supporting several proposed settlements to the litigation. Dr. Hartman is currently extending his analysis to state AG litigation, to assist those AGs to recover the overcharge damages paid on Medicaid reimbursement as a result of the conspiracy, as well as reimbursement by other governmental agencies.

2007-Present: Working as a consulting expert, Dr. Hartman worked with a team of economists estimating econometric models to analyze and quantify the extent to which allegedly illegal off-label promotion by the manufacturer of the drug Zyprexa caused increases in the amount of Zyprexa prescribed and sold.

2008: Working as the testifying expert, Dr. Hartman submitted testimony supporting certification of and calculation of damages for by the class of users of and payers for the drug Bextra as a result of fraudulent marketing activities and fraudulent clinical representations made by the drug’s developers and/or manufacturers (defendants Pharmacia, Pfizer, and Searle).

2008-2009: Working as the testifying expert for the named plaintiffs and the class, Dr. Hartman submitted testimony in support of class certification for the indirect purchasers of the drug Estratest, which was marketed and promoted by its manufacturer Solvay for hormone replacement therapy, despite the fact that it had received no FDA approval to do so even though Solvay had actively sought FDA approval and repeatedly made applications to the FDA for decades.

2008-2009: Working as the testifying expert for the United States Department of Justice, Dr. Hartman developed models to critically analyze the cost submissions to the U.S. Court of Federal Claims by the Energy Northwest. Dr. Hartman’s analysis focused upon correct procedures to analyze cost effective responses in the actual world to DOE delays in taking spent nuclear fuel.

2009: Working as the testifying expert for a large health insurer, Dr. Hartman critically assessed whether providers submitted claims in excess of what was allowed under Medicare reimbursement practices and procedures.

2009-2010: Working as one of two testifying experts, Dr. Hartman submitted testimony analyzing liability and calculating monetary damages caused by the allegedly fraudulent promotion of the anti-psychotic drug Risperdal for indications that were not approved by the FDA (off-label promotion). As part of his analysis and testimony, he estimated and presented econometric models calculating those prescriptions induced by the off-label promotion.

2010-Present: Working as a testifying expert, Dr. Hartman developed and submitted testimony in support of class certification, calculation of damages and market definition for the class of indirect purchasers of Provigil.
The class alleges monopolization and violation of the Hatch Waxman Act (Drug Price Competition and Patent Term Restoration Act) to foreclose generic entry.

2010-Present: Working as a testifying expert, Dr. Hartman developed and submitted testimony in support of class certification, calculation of damages and market definition for the class of indirect purchasers of Toprol XL and metoprolol succinate. The class alleges unlawful double patenting and violation of the Hatch Waxman Act (Drug Price Competition and Patent Term Restoration Act) to foreclose generic entry.
Attachment A.2
RAEYMOND S. HARTMAN
RECENT APPEARANCES AT DEPOSITION AND TRIAL

2003

*In re Terazosin Hydrochloride Antitrust Litigation*, Case No. 99-MDL-1317 Seitz/Garber, consolidated, United States District Court for the Southern District of Florida, (deposition)

*Anne Cunningham and Norman Mermelstein, Individually and on Behalf of all Others Similarly Situated, v. Bayer AG, Bayer Corporation, Barr Laboratories, Inc, The Rugby Group, Inc., Watson Pharmaceuticals, Inc. and Hoechst Marion Roussel, Inc.*, Index No. 603820-00, Supreme Court of the State of New York, County of New York (deposition)

*In re Ciprofloxacin Hydrochloride Antitrust Litigation*, Master File No. 1:00-MD-1383, United States District Court for the Eastern District of New York. (deposition)

*Cipro Cases I and II*, Judicial Council Coordination Proceeding Nos. 4154 and 4220 (Superior Court, San Diego County) (depositions)

*In re Relafen Antitrust Litigation*, United States District Court, District of Massachusetts, Master File No. 01-CV-12222-WGY (deposition)

*Dr. Gregory Derderian, et. al., Plaintiffs, v Genesys Health Care Systems, et. al., Defendants*, Case No. 99-64922-CK, State of Michigan, Circuit Court for the County of Genesee (testimony before arbitration panel)

*In re D. Lamar DeLoach, et. al., Plaintiffs, v. Philip Morris Companies, Inc., et. al., Defendants*, in the United States District Court for the Middle District of North Carolina, Greensboro Division, Case No. 00-CV-1235 (deposition)

2004

*In re Ciprofloxacin Hydrochloride Antitrust Litigation*, Master File No. 1:00-MD-1383, United States District Court for the Eastern District of New York (deposition)

*In re Lupron Marketing and Sales Practices Litigation*, MDL No. 1430, CA No. 01-CV-10861, United States District Court, District of Massachusetts (deposition)

*In re Pharmaceutical Industry Average Wholesale Price Litigation*, United States District Court for the District of Massachusetts, MDL, No. 1456, CIVIL ACTION: 01-CV-12257-PBS (deposition)

2005

*In re Lupron Marketing and Sales Practices Litigation*, MDL No. 1430, CA No. 01-CV-10861, United States District Court, District of Massachusetts, (trial)
In re Tennessee Valley Authority, Plaintiff v. United States, Defendant, United States Court of Federal Claims, No. 01-249-C, (deposition, trial)


2006

In re Pharmaceutical Industry Average Wholesale Price Litigation, United States District Court for the District of Massachusetts, MDL, No. 1456, Civil Action: 01-CV-12257-PBS (deposition; deposition in related matters for the State of Montana and the State of Nevada; trial)


System Fuels, Inc., on its own behalf and as agent for System Energy Resources, Inc. and South Mississippi Electric Power Association, Plaintiff, v. The United States, Defendant, in the United States District Court of Federal Claims, No. 03-2624C (deposition)

New England Carpenters Health Benefits Fund; Pirelli Armstrong Retiree Medical Benefits Trust; Teamsters Health & Welfare Fund of Philadelphia and Vicinity; and Philadelphia Federation of Teachers Health and Welfare Fund v. First Databank, Inc., and McKesson Corporation, United States District Court District of Massachusetts, C.A. No. 1:05-CV-11148-PBS (deposition)

In re Express Scripts, Inc., PBM Litigation, United States District Court Eastern District of Missouri Eastern Division, Master Case No. 4:05-md-01672-SNL (deposition)

In re Prempro Products Liability Litigation, in the United States District Court for the Eastern District of Arkansas, Western Division, MDL Docket # 4:03CV1507WRW; In re Hormone Therapy Litigation, in the Court of Common Pleas Philadelphia County, November 2003, #00001 (deposition)

In re: Neurontin Marketing and Sales Practices Litigation, MDL Docket No. 1629, Master File No. 04-10981, United States District Court, District of Massachusetts (deposition)

System Fuels, Inc., on its own behalf and as agent for Entergy Arkansas Inc., Plaintiff, v. The United States, Defendant, in the United States Court of Federal Claims, No. 2623C (deposition)

2007

System Fuels, Inc., on its own behalf and as agent for System Energy Resources, Inc. and South Mississippi Electric Power Association, Plaintiff, v. The United States, Defendant, in the United States Court of Federal Claims, No. 03-2624C (trial)
New England Carpenters Health Benefits Fund; Pirelli Armstrong Retiree Medical Benefits Trust; Teamsters Health & Welfare Fund of Philadelphia and Vicinity; and Philadelphia Federation of Teachers Health and Welfare Fund v. First Databank, Inc., and McKesson Corporation, United States District Court District of Massachusetts, C.A. No. 1:05-CV-11148-PBS (video taped tutorial)

2008

Energy Northwest v. The United States, United States Court of Federal Claims, No. 04-10C (deposition)

The Commonwealth of Massachusetts v. Mylan Laboratories, et al., United States District Court for the District of Massachusetts, Civil Action No. 03-CV-11865-PBS (deposition)

Susannah K. Alexander, Individually and on Behalf of all Others Similarly Situated, Plaintiffs, v. Solvay Pharmaceuticals, Inc., et al., Defendants, Superior Court of the State of California, County of Los Angeles, Case Number BC300364 (deposition)

Gregory Clark and Linda Meashey, individually and on behalf of others similarly situated v. Pfizer Inc., and Warner-Lambert Company, LLC, No. 01819, Philadelphia County Court of Common Pleas (deposition)

2009

Energy Northwest v. The United States, United States Court of Federal Claims, No. 04-10C (trial)

In re: Neurontin Marketing and Sales Practices Litigation, MDL Docket No. 1629, Master File No. 04-10981, United States District Court, District of Massachusetts (deposition)


In re Charles Foti, Attorney General ex rel, State of Louisiana v. Janssen Pharmaceutica, Inc., et al., 27th Judicial District Court, Parish of St. Landry, Docket No. 04-C-3967-D (deposition)

2010


In re: SmithKline Beecham Corporation, SmithKline Beecham, p.l.c., and Beecham Group, p.l.c., v. Apotex Corporation, Apotex Inc. and TorPharm, Inc., v. SmithKline Beecham Corporation, SmithKline Beecham, p.l.c., Beecham Group, p.l.c., Pentech Pharmaceuticals, Inc. and Par Pharmaceuticals, Inc., United States District Court for the Eastern District of Pennsylvania, CA No. 00-CV-4304 (deposition)

In re: The State of Texas ex. rel. Ven-a-Care of the Florida Keys, Inc., Plaintiffs, v. Alpharma USPD f/k/a Barre-National, Inc., et al., Cause No. D-1-GV-08-001566, in the District Court of Travis County, Texas, 419th Judicial District (2 depositions)
In re: McKesson Governmental Entities Average Wholesale Price Litigation, United States District Court for the District of Massachusetts, Case No. 1:08-CV-10843-PBS (deposition)

The Commonwealth of Massachusetts v. Mylan Laboratories, et al., United States District Court for the District of Massachusetts, Civil Action No. 03-CV-11865-PBS (evidentiary hearing (July) and trial (September))

2011


United States of America ex rel. Kassie Westmoreland v. Amgen Inc., United States District Court for the District of Massachusetts, Civil Action No. 06-10972-WGY (deposition)

In Re: Metoprolol Succinate End-Payer Antitrust Litigation, United States District Court for the District of Delaware, CA No. 06-71 GMS (deposition).

Vista HealthPlan Inc., et. al., Plaintiffs v. Cephalon, Inc., et. al., Defendants, In the United States District Court for the Eastern District of Pennsylvania, CA No. 06-CV-01833 (deposition).

2012

Wind Farm Noise 2012
Science and policy overview
Compiled by Jim Cummings

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A Brief Introduction to a Long Report

Here we go again. This is the Acoustic Ecology Institute’s third comprehensive annual overview of wind farm noise issues. Each year’s report goes into depth on different topics, and the three complement each other quite well, though each one clearly engages the issues with more detail and reflects a more nuanced appreciation of the topic than the ones that came before.

Wind Farm Noise: 2009 in Review offered a broad-based look beneath the surface of the noise issue. While taking noise complaints seriously, it acknowledged that they are far from universal, with many projects spurring few problems. It looked at ways that the nature of turbines sound make it difficult to rely on simple noise limits. And a fair amount of space was devoted to the social dynamics at play in rural communities, and AEI’s approach to reconciling the divide between reassuring research overviews and the life-changing impacts reported by some neighbors.

Wind Farm Noise 2011: Science and policy overview includes a 10-page introduction that provides a context for making some sense of both community noise complaints and the industry’s faith in its standard siting practices. A long section on community noise standards compares wind turbine noise with other sources of community noise, and includes several pages summarizing the points of view of some of the more cautionary acousticians. Brief sections addressed health effects and property values research. Appendix A summarizes AEI’s presentation on Community Responses to Wind Farm Noise at the DOE-funded New England Wind Energy Education Project webinar on noise. Appendix B offers a 5-page introduction to AEI and its approach to wind farm noise issues.

Some readers may be put off by the length of these reports; this one will be the longest yet, thanks to the inclusion, as appendices, of three extensive research overviews that were published separately since the Wind Farm Noise 2011 report was completed. I want to take a moment to explain the reason for the length of these publications, and to invite you to take advantage of the built-in skimming opportunities I’ve included.

In my work as an editor, I seem to be drawn to public policy topics where the public dialogue has become polarized to a degree that can undermine the goal of making clear and well-informed decisions. As each side makes seemingly incompatible statements with equal assurance, the general public and decision-makers (at the local, state, or national level) are left struggling to make sense of the situation. Too often, the primary problem is that both sides oversimplify the picture, discounting inconvenient information that might undermine their self-assurance. This is where AEI comes in: its online news and science coverage, and especially topical special reports such as this one, aim to include more substantial background information and detailed analysis, in order to provide the wider context necessary to appreciate the valid points (and distortions or simplifications) made by everyone involved, and to understand the subtleties and ambiguities that are often painted over by advocates on one side or the other in the name of presenting a “clear message.”

Yet I know that most of you won’t have the time to read all of this in detail; I encourage you to scan the text using the underlined and colored sections as skimming aids, and to dive in to sections that are most interesting to you. You should be able to skim the whole thing in fifteen minutes or so. For those of you charged with drafting local wind farm ordinances, or
who work for state or federal agencies or wind farm development companies and often find
yourselves discussing these issues with each other or the public, I encourage you to set
aside an hour or two to delve more deeply into the sections here that are relevant to you.
The appendices, which summarize recent research on low-frequency noise and infrasound,
health effects, and turbine quieting techniques, each offer comprehensive overviews that
are not available elsewhere.

With that, let's open the door and begin exploring the current state of the contentious
question of wind farm noise. I hope that these pages shed some light that's helpful to you.

**Key topics in this year's report**

The body of this report contains several relatively short sections (3-11 pages each) on a
range of topics related to wind farm noise. We’ll start with a quick “big picture” framing of
the state of the current public policy debate over wind farm noise. I’ll then go a bit deeper
in that direction by sharing some experiences and reflections from a series of visits I've
made to communities where noise has become a volatile issue.

The three main sections of this year's report that give examples of the ways that wind
companies and local communities are addressing and responding to noise issues. The first
will share some maps from actual projects, showing the "noise contours" suggested by the
sound modeling used by the wind developer; these give a sense of the distances at which
real-world projects are expecting various noise levels to occur. The next section will
summarize the few surveys that have been made in communities where wind farm noise
has become an issue, and consider as well the ways that some communities have re-
considered earlier noise fears and their local siting\(^1\) standards after living with a wind farm
for a few years. Finally, we'll take a look at the range of distance setbacks and noise limits
being adopted by various communities in the past couple of years.

The report proper will conclude with three sections containing what I consider to be the
key takeaways from the in-depth research summaries that are included here as
Appendices: a section each on low-frequency noise, health effects, and technologies and
new research that could lead to quieter turbines. While these kernels offer some useful
perspective, of course I think that the full Appendices are well worth a read—they contain
a one to two page summaries of each of a dozen or so important research papers, and
provide some threads of inter-connection between them. So please do delve into the
Appendices to get a more detailed and comprehensive look at these topics.

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\(^1\) A note on the word “siting”: some readers of previous AEI reports have said this word confused
them. I think they saw it as a variation on sit or sitting, and weren't sure how it applied. It is a
variation on the word “site,” with an “-ing” suffix: i.e., choosing where to place turbines.
Wind farm development and community responses: the current “big picture” and AEI’s role as an honest broker

Four and a half years ago, in the spring of 2008, AEI waded innocently into the wind farm wars with a blog post summarizing several recent news items about towns adopting or considering more stringent setback standards for wind farms, based largely on noise concerns. Little did I realize then just how contentious this issue would become, or how unusual AEI’s middle-ground voice would be in the midst of an increasingly polarized, and at times distorted, public policy discussion.

As a member of the American Society for Acoustic Ecology, the American Wind Energy Association, and the Acoustical Society of America, I bring an unusual blend of interests to these questions: a sensitivity to the ways that local soundscapes are central to our experience of place and home, a commitment to a renewable energy future, and an ability to read and make sense of academic and consultant studies of acoustics. As a writer and editor with a 25-year history of making complex environmental and scientific subjects comprehensible to a general audience, and over a decade of covering sound-related environmental topics, I’ve created a body of work here at AEI that has become a valuable resource for a wide range of stakeholders interested in ocean noise, wind energy, and public lands recreation issues1. The primary goal of AEI’s reports, research summaries, and news coverage is to create a broad context within which readers might better understand the diverse – and often apparently contradictory – statements being made by those in the public spotlight on these issues.

On the question of wind farm noise, the public dialogue continues to be quite cacophonous. Noise concerns have been swept up into a broader resistance to wind energy; some of this resistance is based on the scale of the technology and questions about its practicality or cost-effectiveness, some targets government incentives as part of a focus on reducing government spending in general, and some is rooted in a more fundamental skepticism about climate change and thus rejects the need for energy alternatives. Much of the public concern about wind farm noise has shifted to questions about the health effects of inaudible infrasound, a topic which is far harder to gain clarity about than simply considering audible noise and assessing public acceptance and annoyance rates. All this has brought a confusing array of voices to the table as communities consider new wind developments.

Meanwhile, the wind industry is beginning to shift its perspective on noise issues, with most developers now acknowledging that turbines will be audible and that some people will be annoyed. A few within the industry still claim that “noise is not a problem with modern wind technology,”2 but this is becoming far more rare. However, noise annoyance is generally seen a “subjective” response, and most companies consider current siting standards to be sufficient for most locations. The majority of new wind development still occurs in western locales with lots of space, and/or willing hosts on farms and ranches; increasingly, though, projects are being built in more populated areas where turbines are sited in and amongst homes or on nearby ridges, just far enough from non-participating...
homes to meet typical 45-55dB noise criteria, assuring that dozens of neighbors will hear turbines on a regular basis. While wind developers continue to have faith in this sort of relatively close siting, and have often shown willingness to respond to noise complaints by quieting existing turbines to the degree that is practical, the negative experiences of neighbors in some communities have led many towns and counties to adopt more restrictive wind farm siting ordinances, or to ban industrial wind development altogether. At the same time, industry players are working constructively with other rural communities and building large projects that trigger few if any complaints. Around Breckenridge, MI, this spring, the Gratiot County Wind Project became Michigan’s largest (133 turbines), with setbacks of as little as 1000 feet. Utilizing a Community Participation Model that included among other things “50 cups of coffee per MW,” the project is an example of how to work constructively with communities where wind energy is welcomed with open arms. Clearly, the industry is facing an increasingly varied landscape for development going forward; companies that adapt will find far more opportunities for future projects.

At the risk of offering an arguably facile and broad-brush picture, I think it’s worthwhile to briefly give a sense of how widespread noise complaints seem to be (see the later section of this report on surveys for more detail). In fact, it’s certain that whatever numbers I suggest here will trigger arguments—likely from both industry and community groups. But it’s worth taking a crack at it, to give some context to all that follows.

We are sorely lacking in any industry-wide community response surveys, which would be especially useful in identifying any possible correlations between community characteristics and either tolerance for turbine noise, or sensitivity to community noise sources. We don’t even have any clear data on what proportion of wind farms actually trigger noise issues. However, there now exists a well-established and widespread ecosystem of online groups scouring media reports for all articles about wind energy; some compile primarily positive stories about projects moving forward with community support, and some gather every mention of any downsides of wind projects and all regulatory setbacks and denials, everything from noise and health complaints to traffic accidents and town council deliberations. Between my own Google News alerts and email subscriptions to both industry and community group news compilations, I feel fairly confident that I have a bead on the general scale of relative successes and problems.

My sense is that most wind projects are still being built in areas far from homes, or in farm and ranch communities where they are predominantly welcomed with open arms; for these wind projects, it appears that running into widespread noise problems is the exception rather than the rule. Indeed, in the first nine months of 2012, 77 new wind farms (averaging 52MW each) came online in the US, and noise complaints have been minimal or non-existent at the vast majority. But in communities where a substantial number of residents, especially non-participating residents, live within a half mile or mile, the situation is far less clear-cut. Complaint clusters are nearly all from this sort of community, though complaints don’t always arise when non-participants live nearby; it may be that some critical mass of affected neighbors tips the scales toward a community backlash. There are now many communities in which I feel confident saying that a third to half of the
residents living nearby feel negatively impacted by the presence of a wind farm; they don’t like the new noise, although many are trying their best to just get used to it and live with it. In such communities, about half of these, or up to 20% or so of nearby neighbors, are strongly impacted, with sleep disruption, stress issues, and their sense of home and place forever changed; some of these push strongly for operational changes in the wind farm and consider moving away. And it appears that extreme impacts, including chronic loss of sleep, stress, or noticeable health changes, may be affecting somewhere around 5% or so of those within a half mile or mile in some communities, with many or most of these people wishing they could move away (though only a few tend to be financially able to do so).

As I say, I know these numbers may infuriate both sides, but this is the best sense I have of it at this point. While if history is repeated, I’ll probably be upset to see some bits of what I just said selectively quoted by partisans for one side or the other, I’ll close here by stressing that, to me, the idea that “only” 5% of neighbors may be severely impacted does not suggest that impacts are too small to warrant consideration. If turbines were built on the ridge that rises a quarter to third of a mile from the homes that stretch down the heart of my home valley, I wouldn't find any solace in the thought that only one or two of the seventy households would be so affected that they’d need to leave the homes and yards that they’ve built here with their own hands over the past few decades – and knowing the folks here, my guess is that most of us are deeply connected to this landscape and its peaceful qualities (even though we live within earshot of an interstate) and the impact would easily match or exceed the proportions I noted above. The county, or even the neighborhood, might conceivably decide to build such a project anyway; I would hope that if so, the decision would be made with full consideration of the possible impacts, rather than after simply pretending or assuming they were not real.

It’s heartening to me to see that, in fact, communities nationwide are undertaking just this sort of deeper consideration of the inevitable audibility of wind farms in the landscape around them. Some towns are affirming the existing 1000 foot approach, knowing that most of their residents will be content hearing turbines in their working landscapes; others are choosing to keep industrial turbines out of more pastoral landscapes altogether, not wanting to change the lives of even a few close neighbors. Most are experimenting with moderated responses somewhere between these extremes, with setbacks of 2000 feet to a mile or more, and noise limits as low as 35dB at night. We’ll survey some of these choices, across the entire spectrum, at the end of this report. But for now, I trust that this brief big-picture context has been enough to give you a bit of perspective as we embark on the meat of AEI’s 2012 Wind Farm Noise science and policy overview.
On the Ground in Wind Farm Communities

While most of my work on wind farm noise issues takes place online, over the years I've had the opportunity to visit six communities where noise has been a contentious issue (as well as an equal number of wind farms in the wide open spaces of the west). In two – Falmouth, Massachusetts and Vinalhaven, Maine – I spent several days, each time spending the night with affected neighbors, talking to a wide range of locals (including some who don’t mind the sound of the turbines) and met with the organizations that had championed the wind projects. At the other four – Freedom and Roxbury, Maine, Keyser, West Virginia, and Fond du Lac County, Wisconsin – I visited a few neighbors, all of whom hear the turbines, and some of whom were upset about the sound. During these visits, I didn’t do formal interviews or take detailed notes; the purpose was to simply get a sense of the human aspects of these issues that I’ve been tracking from afar for four years via the screen in my office. I wanted to get a more visceral feel for the perspectives of a variety of people.

I came away with a much deeper appreciation for the depth of despair and frustration felt by some wind farm neighbors, as well as the challenges confronting project planners who didn’t expect noise to be a significant issue. The people I’ve met who are struggling with noise include a mailman, a high school teacher, two retired college professors, an air traffic controller, a farmer, a geologist, and a solar energy professional – grounded, level-headed people, none of whom had a bone to pick with wind energy, and most of whom were excited about their local projects before turbine noise entered their yards and bedrooms. They aren’t hysterical or overly wound up; they are, however, distraught at the impact on their lives and intent on rectifying the unintended consequences of their local wind projects. On the other side of the local divides, the people working for groups that planned the projects are not the uncaring, stubborn stonewallers that some neighbors may suspect; they are responsible for multi-million dollar local projects that they couldn’t – and don’t want to – shut down, and are working in a variety of ways to understand why the reactions to turbine noise are so much more vehement than were expected.

In some communities, communication across this divide has come to a near-total standstill, thanks to lawyers’ recommendations, distrust about motivations, or mutual frustration at the very different emotional tones and practical priorities of those each side of the gulf. As always, personalities loom large in shaping the ways that communication develops or flounders; this may be especially true when one side is angry or frustrated, and the other is being careful about how to respond and is fundamentally enthused about the project. One community, Falmouth, is engaged in a “wind turbine options” process involving a full range of stakeholders, including town officials, local pro-wind environmental groups, and affected neighbors; the process has not been easy, and it remains to be seen whether the spring town meeting will be able to adopt a plan that works for everyone, but at least the community is working on it together. Unlike most wind farm projects, this one is town-owned, allowing far more local control over how to deal with noise issues, including shutting them down at night while the options process unfolds (it bears mentioning that this relatively collaborative response took about two years, and a heated town meeting, to
get rolling, despite widespread neighborhood complaints from the first days the turbines became operational).

Most of the towns I visited were coming to grips with fallout from pre-construction sound modeling that suggested turbines would be either inaudible or so close to background sound levels that they’d be easy to live with; instead, the noise is, at times, intrusive enough that a significant proportion of people living within a half or three-quarters of a mile are quite disturbed. (It’s hard to nail down proportions, but it seems clear that at least 20%, and up to half, of nearby neighbors are being affected in each place I visited besides Roxbury; most strikingly, over 40 homes within a half mile of the Falmouth turbines reported sleep, stress, or other impacts to their local Department of Health).

Even project planners have, at times, been taken aback by the prominence of turbine sound at neighbor homes. In Falmouth and Vinalhaven, neighbors alarmed by the unexpected noise levels asked key project planners to come to their homes and listen within the first few days of operations; in both cases, their first reaction was surprise. One told a homeowner, “We knew they’d make noise, but I didn’t think they’d be this bad,” and another said with chagrin that the sound models must be wrong (I suspect this was in reference to how clearly audible it was, rather than the actual dB level). In both places, project planners had accepted without much doubt the then-standard perspective that wind in trees would largely drown out turbine sounds whenever the wind was blowing. In Keyser, a company rep was initially similarly frank with neighbors who were living near turbines that had caused no noise issues for the company in the flat midwest, but were surprisingly loud perched atop a steep Appalachian ridge. In each case, after initially being quite empathetic, project planners pulled back from such frank discussion with neighbors (who were becoming more distraught and asking for immediate action), and began working in various ways to quiet the turbines without substantially impacting the required/desired energy output.

Roxbury (above) was an interesting contrast, because the turbines are over a mile and a quarter from nearly all the neighbors – even those locals who had been most concerned about noise impacts agree that it’s not as bad as they feared, and they hear turbines only when it’s very still (one reports hearing them every quiet morning, another, on quiet
winter nights; sleep has not been disturbed except for a couple nights when there was a mechanical issue). One person, two miles away, heard them a couple times when clouds were low and socked in. Still, at each distance (whether a mile or two miles), even those with no complaints about the wind farm all said that they wouldn’t want turbines any closer than they are. (It should be noted that while noise is not an issue, many locals dislike the lights shining across the pond and the ridgetop road and construction.) Likewise, in Wisconsin, neighbors surrounded by turbines in a large wind farm had varying senses of what would be livable: one (with two turbines about a quarter mile away) said if there were no turbines within a half mile, he’d feel OK about it, and another (with three turbines within a half-mile and two more a bit further away) thought a mile would be more like it. In Freedom, Maine, I met with neighbors and with wind proponents; the most striking effect in this community that has lived with turbines for a few years is that local discussions about a town-wide wind ordinance are focusing on a much different range of options/opinions – the strongly pro-wind element is proposing a 4000-foot setback, rather than the more typical starting point of 1000-1750 feet.

I've also visited several wind farms in the wide-open spaces of the west, in California, Wyoming, Nebraska, Kansas, and Texas. In such places, I've gotten a solid feel for the foundation of the American wind industry; indeed, even now, the vast majority of new wind development takes place far from towns and rarely spur noise complaints. While the striking feature of these landscapes is the extremely low population density (tens or hundreds of turbines per nearby home, rather than the inverse, as seen in areas where complaints are more common), many homes have turbines within a half or even quarter mile (or less), and residents have not been up in arms. This is the fundamental reason that wind developers have considered setbacks of 900-1200 feet to be totally reasonable, and unlikely to cause problems for neighbors.

Yet a growing body of both research and experience suggests that community response/annoyance rates can vary greatly in different types of communities. Last year’s AEI annual wind farm report went into great detail on this topic, and I refer you there for the full picture; we’ll dip into that topic a bit this year in reviewing the range of setback standards recently adopted around the country. Suffice to say that ranchers and large-
scale farmers, used to working on and around machines, don’t generally consider wind
turbines to be particularly loud, while retirees or bedroom rural residents are far more apt
to react negatively when the sanctity of their backyards or utterly still nights is broken by
the presence of wind turbine sounds. In addition, having an income from nearby turbines
(as many ranchers do) makes it more likely that moderate noise will be heard as a welcome
sign of income, rather than as an intrusion. There is also some indication that in flat ranch
country, the sounds of turbines are more steady than in more complex terrains where
turbulent air and generally more rapidly shifting weather conditions lead to more dramatic
surges and variation in turbine noise levels.

This is probably a good place to stress that in every wind farm I’ve visited where the
turbines were turning at close to their full speed (about 20rpm, or one blade passing
vertical each second), the turbines have always been audible out to at least a half mile;
generally, they’ve faded into the background sounds of distant roads or nearby leaves by
about three quarters of a mile. So far, this has been in moderate wind conditions (usually
just a light breeze at ground level; a couple times, moderate ground breezes in which I had
to turn my head to keep wind-in-the-ear noise from being an issue); I’ve never been near a
wind farm at a time of high winds, or in periods with irregular (knocking, banging,
impulsive) sounds or palpable pressure waves often cited by neighbors as the most difficult
to live with. There have been several occasions in which I could easily hear turbines
through nearby rustling leaves, with the turbines being clearly a lower-frequency sound,
though the sound levels seemed similar.

The experiences of the neighbors I met varied quite a bit. Again, earlier AEI annual
reports and presentations contain a good range of experiential descriptions, and I
don’t want to repeat all that here; a few highlights from my recent east coast trip may offer
a sense of it. The most poignant comment I heard was from someone who lives a bit
over a half mile from a small wind farm, on the next hill over; he spoke of that first
snowfall of the year, when everything is totally still, absolutely quiet and so profoundly
peaceful...he paused, then said sadly, “I’ll never have that again...” (when clouds are low
and socked in, sound travels especially well). Another stressed that while the background
whoosh of the turbines gently turning is an unwelcome addition to their local soundscape,
the real impact comes with much more intrusive knocking and banging, night-time sound
peaks, or pressure waves that are felt both outside and inside their home. She said that if
they’d been told that they’d have thirty horrible sound days a year, she’d have been more
prepared for that, and also stressed how different it would feel even now, if the wider
community also understood that it’s very bad quite often, instead of considering neighbors to be whiners or trouble-makers (note that she didn’t say that if she’d been more prepared for the intrusive sound, then she’d be OK with it now–just more prepared). On Vinalhaven, the story of a rental property around a half mile away from the turbines may be especially illuminating. As is often the case with vacation rentals, the owners hosted many “regulars” each summer for a week or two at a time. After the first summer of turbine operations, none of the regulars returned this summer. These are people who, not being landowners with investments there, might be relatively objective, dispassionate outsiders for whom the noise might be less of an issue; they stayed a week or two, long enough to get a feel for how often the turbines affect the sense of place, in the least-objectionable season, noise-wise. And all chose not to return. Two other neighbor experiences were especially striking. One person, who often works in his extensive backyard gardens, reports often feeling pressure building up in his head while working, and has found that he can sometimes walk a few hundred feet one way or the other and apparently get out of the zone where this is occurring; this could be an indication that his yard is sometimes in the “wake” of the turbine, where air pressure waves spiral downwind from the turning blades (these are not sound waves, but simply air pressure, which I suspect is a bigger contributor to neighbor complaints than is currently recognized). The last testimonial that was especially impactful was from someone who’s had to move from his retirement home (built with his own hands over many years) because turbine noise kept him awake too much at night and destroyed his enjoyment of the place during the days. He was the most vehement in expressing the core feeling shared by many of those most affected: that, in his words, “the number one issue” is the collateral damage occurring as lives are disrupted, and this needs to be acknowledged, addressed, and stopped. He sees it as stealing from the middle and lower class residents around wind farms; not just the possible (he thinks certain) financial loss in reduced property values, but even harder, losing the emotional investments in community and place; it’s just morally wrong, he stressed.

Faced with these sorts of reactions from neighbors, wind project managers are left with a high-stakes quandary. Project investments, whether private or public, were based on getting the projected electricity generation out of the turbines, so there’s a lot of pressure to keep them turning. In Vinalhaven, the turbines supply the local electric co-op that services the island; this may be the last community in Maine where well over half the 1200 year-round residents are working lobstermen and their families, all used to life with boat engines both up close and at all hours in the distance, so the couple of dozen families living around the quiet cove near the turbines (most of whom are either summer residents or recent arrivals, i.e. first generation, five to twenty-five years) get little empathy about noise. Falmouth, as noted, is a town-owned project, with the electricity supplying the local wastewater treatment plant and reflecting a strong community commitment to a renewable energy future. Still, in both places (and in Keyser) those behind the project have made efforts to reduce noise. At Vinalhaven the manufacturer added serrated edges to the blades, and operators have experimented with Noise Reduced Operations modes; each of these can reduce turbine noise by a couple decibels or so without reducing electric production very much, which together should help to some degree (the serrated edges seemed to reduce some of the intrusive throbbing, according to neighbors, though may have increased the volume of the swooshing; the pulses remain a problem in high winds)10.
At Falmouth, night time shut-downs have reduced impacts temporarily, the town Health Department has held hearings and conducted surveys, and the state agency that was behind the project, the Massachusetts Clean Energy Center (MassCEC), along with the state Department of Environmental Protection (DEP), have engaged in short-term noise monitoring. The MassCEC is also working statewide to try to understand what factors lead to more vigorous community reactions, including some preliminary surveys and plans for a detailed statewide turbine noise study during 2013. These efforts, taking place over periods of months and years, seem methodical and even diligently fast-tracked to those used to working within the context of the planning process of a state agency, electric company, or wind developer, while at the same time appearing incredibly slow (and half-measures) to neighbors.

A deeper, difficult question also comes up for project proponents and operators: in moving forward with a project that has community-wide benefits, is it acceptable to create negative impacts on some proportion of the community? If so, and most project planners would agree, then how many? 5%? 10%? (Such questions usually consider the percent of the entire community, rather than of nearby neighbors or of those who hear the turbines). The wide-angle lens sees thousands of residents benefiting from locally-produced wind energy, while some (or many) of those within a half mile or so are dealing with noise impacts. In both Falmouth (within the MassCEC) and Vinalhaven (within the Island Institute11 and Fox Islands Electric Coop), these questions are real, and are being grappled with, albeit in ways that often leave neighbors feeling ignored in the meantime. For neighbors, these are experiences that are real, and the questions are about how and when project managers will accept responsibility for what they see as mistakes made in siting turbines close enough to cause unexpectedly severe problems. Some neighbors want turbines shut down or moved, or operated in low-production modes that won’t create intrusive sound levels. Others want to be sure that other communities understand that noise can be a serious issue, and think that project planners should, in the future (at least), see these problems coming and proactively make plans for compensating or buying out more of the nearby neighbors. It does not comfort neighbors to hear that project planners may consider it unfortunate but acceptable that some people feel the need to move away from the area, just as people find airport or new highway noise unacceptable.

I don’t to pretend to know the way through these murky and highly-charged conflicts. My intention is to try to paint a picture that makes some sense of all the voices that are being raised. My visits to wind farm communities have made all of this more real to me, while keeping up with ongoing research continues to expand my understanding of the factors that may contribute to the experiences of neighbors, the challenges of those working to build wind projects responsibly, and the potential directions that the wind industry may move in the years and decades to come. In addition, in tracking wind farm ordinances adopted in a wide range of communities around the country, it’s increasingly clear that there’s no longer any “one size fits all” approach to wind farm siting. Adapting to varied community standards is becoming an important element of successful wind development.
How loud at how far?
Wind turbine noise propagation

This section will offer a bit of a reality check about wind turbine noise propagation. In some ways, the following examples build on the earlier mention of uncertainty and variability that is inherent when considering noise levels around wind farms.

It's not uncommon to see some pretty reassuring numbers tossed around in basic information about wind farm noise. A widely-reproduced\textsuperscript{12} 2010 image created by GE, a major turbine manufacturer, is one example:

![Wind Turbine Noise Map](image)

Here, we see a very simple, idealized version of the fact that sound is absorbed over distance; it shows 105dB turbine sound dropping below 45dB at 150-200 meters (500-650ft), and below 40dB at 400 meters (1300ft/.25mi).

A bit more realistic is an estimate from the American Wind Energy Association’s 2011 Turbine Noise Fact Sheet\textsuperscript{13} says that noise will be 35-45dB at 350m (1150ft/.22mi). These reassuring numbers have been a big part of the enduring conventional wisdom that says that setbacks long considered standard operating procedure (e.g., 1200-1500 feet) will keep noise levels at tolerable levels (i.e., 40-45dB).

However, actual sound contour maps generated by consultants hired by wind energy developers paint a much less sanguine picture. Below are four such maps, all of which show sound dropping to 45dB, and to 40dB, at a surprisingly large range of distances on the ground in each particular project site. These projects were picked at random from sound studies I collect in my files. I’m highlighting the distance to 45dB because that is a fairly common noise threshold in state and county noise standards (sometimes for daytime,
and often for night). The distance at which sound drops below 40dB is of interest for a couple of reasons, primarily because of the fact that noise levels higher than this are often clearly audible in the quiet of the deep night (i.e., 40dB is often 5dB or even 10-15dB higher than rural ambient night time sound levels, thresholds known to trigger community noise problems); in addition, since some jurisdictions are looking at noise limits below 45dB, this give us a bit of a reality check about what that might look like on the ground.

It's worth remembering, as well, that even the variability shown below is just a reflection of topography and turbine layout (and perhaps prevailing winds), and is based on idealized sound power levels from turbines in steady winds, with no inflow turbulence. Some may be based on “worst case” propagation conditions, such as layers that reflect the sound back to the ground, and ground conditions that encourage propagation. Whatever the factors they include, these maps reflect the average levels that will, at times, be exceeded. (See p.36-41 for more on these sources of variability)

<table>
<thead>
<tr>
<th>Wind project</th>
<th>45dB contour (sound drops below 45dB)</th>
<th>40dB contour (sound drops below 40dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardscrabble</td>
<td>1200-2000 feet</td>
<td>3000-4000 feet</td>
</tr>
<tr>
<td>(operating, NY)</td>
<td>.22-.38 miles</td>
<td>.57-.75 miles</td>
</tr>
<tr>
<td>Canton Mountain</td>
<td>1300-2640 feet</td>
<td>2100-4500 feet</td>
</tr>
<tr>
<td>(proposed, ME)</td>
<td>.25-.5 miles</td>
<td>.4-.85 miles</td>
</tr>
<tr>
<td>Blue Creek</td>
<td>1700-2640 feet</td>
<td>4000-6600 feet</td>
</tr>
<tr>
<td>(operating, OH)</td>
<td>.3-.5 miles</td>
<td>.75-1.25 miles</td>
</tr>
<tr>
<td>Horse Creek</td>
<td>2000-3000 feet</td>
<td>4000-6500 feet</td>
</tr>
<tr>
<td>(proposed, NY)</td>
<td>.38-.55 miles</td>
<td>.75-1.2 miles</td>
</tr>
<tr>
<td>AWEA fact sheet</td>
<td>1150 feet</td>
<td>1300 feet</td>
</tr>
<tr>
<td>GE graphic</td>
<td>500-650 feet</td>
<td>1300 feet</td>
</tr>
<tr>
<td></td>
<td>.22 miles</td>
<td>.25 miles</td>
</tr>
</tbody>
</table>

What’s most striking to me in looking at these maps is that the distance it takes to drop to a threshold of interest can vary by 50% or more. On a practical level, there are locations around three of these four projects where sound is over 45dB all the way out to a half mile or more. And even more striking, there are many locations around each project at which sound levels don’t drop to 40dB until three-quarters of a mile, and in two, including Ohio’s largest wind farm, sound of 40dB or more extends to well over a mile in some areas.

AWEA’s projected distance at which noise will be below 45dB turns out, at best, to reflect only those areas around each wind farm where this happens at the closest (actually, every project map shows 45dB always occurring at greater distances than the AWEA estimate,
and in many areas, at twice the distance or more). The GE graphic, which continues to appear in articles and information packets, is too far from reality to even consider.

Below are the project sound contour maps. Full-sized versions, with the distance scale and contours more clearly reproduced, are available on AEI's Wind Farm Noise resource page, linked in the footer of each page of this report. (The exact layouts of some of these projects may have been changed since these maps were produced, but these versions remain representative examples of the variability being illustrated.)

**Hardscrabble Wind Farm**

![Hardscrabble Wind Farm Map](image)

**Blue Creek Wind Farm**

![Blue Creek Wind Farm Map](image)
In his sound analysis for the Buckeye Wind project in Ohio\textsuperscript{18}, David Hessler again stresses that even when modeling using conservative assumptions and worst-case conditions, there are likely to be times “when the actual sound will exceed the predicted levels in the plots. Of course, there will also be times, probably the majority of the time, when the perceptibility of Project noise will be less than indicated in the graphics.” He elaborates:

Operational sound emissions from wind turbines are often unsteady and variable with time largely because the wind does not always blow in a completely smooth and ideal manner. When unsettled air or gusty winds interact with the rotor, or the airflow is not perfectly perpendicular to the rotor plane, an increase in turbulence and noise results. On top of this, turbines often (although not always) produce a periodic swishing sound. These characteristics make operational noise more perceptible than it would be if it were bland and continuous in nature. Consequently, wind turbines can commonly be discerned at fairly large distances even though the actual sound level may be relatively low and/or comparable to the magnitude of the background level; therefore the possibility of impacts at residences beyond the impact thresholds shown in the plots certainly cannot be ruled out. There may also be times, due to wind and atmospheric conditions, when project sound levels temporarily increase to levels that are significantly higher than the predicted mean levels. During these - usually brief - periods of elevated noise complaints also may occur.
Community Response Surveys

As mentioned earlier, we are sorely lacking in industry-wide community response surveys, which would be especially useful in identifying any possible correlations between general community characteristics and their relative degree of noise tolerance or noise sensitivity. (e.g. differences between working farms and ranches and towns where people have moved to have peace and quiet) What surveys we do have, with the notable exception of the body of work from Scandinavia that’s becoming a bit dated, have limitations that make it hard to fully rely on them; most fundamentally, they are often relatively informal, and don't include the sorts of careful structure that can hide the purpose of the survey (so as to not sway opinion) or supplemental study that can confirm how representative the sample is.

Some are broad community-wide surveys (most often finding overwhelming support for wind energy, on the order of 70-90% positive), which tell us nothing about what it’s like for those living the closest, so cannot really inform difficult decisions about siting standards. Others, which tend to crop up in communities where there have been clusters of noise complaints, may suffer from self-selection bias in respondents; these often suggest that 30-50% of residents within earshot have strongly negative reactions to wind farm noise. This summary doesn't include the many broad community surveys, because my main interest is informing decisions about how far turbines need to be from homes in order to avoid causing significant noise impacts among the nearby neighbors.

Despite the shortcomings of the surveys that have been done, it’s striking to see the close similarity in their response rates. The fact that the one universally respected series of academic studies of community responses came to a generally similar assessment offers further validation. It’s also worth noting that the respected Scandinavian studies, unlike all the others, took place in areas where noise complaints were not already rampant; this could suggest that there is more “quiet annoyance” than we presume in areas where there have not been enough vocal complaints to spur surveys (it could also suggest that “annoyance” is not always closely associated with life-changing disruption).

Any community response survey will lead to the key question: what level of noise annoyance is acceptable? All new sources of community noise can be expected to trigger complaints and dissatisfaction. While there is no hard and fast threshold of complaint rates that community noise management aims to stay beneath, it seems that a 10% rate of moderate to severe annoyance is often considered to be within expectations. Triggering significant annoyance in 25% or more of the affected population is beyond what many community noise managers would like to see. Some community noise sources (including most industrial facilities) can incorporate noise-muffling design features to keep noise levels at neighbors low enough to avoid such high rates of annoyance. In other cases (airports, new highways), a higher proportion of neighbors may find the noise excessive, but the projects proceed because of the public benefits.

These are difficult questions, and ones that are coming to the fore in many rural areas where wind farms are proposed; the debate moves beyond simply noise impacts, to
questions about whether the benefits of the energy produced by a given wind farm (or the total of wind farms proposed in a region) are worth the change to the local landscape and sense of place. These larger questions are beyond the scope of this report, and of AEI’s focus. Here, we are looking not at arguments for or against proposed wind developments, but at how people living near existing wind turbines respond to the noise that they hear.

The classic Scandinavian community response surveys, 2000-2007

AEI’s Wind Farm Noise 2011\textsuperscript{19} report included a comprehensive summary of our analysis of the widely-cited surveys from the Scandinavian research team that includes Eja Pedersen, Kerstin Persson Waye, Frits van den Berg, and their colleagues. Rather than repeat all of that here, I point you to the earlier report, or to AEI’s presentation to the DOE-funded New England Wind Energy Education Project\textsuperscript{20}, which contains much of the same information: The key slide is reproduced here:

The essence of AEI’s analysis is that in rural areas, it appears that 22\% of those who can hear turbines report being moderately or very annoyed; when noise levels are over 40dB, up to 44\% of rural residents report moderate or higher annoyance. While wind proponents often cite the overall annoyance figures of 8-9\% in these studies, this number includes a third to half of respondents who report never hearing turbines, as well as large numbers of people in suburban areas. AEI’s interpretation of these findings conforms well with annoyance rates reported in several more informal surveys: as turbines begin to be audible (25-35dB), 10-15\% of those close enough to hear these levels report moderate or higher annoyance; as turbines become more commonly audible (35-40dB), annoyance can top 20\%, and at over 40db, 25-45\% of the nearby population may find the noise to be disturbing.
**AEI’s approach to considering less professional surveys**

The primary weakness of surveys such as those considered below is “self-selection bias,” the chance that people having a problem with the wind farm will be more likely to take the time to fill out a survey. None of them had the budget to do the sort of follow-up survey employed by academic researchers, which can confirm that their subjects are representative also of those who did not participate. In our analysis of these surveys, we will consider the reported survey results, and for key results will also present the most extreme bias possibility: that *every* person who did not return a survey is in fact not bothered at all by turbine noise. Of course, it’s most likely that the actual community response is somewhere between the two numbers that result.

A secondary concern about some of these surveys is that they took place in areas where substantial public outcry about wind farm noise had already arisen; this critique I consider to be less valid, in that it presumes that people who are not actually all that bothered will be convinced by other’s complaints that they, too, are upset. At its most extreme, such critiques posit a “nocebo” effect whereby people are sensitized to their own annoyance or find themselves awakening more often simply because the idea of noise problems is in the public eye. 21 I consider it more likely that people are becoming more frank about their opinions and experiences in areas where the question is openly discussed in a town; and conversely, in areas where there is little if any public discussion of noise problems, there could well be somewhat more “under the radar” annoyance than we are aware of, because people generally avoid making waves in small communities. And, as I’ve often stressed, we badly need more community response surveys, in a wide variety of types of communities, including where noise has not been an issue.

**Lincoln Township, Wisconsin, 2001**

Of the several surveys that have taken place in wind farm communities after construction of wind farms, the most notable is from Lincoln Township, Wisconsin. A team from the University of Wisconsin conducted the survey in 2001, and the results were detailed in the Final Report of the Lincoln Township Wind Turbine Moratorium Study Committee in 2002. This survey stands out for several reasons, and it’s surprising to me that it hasn’t been more widely appreciated as an early indication of the sorts of problems that have become more widespread in recent years. Perhaps one reason is that it’s gotten a bit of a reputation as a source that has been “selectively quoted” by wind farm opponents; it’s true that most anti-wind sites tend to highlight the results from closest to turbines, but the survey itself stands up to scrutiny and should not be marginalized. This survey is especially valuable, for it clearly illustrates the ways that community-wide responses can differ markedly from those of the people living close enough to be most affected. Survey forms were sent to all 314 property owners residing in Lincoln Township; 227 returned the forms, for a solid 72% response rate. The survey included a long set of questions about living with the 31 wind turbines that were already operating in the town; in addition to assessing noise problems, it asked about blinking lights, shadow flicker, and TV reception (the latter was, as it turned out, the most widespread problem, with noise second).

**Noise annoyance**

Community-wide feelings are well captured with two questions. Asked, “Do you believe Lincoln Township is setting a good example in hosting wind turbines?” 71% of respondents
said yes. Town-wide, only 14% said yes when asked, “Are the wind turbines causing problems with noise?”

But if we look closer, a striking pattern emerges: at under a half mile, exactly half of the residents said noise had been a problem, while of those living between a half mile and mile, 33% agreed noise was a problem; beyond a mile, those rates dropped to 4% and less. And in case you’re concerned that self-selection bias led those without any problems to simply not respond to the survey, even if all 87 residents who did not respond are in fact not bothered by noise, we still see noise as an issue for 43% of residents living under a half mile away, and 29% of those between a half mile and mile. The residents living between a quarter and half mile were also the only group to disagree with the community consensus that they were setting a good example; 55% said no, a few more than the number bothered by noise at that distance. (No sound modeling or real-world sound monitoring is reported here; we can likely assume that within that turbine noise occurs along a gradient, with 45-55dB at the closest homes a quarter to third of a mile away, 40-45dB fairly common at a half mile, and 30-35dB being a routine level at a mile or so.)

**Sleep and health**
The survey also asked questions about sleep and health, though here the results are harder to rely on; the basic sleep question asked only whether turbines had woken the respondent in the past year (though a follow-up gathered some rough information on how often it happened), and the health question asked for no details about what the respondent was referring to. The largest sleep impact was noted between a quarter and half mile, where 35% had been wakened, and most of these more than 16 times (the highest category listed). Beyond a half mile, waking dropped to under 10%, and infrequently. The health numbers closely mimicked the sleep ones out to a half mile, but at a half mile to mile, 21% reported health effects (14% if all non-respondents are considered “no”), far more than the sleep numbers.

It’s worth noting that among those living the closest – within a quarter mile of turbines – while noise was noted as a problem for just under half, sleep and health effects were reported by only 11%. And, for good measure, a surprising number of folks (7% overall) reported positive health effects from the turbines, though again, no suggestion is offered as to what these may have been; just as many people at a half mile to mile reported positive as negative health effects.

**How many people are we really talking about?**
As in many such situations, while the percentages of noise problems within a half mile are striking, the numbers represent relatively few people; about three quarters of township residents live a mile or more from turbines, and only 13% within a half mile. Thus, any survey in a small town can be critiqued by noting that (e.g., using the Lincoln numbers) only 14 people reported being woken, or only 32 homeowners had issues with the noise levels. Do we really want to bring America’s renewable energy future to a grinding halt because of a few dozen people?
But such critiques miss the message that's contained in these surveys. No one is suggesting that ten people being woken up within a half mile, even if it happens regularly, is reason enough to halt all wind energy construction. But surveys like this one, and others with similar results, highlight with stark clarity that living with wind turbines is dramatically different within a mile, and especially within a half mile, than it is at larger distances. This survey, with its remarkable response rate and done over a decade ago, is a clear harbinger of the road we've continued to travel on, and the push-back that has only grown as more projects are built closer to homes.

Both sides in the debate use surveys like this to make their points. Anti-wind groups highlight the high, if vague, health numbers, while industry groups point to community-wide approval and the small numbers of people for whom the turbines create problems. We need to step back and consider whether, in some types of communities, larger setbacks would make more sense. Larger setbacks – say, a mile, to move into the zone where impacts dropped dramatically here – would certainly mean that in some towns, it would be more difficult to build. But if there are provisions to allow closer siting to residents who don’t mind hearing turbines regularly, then it’s quite possible that projects could proceed; in Lincoln Township, 56% of those in the half mile to mile range said they’d be willing to host a turbine. If enough landowners can’t be found to host turbines closer to their homes, then we are probably looking at a community where the long-term prospects are dim, with disgruntled landowners and riled up neighbors making things difficult for this project, and for future projects in the region.

Other surveys are not as solid as this one, but every survey that I have come across in a town where turbines are operating suggest similar rates of dissatisfaction with the noise of turbines among those living within a half mile to mile, with roughly half of those within a half mile and 20-30% of those a half mile to mile reporting that noise is a problem for them. (That said, it’s rare to bother to do a survey about turbine noise in a town where there have been few complaints; I’d love to see such surveys done on a much more regular basis, so we get a better idea of the range of dissatisfaction across a wider spectrum of wind projects.)

Jonesburg, Wisconsin, 2009
A 2009 survey of those within a half mile or a bit more of turbines in the Jonesburg, WI area found exactly 50% saying noise is a problem (with just a 46% response rate, this represents a minimum of a 23% negative response, still a significant minority). Half of those noting problems with noise said their sleep is disrupted at least once a week. Among the 219 local residents who completed the survey, 23 were hosting turbines, 6 of whom said if they could turn back the clock, they’d choose not to sign the contract. 62% felt that setbacks should be a half mile or more, while 22% supported the current state siting policy of 1000 foot setbacks.

Complaint rates in Vinalhaven, Mars Hill, Falmouth
And while lacking formal surveys of annoyance, generalized complaint rates in three towns with significant noise issues fit this picture of higher rates of significant noise annoyance than we’d like to see. In Vinalhaven, ME, residents in 5 of the 15 year-round homes within a half mile or so of the turbines filed formal noise complaints, with several others speaking
of moderate annoyance while learning to live with it. In Falmouth, MA, 45 families have taken issue with the noise; 16 of 59 homes (27%) within a half mile south of the turbines have filed formal reports with the health department, and 11 of 49 homes (18%) the same distance to the west have done the same, while a neighborhood survey to the west found that 21% of a larger sample of 75 homeowners reported effects on health and well-being.

In Mars Hill, ME, which likely represents a worst-case “Altamont of noise issues” situation (turbines on ridge above homes, plus a permit allowing turbines to run at 5dB above state noise limits), a survey of health effects found that 82% reported new or worsened sleep disturbance (18 of the 22 adults surveyed; these 18 represent 55% of the adult population within 3500 feet of the turbines), with chronic headaches occurring for the first time in 32% of study subjects (representing at least 21% of total residents). Stress was reported by 59% of respondents, and depression for the first time in 45% (representing a minimum of 39% and 24% of all residents, respectively).

Waterloo Wind Farm, South Australia, 2011-12
Perhaps the most striking of recent surveys took place among residents near the Waterloo Wind Farm in South Australia. A 2011 survey was done by a masters degree student, Zhenhua (Frank) Wang, and only a briefing paper summarizing the results has appeared publicly; the author was quoted as saying he was concerned about the summary being leaked and would not release the full results until it received academic peer-review. The survey was just one aspect of Wang’s thesis, which examines the growth of wind power, public reactions, and the current effectiveness of South Australia’s environmental noise guidelines; it’s unclear whether the thesis is indeed complete, or to what degree Wang or the University are now trying to avoid being pulled into the public debate over wind farm noise; in any case, no further details have been forthcoming. In July 2012, a local individual replicated the survey, in an attempt to fill in the data gap left by the lack of full results from Wang’s study. The surveys should both be considered along with the informal surveys noted above, rather than as solid academic research; the results are similar enough that they bear consideration, whatever the fate of Wang’s original policy-oriented research. Adding to the mix is a survey of the wider community by Waterloo’s owner, which has some balancing, yet also provocative, results.

Delivered to all 75 households within 5km (3 miles) of Waterloo Wind Farm turbines, both surveys had greater than 50% response rates, and as explained above, I'll assess the results both as presented, and conservatively “downgraded” as a hedge against self-selection bias by presuming that all non-respondents are not affected. American readers will note with surprise that this study finds high noise annoyance at distances far beyond those usually reported in here; I don’t know enough about the situation down under, but while noise complaints are exceedingly rare in the U.S. beyond a mile or so, it seems far more common to hear of noise issues at well over 2km (1.25miles) in Australia and New Zealand. Public planning there includes consideration of effects on “rural amenity,” which may open the door to lodging complaints when noise is distant or relatively rare, situations in which Americans may feel that resistance is futile. The turbines at Waterloo are on ridges above rural valleys, which can more often lead to calm conditions at neighboring homes while the
wind is strong at the turbines, as well as, in some places, funneling sound along valleys.

*Noise annoyance*

Wang found that 34 of 48 respondents (71%) reported being moderately (n=17, 35%), very (n=9, 19%), or slightly (n=8) affected by wind farm noise; this high negative response was widely noted among anti-wind activists. Wang’s summary noted that this 54% “moderate or very” negative response was significantly higher than that reported in the Pedersen, et al studies. Using the aforementioned extreme conservative assumption, Wang’s study suggests that at least 45% of the 75 households within 5km are affected by wind farm noise, with 12% very affected and a further 23% moderately affected; this conforms fairly closely to AEI’s interpretation of the Pedersen work, adjusted to consider rural responses separate from more populated areas. In plain terms, the most conservative reading of this data tells us that over a third of those hearing the turbines even occasionally are bothered to a substantial degree by the noise.

*Sleep and health effects*

Wang further found that of those reporting being affected by noise, 38% said they had health effects, primarily sleep disruption and headaches; this represents 13 households, or 27% of his respondents, or 18% of the 75 households in the area.

Unfortunately, many of the websites spreading the news of this briefing paper not only presumed that the survey was the primary content of a completed masters’ thesis (one they’re convinced was eventually “buried” by the university), but also sported headlines claiming that the survey found that “Wind Turbine Syndrome” is occurring in 70% of wind farm neighbors; remember that this 70% represents annoyance, rather than health effects, and includes those only slightly annoyed. This is an example of the kind of over-statement that occurs too often, wherein health effects are not clearly separated from annoyance among those discussing wind turbine syndrome. In fact, only a bit over a third of people who were bothered by noise in this study report any health effects, and the author summarizes these as “mainly related to sleep deprivation and headaches.” Not to downplay the possibility that a quarter (or a fifth, conservatively assessed) of residents within a mile and a half are awakened by turbines, but the sensationalist headlines may well have contributed to the lack of further details from those behind this study.

*Follow-up study*

The privately-run follow-up study, conducted in the spring of 2012, had a slightly lower response rate within 5km than Wang’s, and was also extended to include all 230 residences within 10km (6 miles). Within 5km, it found slightly lower overall noise annoyance, but higher rates of sleep disruption, than did Wang. The Morris survey reports that 56% of those within 5km report some degree of annoyance, with 39% being “seriously” or “moderately” affected by turbine noise (15% and 24% respectively); this amounts to a minimum of 31% of the 75 homes. And, while Morris did not inquire about generalized health effects, 39% of the total respondents reported sleep disruption (a minimum of 21%, again using the conservative extrapolation).

*Lower impacts beyond 5km*
Negative responses dropped significantly beyond 5km\textsuperscript{32}. Only 15\% of the 52 respondents at 5-10km reported being seriously or moderately affected by noise (n=1, 2\%; n=7, 13\%); this represents 5\% of the 155 homes in this range, again using the conservative extrapolation (which is likely to be more relevant at this range, where noise issues are rare enough that many people would see no point in responding to the survey). Sleep disruption was reported by 21\% of those reporting in this range, or 8\% of the total population there. Both the sleep and annoyance rates may appear surprisingly high for such distant homes, though the few narrative comments provided suggest that at this distance, most of those reporting issues were dealing with low-frequency noise, which can indeed travel long distances before dropping to inaudibility; vibrating in homes and fences were among the things noted, as well as low clouds and cold nights, both of which enhance sound propagation.

**TRUenergy survey\textsuperscript{33}**
A survey by the owner of Waterloo Wind Farm sampled 358 people in the area that is home to three wind farms. As usual in a broad-scale survey, they found that 70\% support wind farms, and only 11\% are opposed. Yet, 25\% of this much larger population said noise is an issue, by far the biggest negative attribute (only 10\% disliked how they look). Even more striking, though only 11\% we opposed to wind in the region, 27\% would not want a wind farm built on property near them. Bear in mind, this is a population that has experience with wind farm noise.

**Cape Vincent, New York, 2009**
A survey in Cape Vincent, NY\textsuperscript{34}, also finds relatively low negative reactions to wind turbine noise among residents living about 2 miles (3.2km) from a wind farm on an island in the St. Lawrence River. Here, visual impacts were far more of an issue than sound, though a surprising number did report noise as a problem. 69\% do not notice turbine noise, while 16\% report being rather or very annoyed by noise, and another 11\% slightly annoyed. Of the 31\% who do hear the turbines, about half report being annoyed by the sound at least once a week, most of these daily, while a quarter say they were annoyed at least once a month and another quarter are annoyed less often than that. Applying our routine conservative correction factor, in this location at least 16\% of the people living 2 miles from the turbines reported some annoyance, with a minimum of 5\% being very annoyed. While these figures represent much lower annoyance rates than among people living within a half-mile or more, they may seem surprising at two miles. This could be because this site represents our first survey of response to offshore turbines; the sound is travelling over open water from the island to these residents along the shoreline of the river.

While again stressing that our understanding of local differences would be well served by seeing more community response surveys in towns where it appears that wind farms are not causing much local controversy, it’s hard to look at the consistent findings of the surveys that have taken place without having a better appreciation of the fact that living with turbines is very different within a half mile or so than it is for those living a mile or more away. Where exactly to draw the line that divides “acceptable” from “excessive” noise is the difficult question, and one may vary from town to town, as we’ll see in the next section.
Recent recommendations and decisions about wind farm setbacks and noise limits

Wind farm noise first appeared on AEI’s radar in May of 2008, when I noticed a flurry of press reports about towns considering larger setback requirements because of questions about noise, and the concerns voiced by developers about how this would limit their ability to build in some areas. That first blog post has a sort of innocence; little did I know how deeply I would be pulled into this now-roiling public policy debate. Over the four and a half years since then, those initial questions have led to an increasingly rich body of research, and a diverse range of local ordinances.

In response to both the increasing awareness that significant minorities of people living within earshot of wind farms find the sound objectionable, and the understanding that sound peaks can be notably higher than average sound levels used as regulatory criteria, noise limit recommendations appear to be shifting lower in many cases. This can be seen in best practices recommendations from even very mainstream acousticians, as well as in some government recommendations. And, the wide community variability in tolerance for wind turbine noise is clearly reflected in an increasingly diverse set of local and county ordinances adopted over the past couple of years.

Professional recommendations

Among mainstream acousticians, David Hessler’s 2011 Best Practices Guidelines, developed for the National Association of Regulatory Utility Commissioners, is a good example of the gradual shift of thinking. In his reading of the annoyance literature, he observes that “the threshold between what it is normally regarded as acceptable noise from a project and what is unacceptable to some is a project sound level falls in a gray area ranging from about 35 to 45 dBA (Ldn).” Citing the classic Pedersen, et al studies, he notes “relatively high annoyance rates of around 20 to 25%” among residents living in areas with project sound of 40-45dB. Bearing the higher peak sound levels in mind, he thus currently recommends a 24-hour mean (Ldn) sound level of 40dB at residences in most cases, or 45dB “as long as the number of homes within the 40 to 45 dBA range is relatively small.”

He also stresses that for locations with ambient levels over 35dB (which includes most rural locations during the day), it’s important to keep turbine noise to no more than 5dB louder than ambient; this is in contrast to many locales where 10dB over ambient is allowed (he also says that “it is important to note that in the particular case of wind turbine noise a 5 dBA increase does not represent the point of inaudibility.” Both of these recommendations are based on reported annoyance and complaints at existing wind farms; while not going all the way to a 30 or 35dBA limit as suggested by some (who may also feel that 5dB over ambient is important in quiet night time conditions as well), this is a notable downward shift from today’s regulator norm of 45-55dB.
Karl Bolin is another mainstream acoustician who is moving toward a somewhat more cautionary stance on wind turbine noise, summarizing annoyance studies as compared to other common community noise sources and concluding that today's 45-50dB turbine noise guidelines may be a bit too high:

Overall, these comparisons suggest that guidelines for wind turbine noise in the interval 35–40 dB would correspond to the proportion of annoyed persons comparable to the proportion annoyed by road traffic noise at a typical guideline value.

Møller and CS Pedersen join many of their European colleagues in considering 35dB a "very reasonable limit for wind turbine noise," the same range suggested by TH Pedersen and Nielson, who recommend 33-38dB. As they note, "A limit of 35 dB is used for wind turbines in Sweden for quiet areas... It is also the limit that applies in Denmark in open residential areas (night) and recreational areas (evening, night, and weekend) for industrial noise (but not for wind turbine noise)."

The Danish Society for Occupational and Environmental Medicine (DASAN, Dansk Selskab for Arbejds- og Miljømedicin) issued a consultation statement in response to 2011 revisions in Denmark’s wind turbine regulations that urged a 35dB limit:

A number of original papers and several reviews show that between 10% and 40% of citizens living close to wind turbines feel annoyed or extremely annoyed by the noise, and it is shown that the number of annoyed people rises sharply when the noise exceeds 35 dB,...DASAM recommends that the noise limit value is decreased from the current 39 dB (A) so in the future no more than 35 dB is allowed at residences at a wind speed of 8 m/s. It is also recommended to use 35 dB as the noise limit value in noise sensitive land use – today it is covered by the 44 dB noise limit value. Based on present knowledge, this means that less than 10% of citizens living close to wind turbines will be annoyed by the noise.

During 2012, the Massachusetts Departments of Environmental Protection and of Public Health collaborated on a survey of health impacts around wind farms. While concurring with most other previous literature surveys that there was little evidence of direct health effects, and stopping short of making any specific recommendations on noise limits, the section on noise limits identified, as a “promising practice,” Denmark’s noise standards of 42-44dBA in sparsely populated areas, and 37-39dBA in residential areas (using ten-minute averages), noting that “these limits are in line with the noise levels that the epidemiological studies connect with insignificant reports of annoyance.”

The formal recommendation was a bit more murky:

The Panel recommends that noise limits such as those presented in the table above be included as part of a statewide policy regarding new wind turbine installations. In addition, suitable ranges and procedures for cases when the noise levels may be greater than those values should also be considered. The considerations should take into account trade-offs between environmental and health impacts of different energy sources, national and state goals for energy independence, potential extent of impacts, etc.
In October, 2012, Kenneth Kimmell, commissioner of the Massachusetts Department of Environmental Protection, acknowledged that the uproar around several wind farms in the state has affected how the state considers current siting standards, saying, "All of us have been caught by surprise to some degree to some of the opposition to wind power...I do think that some of our experiences are guiding us to be a little more cautious about where wind turbines are sited."44

Not wanting to fill pages here with redundant information, I point you toward AEI’s Wind Farm Noise 2011 annual report, pages 14-26, for detailed discussion of recommendations from some of the more cautionary acousticians, who generally suggest noise limits of 35dB or less in order to minimize or eliminate substantial negative community response that can be expected as a noise source approaches 10dB louder than background ambient sound levels (rural ambient sound is often 20-25dB at night, and 35-40dB during the day).

In particular, some of these community noise specialists45 stress that noise limits in rural areas require a “normalization” of typical noise standards to adjust for the expectation of more quiet in rural areas (thanks in part to the lack of the steady-state background noise more common in urban and suburban settings). In practice, and as applied by the EPA in the past, this would lead to a 10-20dB downward adjustment of acceptable noise levels in rural areas (often 10dB for rural setting, 5dB for a new or unfamiliar noise source, and sometimes 5dB for an impulsive source). As compared to fairly common noise limits of 55dB day/45dB night, if all these corrections were applied, it would result in noise limits of 35dB; if just the rural correction were applied, it would result in limits of 45dB day/35dB night. One early observation along these lines46 suggests “the EPA normalization factor of +10dB for quiet rural settings is justified and needed not on the basis of the background sound but on the basis of the community expectations for a quiet environment.”

The wind industry does not appear to have generalized recommendations concerning siting with respect to noise levels; instead, a case-by-case approach is usually advocated. The American Wind Energy Siting Handbook47 does not contain any specific setback or noise recommendations. It references a DOE Wind Energy Guide for County Commissioners48 that cites several “wind myths and facts” documents from 2005 to address noise concerns. These older documents predate many of the more substantial siting and annoyance issues in small towns over the past several years. As noted earlier, the American Wind Energy Association’s 2011 Turbine Noise Fact Sheet49 suggests that noise will be 35-45dB at 350m (1150ft/.22mi); many wind developers consider setbacks in the 1000-1200 foot range to be standard operating procedure, with setbacks of up to 1400-1800 feet sometimes being acceptable. It appears to be rare for wind companies to readily accept setbacks of much over a third of a mile; in the project sound contour maps included above, individual turbines are carefully sited in order to keep noise levels at all homes within local limits. Without any clear statements of current recommendations, I think it’s fair to say that the industry norm (or certainly preference) is setbacks of a quarter to half mile, or noise limits of 45-55dB.
Wind historian encourages building where noise is unlikely to be an issue

One of the wind industry's longtime champions, historian Robert Righter, has become much more sensitive to noise concerns, as well. This year, the University of Oklahoma Press published his second book-length history of the industry, *Windfall: Wind Energy In America Today*. (not to be confused with an anti-wind documentary film with the same title)

I've summarized his thoughts both on AEI’s blog and for Renewable Energy World, and I encourage you to read the full review, and indeed, the book. In brief, Righter is a strong proponent of wind energy, past, present, and future. The book is wide-ranging, covering all aspects of the industry's growth and current increasing role in our energy mix with enthusiasm and optimism. But he spends chunks of three chapters addressing the increasing problems caused by wind farm noise in rural communities, chides developers for not building farther from unwilling neighbors, and says that new development should be focused on the remote high plains, rather than more densely populated rural landscapes in the upper midwest and northeast. While not ruling out wind farms in the latter areas, he calls for far more sensitivity to the quality of life concerns of residents.

Righter stresses the need to set noise standards based on quiet night time conditions, “for a wind turbine should not be allowed to invade a home and rob residents of their peace of mind.” He says, “When I first started studying the NIMBY response to turbines I was convinced that viewshed issues were at the heart of people's response. Now I realize that the noise effects are more significant, particularly because residents do not anticipate such strong reactions until the turbines are up and running – by which time, of course, it is almost impossible to perform meaningful mitigation.”

As a bottom line, and despite his support for the industry and belief that we may learn to appreciate a landscape with more turbines, Righter calls strongly for new development to proceed in ways that minimize or eliminate intra-community conflict.

“In the final analysis, we can best address the NIMBY response by building wind turbines where they are wanted...and where they do not overlap with other land use options. Conversely, wind developers should give serious consideration to not insisting on raising turbines where they are not wanted...Unlike Europe, our nation has land; there are vast areas of the United States that have excellent wind resources and welcome the wind turbines”

Local, county and state ordinances: one size no longer fits all

Over the past couple of years, towns and counties across the US, and Australian states, have adopted new wind farm siting standards that reflect a growing diversity in local tolerance for wind farm noise. While in some cases, factors other than noise (including visual impacts and general aesthetics of place) contribute to the decisions, it appears to me that when broader aesthetic considerations are the primary driver, localities are more apt to simply ban industrial wind development altogether. In the UK, the past year has seen an especially dramatic move toward such local bans or denials of permits primarily on local
aesthetic concerns. In March, a UK High Court ruling affirmed that local councils have the right to deny wind farm applications on the basis of protecting “character and appearance” of rural landscapes\(^5\). A few towns in Maine and Vermont have followed suit, as did at least one in Michigan.\(^5\) When we look at the deliberations that take place in county commissions and local planning departments or wind ordinance committees, it’s clear that noise is often the central concern, especially in places where the final decision involves setbacks of a mile or less (turbines are still very prominent visually at a mile). What follows is a sampling of the range of standards approved over the past couple of years.

**Status quo is fine with us; we don’t mind hearing turbines**

Connecticut (2012 draft of state standards)
1.1x turbine height to property line, 61dBA day/51dBA night at homes

Woodford County, IL (Feb 2012)
4x turbine height to non-participating homes (had been 750 ft)

Wells County, IL (Nov 2012)
1200ft to home/440ft to property line; 50dB

Boone County, IL (ongoing late 2012; couldn’t reach decision before new board elections)
Planning, Zoning and Building Committee recommended 2000 ft; Regional Planning Commission rejected that proposal.
Current discussion is in the 1200-1500 foot range
October hearing, company said they could live with 1400
November hearing, landowner rep said 1200 would make it hard to proceed.

Farmington, ME (2012)
60dB at property line

Palmyra, MI (2011)
45dB; planning board rescinded a previous reduction to 40dB after developer said it would likely prohibit construction in town

Gratiot County, MI
1000 ft to home / 1.5 hub height to property line; 55dB with louder OK in high winds
(Gratiot County Wind Project, Michigan’s largest, went online June 2012)

Carbon County, WY (Oct 2012)
1000 feet

Antrim, NY (Nov 2011)
Voted down an ordinance that would have required setbacks of 6x turbine height (1800-2400 feet) and night noise limit of 40dB or ambient+5, whichever is less. nbAs the signs around town said, “A No vote is is a Yes for Wind!”
Exclusionary/extremely precautionary; we don’t want to hear turbines

Outright bans are the most extreme response, of course, as noted above. Meanwhile, some communities approve ordinances that are designed to keep turbines far enough away to be very rarely heard; in some situations, such large setbacks effectively preclude development in that town. Many such ordinances include provisions allowing wind developers to obtain easements from landowners living closer to the turbines; this approach protects the soundscape of citizens who don’t wish to hear turbines, while providing an opening for developers to negotiate mutually agreeable contracts with neighbors in addition to turbine hosts. (While such ordinances provide only a potential opening, we should bear in mind that most surveys suggest that up to half or more of people living within a mile of wind farms don’t mind the noise; this provides a realistic possibility that enough good neighbor agreements could be obtained to proceed, at least sometimes.)

Peru, ME (Nov 2012)
1.5 miles from property line; 35dBA day/25dBA night
Selectmen had initially voted this down, and the wind committee chair preferred 1 mile; 40/35dB.

“I am as much against wind power as anyone on this committee,” Committee Chairman Jim Pulsifer said, but, “I have a problem with the absurdity of this ordinance.” (note: he felt the permanent sound monitoring provision and decommissioning bond would be enough to deter companies without inviting a challenge) Committee member Mike Breau responded that they were all afraid of being sued. “No one wants to be sued, but we have a right to protect our people,” he said. “Five years ago our limits wouldn’t have been defensible, but now they are defensible because we have more data. If you look at all of the data out there, it is defensible. We are on a learning curve. What existing sites are telling us is their setbacks were too low and their noise limits were too high.”

Middletown, RI (Sept 2012)
30dB; no shadow flicker on neighboring properties (revised from “minimize”)

Sometimes, a setback that would be exclusionary elsewhere because of limited room to build is instead a strongly precautionary provision because there is plenty of open space. Three such decisions were made in the US in 2011.

Coconino County, AZ (Feb 2011)
2 mile setback (the Perrin Ranch Wind Energy Center plan had included some turbines around a mile from homes; the project proceeded under the tighter restrictions)
Lights are triggered by aircraft radar; County wanted a property value guarantee as the same company had implemented in an Illinois project, but it would be unenforceable in AZ County Supervisor Carl Taylor: "My hope is that given the control of the lights and the removal of these things to where they are way out of range in terms of sound disturbance, that people will pretty rapidly say 'no big deal.' That's my hope."
Umatilla County, OR (June 2011)
2 miles from non-participating homes; landowners allowed to waive the limit and allow closer siting.

Upon appeal, the state Land Use Board of Appeals did not object to the 2-mile limit, but sent the ordinance back to the county because it allowed landowners themselves to waive the setback limit; individuals should not have the legal right to waive a county rule. So, the county re-wrote the ordinance to use their standard variance process, in which a landowner can request a variance and the county then chooses whether to grant it. It appears that the court filings of these revised provisions are still in process in late 2012

Caratunk, ME (2011)
1.5 miles or more from property line; formula based on number and size of turbines

The rules are restrictive, but there are still places in Caratunk where development could be possible

Likewise, the recent more precautionary standards from Australia belong in this category as well, I think. My impression is that they don’t preclude development, because there is plenty of open space, but I have not seen clear indications of new projects moving forward since these rules were imposed. (I’m not really looking that hard at Australia, though....)

Victoria, Australia (2011)
2km from homes

New South Wales (Mar 2012 draft; no final decision yet)
2km from homes, or obtain waiver from any homeowners closer

OR

Developer can engage in a “gateway” process to obtain a government-issued waiver from the 2km setback. It appears that projects obtaining “gateway” waivers would still need to meet a 35dBA limit (or ambient+5, whichever is greater) at homes.

South Australia
35dBA in areas “primarily intended for rural living”
40dBA in other areas
Landowners can agree to allow higher sound levels

I’m not sure whether the recent decisions in the UK to adopt 2km (1.25 mi) setbacks from homes belongs are extremely precautionary or exclusionary. Since outright bans and denials of permits are increasingly common there, I suspect that the places that adopt a setback standard may have suitable sites for development using these setbacks. Among the places adopting the 2km standard in recent years are South Cambridgeshire and Lincolnshire.
Seeking middle ground: making room for wind, but keeping it at a more comfortable distance

Many of these ordinances seem to center on the range of a half to three quarters of a mile, with a few stretching to a mile (reminder: a half mile is 2640 feet; three quarters of a mile is 3960 feet). Several include waivers to allow closer siting to willing neighbors. All involved extended community deliberation, usually including a committee appointed to come up with a plan for approval by selectmen, county commissioners, or town-wide vote.

Riga, MI (Nov 2011)
45dBA day, 40dBA night

Claybanks, MI (2011)
3000 feet from non-participating property line; 40dBA
(more problematic are participating landowner limits of 1500 feet/47dBA, apparently without waiver option)

Rumford, ME (Nov 2011; passed 1137-465)
4000 feet to property line; 50dB day/40dB night. Mitigation Waiver agreements allow closer siting.

This one’s especially interesting, as it was a “third time’s the charm” decision. An initial 1-mile proposal was voted down for being too stringent, while a second plan that allowed 45dB at night lost for not being protective enough.

Sumner, ME (May 2012)
1 mile from neighboring property, with easements for closer siting
(This proposal was framed locally as requiring the wind developer to reach agreements with all landowners within a mile of a tower; passed by a 2-1 margin among local voters)

Industrial Wind Ordinance Committee Chairwoman Kathy Emory: "The setback of 1 mile may still be too much for some and not nearly enough for others. It is the opinion of the IWOC and is supported by significant research as well as the setback utilized by at least 15 other towns in the State of Maine who have enacted ordinances that a 1 mile setback is adequate and protects all.”

Dixfield, ME (Nov 2012; passed 651-622)
4000 feet from property lines; follow state noise limits of 55dBA day/35dBA night

This was the pro-wind proposal in town; it the vote had failed, they would have drafted an outright ban. “Basically, it comes down to this vote,” Town Manager Eugene Skibitsky said. “If you’re in favor of wind power, vote yes. If you’re not in favor of wind power, vote no.” He favors it as "a great opportunity to stabilize the tax base"56

Meanwhile, setbacks that might be considered middle-ground proposals in some more wide-open regions are effectively exclusionary in towns where there is not enough room (especially if they don’t include waiver options)
Frankfort, ME (Nov 2011; passed 244-222)  
1 mile from property line; 45dBA day/32dBA night (both 10dB lower than state standards)  
But: this is the only land-use rule in town, so it has been challenged in court by landowners who want to host turbines\(^\text{57}\); I cannot find any press coverage to confirm how the civil suit against the town is progressing. The developer had asked for 1000 feet and state noise limits; it appears that in this town, at least for the proposed project, the ordinance was designed to be exclusionary.  
At a local meeting on the proposal, Josh Dickson, who served on the committee, said: “At the end of the day, this is research. It’s not perfect. Neither are we. We did the best we can. The decision will be up to you guys, not us.”\(^\text{58}\) (After the meeting, the developer and a citizen perfectly encapsulated the state of much of the dialogue on these issues, engaging in a shouting match in which each screamed that the other was a liar....)  

Goodhue County, MN (2011)  
10 rotor diameters (about a half mile)  
National Wind (the developer) challenged this as unjustifiably stricter than state rules. PUC ruled that 6 rotor diameters (about 1600 feet) should be the standard, but told company to engage in a good-faith effort to negotiate agreements with other landowners within the county’s setback area (note: not a requirement that they succeed in obtaining agreements); 200 non-participating landowners were later offered $10,750 “good neighbor” payments. A June 2012 court ruling denied an appeal of the PUC decision, saying that the county did not meet the “good cause” threshold for superseding state laws, and (strangely, in my view) deemed the 10 rotor setback a “zero-exposure standard.” The project is currently hung up by troubles obtaining state wildlife permits, as well as PTC uncertainties.\(^\text{59}\)  

Cape Vincent, NY (Aug 2012)  
6x total height to residences (about a half mile)  
45dBA daytime (7am-7pm), 40dBA evening (7pm-10pm), 35dBA night  
Plus penalties (reduce above limits): 5dB for “steady pure tone”, 7dB for “impulsive noises”, and 12dB for “highly impulsive noises”  
BP (local developer) proposed “reasonable” guidelines of quarter mile (1320 feet) setbacks, noting that this “exceeds industry standards”; New York State allows localities to supersede state rules only under a “reasonableness” standard. BP is moving to obtain approval for this project via a state “Title X” process that bypasses local regulations.
Several towns that already host some turbines have gone back to the drawing board to adopt more precautionary siting standards, which fall variously in the middle-ground and precautionary/exclusionary categories.

Argyle, Nova Scotia (July 2012)
1000 meters (3280 feet, .62 mile)
   Previous standard were as little as 242m, depending on turbine size; an earlier wind farm in this town at Pubnico Point had raised some serious noise issues (one family 330m away moved out; the developer bought the house and resold it). Warden Aldric d'Entremont says they council had little information to go by when the approved the original setback law: “I’ve been saying for a long time now, (that) 300 metres, like we have in Pubnico, is not far enough. If I had to do it over again I wouldn’t do it at 300 metres.” When asked by a reporter if 1000 meters would be enough, he said, “Most people think so.”

Woodstock, ME (in process late 2012, aiming for March town meeting vote)
1.25 from property lines; 45dB day/32dB night (both 10dB lower than state standards)
   A 10-turbine wind farm in town, built under state noise regs – and no closer than three-quarters of a mile to any home – triggered noise complaints from around half of the people living within a mile and a half. Wind Ordinance Committee member Charlie Reiss said the group tried to find the right balance that would make future projects tolerable for neighbors without creating restrictions so severe that the projects would be impossible to build. The committee will continue meeting and making adjustments to the proposal, in anticipation of the town meeting vote in March.

Freedom, ME (Draft May 2012, moving toward vote in early 2013)
13x turbine height from property line (400ft turbine=5200feet)
Those supporting more wind development in town favor a 4000 foot setback
(4000 feet was also the pro-wind position in Dixfield, above)
   A small wind farm was built in Freedom in 2008, with no local regulations in effect. Several families from 1000-3000 feet, and a few out to a mile, have complained of the noise, though they did not raise the type of ruckus that has occurred in some other communities. But when the town decided to write a wind ordinance, it’s striking to me that those strongly in favor of more wind development are calling for 4000-foot setbacks, which would still allow some buildable locations in town. Planning Board Chair Bill Pickford says, "We had all the sides. I thought we brought in as many people as possible. There are people in town who believe it’s perhaps too strict, but it seems to be line with what every other town is doing," he said. "That’s the norm for every other town that’s adopted something, so I don’t think we’re out of whack here."

Of course, not every town with a wind farm decides that new wind development should be at a greater distance. In the midwest and west, many wind projects are developed in stages, or multiple projects are built in the same region, and it’s rare that later projects face more stringent siting standards than the earlier one (which is not to say...
there’s no local opposition to expansion, just that overall local sentiment doesn’t shift to the point that more stringent standards are developed). The Sweetwater, TX, region is a prime example; in Utah, the Milford Wind project has initiated plans for the third phase of development63, after the first two phases went online in 2009 and 2011.

A word of thanks to local public servants

I’ve often been impressed by the diligence and hard work of the county commissioners, boards of selectmen, and wind ordinance committees that are charged with regulating wind development in a way that makes sense for the people in their communities. They sit through hours of meetings and read hundreds of pages of often conflicting information, and then do their best to represent their friends and neighbors in a reasonable way. A couple of the summaries above include comments from decision-makers that give a sense of the humility and diligence with which the best of them go at it. One more example, from Michigan, captures a bit more of the dynamic64:

"This was the toughest decision they had to make, and hopefully there won’t be anymore like this," Township Supervisor Dave Schabel said. "It’s heavy pressure, does everyone agree with it, no, but they did the best they could."

Commission members visited wind turbines in Ubly, Pigeon and Gratiot Township. “They studied it thoroughly,” said John McQuillan, Merritt Township attorney. "That’s why the Planning Commission is appointed to make this decision."

Dee VanDenBoom, Merritt Township resident, was disappointed with the decision but is hoping the community can move forward.

"We’re peacemakers," VanDenBoom said. "I hope that people can come together as friends and neighbors again."
Turbine sound: low frequency, propagation, peaks & averages
See Appendix A for full research review, published online December 31, 2011

As regular readers will know, AEI’s wind farm coverage has focused primarily on the ways that nearby neighbors respond to the audible noise from wind turbines, with far less emphasis on infrasound. However, given the ongoing public dialogue about the contribution of infrasound and low-frequency sound to the annoyance, sleep disruption, or health effects reported by some wind farm neighbors, I do like to keep abreast of research into the lower end of the sound spectrum. In an Appendix, you can read detailed summaries of several key papers, including close reading of work from both mainstream and more cautionary acousticians, which may help you to understand the subtleties of our current state of understanding in a new and clearer way. Many of these papers go beyond strictly addressing low-frequency sound, and offer useful insights into other aspects of wind turbine noise. Here, I’ll offer just a quick run-through of what I see as the most important themes from this research.

Variability of wind turbine sound

As I’ve studied the literature and talked with both neighbors and project planners, I’ve become increasingly convinced that a primary driver of complaints about wind turbine noise is its extreme variability. To some degree, this aspect has been recognized for years, but recent research suggests that there are some factors regarding variability that are not yet widely recognized.

It’s long been known that wind turbine sound triggers higher rates of annoyance than other sources of community noise, such as roads or airports, with turbine sound unpredictability and variability considered the primary driver of this difference. Not only does turbine sound often pulse at once-per-second, making it more attention-grabbing and harder to ignore than a steady background sound, but it comes and goes at all hours of the day and night. This much is common knowledge.

But there are a three other aspects of the variability that are less widely appreciated, all of which likely play a key role in community responses to wind farms. First, and hardest to quantify, is the radically differing sound quality of turbines in different situations. While we usually think of wind turbine sound as being a gentle swooshing (at times punctuated by pulses in the swoosh), neighbors often report that turbines make knocking, banging, or tumbling sounds; a widespread description is of sneakers in a clothes drier. At times, palpable waves of lower frequency sounds are said to penetrate into homes, and at times are felt in the body. These more intrusive sounds are often the most bothersome, and hardest to ignore. All of these sounds are also potentially associated with times of more air turbulence hitting the turbine blades; the turbulence could be caused by the wakes of nearby turbines, or by times of more turbulent airflow at the wind farm's location. See pages 46-47 for more on current research into turbulence. If these times of atypical turbine
noise could be identified and operations curtailed in these conditions, it’s possible that the negative community response could be greatly reduced.

Variable turbine source levels

While many sound models, especially those used to generate project-specific sound contour maps, base their propagation modeling on relatively worst-case conditions, such as higher winds aloft, sound-reflecting air layers, or frozen, bare ground, these propagation models all start with the turbine manufacturer’s rated sound power level for the turbines being used. These sound power ratings are based on idealized smooth winds and new equipment, often tested in laboratory conditions.

Once equipment is in the field, of course, things get less ideal in several ways. As noted above, wind flowing into turbines is not always smooth and consistent; inflow turbulence tends to create increased low frequency sound as well as unpredictable bursts of other sounds/noise. In addition, turbine blades gradually become slightly worn, with small pocks and pits that can interfere with the smooth flow of air around the blades and create more turbulence (and noise) on the trailing edges of the blades. This is part of normal wear and aging of turbines; routine maintenance includes monitoring for such surface imperfections, and doing fills and resurfacing as needed. But inevitably, many turbines in the field will be operating at less than the peak aerodynamic efficiency at which they were initially tested, and the source sound levels of individual turbines will indeed vary to some degree. And because of the way that sound drops by 3-6dB for each doubling of distance, an increase in source sound level of a few decibels can mean that sound levels are doubled at any given distance, or don't reach a threshold of interest (e.g., the regulatory limit) for up to twice as far.

Surprisingly, very little study appears to have taken place to quantify just how much variation in turbine sound levels there may be in practice. For most wind farm operators, the primary reason for this ongoing maintenance to keep airflow near its designed efficiency is to minimize power losses and loads and stresses on blades, which can then propagate into the internal machinery; small changes in turbine sound levels is not generally something they attend to—perhaps in part because few projects are subject to long-term sound monitoring, with pre-project sound models often being considered the last word on project sound.

A recent study begins to rectify the situation. Møller and CS Pedersen measured the actual sound power levels of nine large turbines, and these field measurements found that individual turbines actually had significantly varied sound output. They then modeled propagation from their individually measured turbines out to the point that turbine sound would drop below 35dB (they chose this threshold because it’s the level required in quiet areas of Sweden, and it’s the level at which Pedersen-Waye found annoyance begin to spike beyond 5-10%). Because the nine turbines had distinctly different initial (source) sound levels, the variation in distance was stunning, with this quiet sound level reached at distances ranging from 629m (2063ft) to 1227m (4024ft). When their models included
cylindrical spreading at greater distances and a sound-channeling layer (as discussed below, see p42-43), sound propagated more than twice as far before dropping to similar levels$^{66}$.

Clearly, replication of the Møller and Pedersen study would be a useful direction for further research. It would be very helpful to know how much the rated sound power levels of new turbines tends to increase over time; in addition, doing field measurements of sound levels around turbines that have been individually would help test the ways any such differences in turbine sound levels actually affect nearby residents’ received levels.

**Average and peak sound levels:**

*How a project can be in compliance and sound like it’s too loud*

Two other papers in Appendix A discuss a consequence of source level and propagation variability that deserves far more widespread appreciation: that actual on-the-ground sound levels will vary greatly, and in particular, will peak at up to 20dB above the long-term average that is generally used as a regulatory criterion. This point is made most clearly by the decidedly mainstream acoustic consultant David Hessler, in a *Best Practices Guidelines paper written under the auspices of the National Association of Regulatory Utility Commissioners*$^{67}$, and is seconded by Australian Robert Thorne$^{68}$, whose work often focuses on human responses to moderate noise. The likelihood of peak sound levels being higher than regulatory criteria based on averages is a fact that needs to be communicated more clearly, both to help create realistic expectations, and because this may be relevant to the choice of what average sound level to aim for.

This little-appreciated factor plays into noise complaints in a couple ways. For starters, it explains why some wind farm neighbors record sound levels on home sound meters that are well above the regulatory limits, while operators of the local wind farm assert they are operating in compliance. A well-publicized example is the Pinnacle Wind Farm in Keyser, WV$^{69}$, where neighbors often recorded sound levels of 65dB, and sometimes up to 70dB. Knowing that the noise limit was 55dB, they were very upset. Yet it's entirely plausible that the wind farm was meeting its 55dBA Ldn criteria (average for the entire day and night), while peaks of 65-70dB were balanced by times when the wind wasn’t blowing and sound levels were 40dB or less. In many locations where post-construction complaints triggered sound monitoring, the wind farms were found to be within compliance, or at worst, slightly over the limit on rare occasions.

This points to the second consequence of peaks sounds being well above the average regulatory limits: *noise complaints will tend to be triggered by the peak times*. If the regulatory limit is set relatively high (as at Pinnacle), it’s very likely that peak times will occur often enough to cause widespread complaints. And if a lot of homes are right on the edge of even a more modest regulatory limit, the peak times will push sound to levels that are well above local background levels, also triggering complaints. This may be what’s happening around the Hardscable Wind Farm in upstate New York$^{70}$, where over a hundred homes are in the 40-45dB zone of the sound contour map that we saw on page 14.
As Hessler stresses:

It is important to note that the...suggested sound level targets discussed (below) are mean, long-term values and not instantaneous maxima. Wind turbine sound levels naturally vary above and below their mean or average value due to wind and atmospheric conditions and can significantly exceed the mean value at times. Extensive field experience measuring operational projects indicates that sound levels commonly fluctuate by roughly +/- 5 dBA about the mean trend line and that short-lived (10 to 20 minute) spikes on the order of 15 to 20 dBA above the mean are occasionally observed when atmospheric conditions strongly favor the generation and propagation of noise.

This graph illustrates Hessler's point about turbine sound variability at one particular location and time. Note that the variability is greatest, and with the highest peak sound levels, at moderate wind speeds. I suspect that the fairly chronic 5-10dB over-average peaks are responsible for much of the community annoyance.

Hessler observes that “the threshold between what it is normally regarded as acceptable noise from a project and what is unacceptable to some is a project sound level falls in a gray area ranging from about 35 to 45 dBA (Ldn).” Citing the classic Pedersen, et al studies, he notes “relatively high annoyance rates of around 20 to 25%” among residents living in areas with project sound of 40-45dB. Bearing the higher peak sound levels in mind, he thus currently recommends a mean (Ldn) sound level of 40dB at residences in most cases, or 45dB “as long as the number of homes within the 40 to 45 dBA range is relatively small.”

He also stress that for locations with ambient levels over 35dB (which includes most rural locations during the day), it’s important to keep turbine noise to no more than 5dB louder than ambient; this is in contrast to many locales where 10dB over ambient is allowed. Both of these recommendations are based on reported annoyance and complaints at existing wind farms; while not going all the way to a 30 or 35dBA limit as suggested by some, this is a notable downward shift from today’s norm of 45dB or more (50-55dB is still quite common).
Australian researcher Robert Thorne agrees that a combination of standard prediction error ranges, magnified over distance, and with the addition of adverse weather effects that either increase turbine source levels or enhance sound propagation, will create peaks of up to 20dB over the predicted levels. He has monitored sound levels at many homes around a mile from wind farms. He notes that "in 60 seconds the sound character varies regularly by more than 20dB" and that "Sound from wind farms can easily be heard at distances of 2000 meters (1.24 miles); such sound was measured...over the range 29 to 40 dB(A) with conditions of calm to light breeze. The sound was modulating and readily observed and recorded. The sound can be defined as being both unreasonable and a nuisance." (Ed. note: it's worth noticing these 40dB peaks at over a mile away; most sound modeling will suggest that such levels are common only within a third to half mile or so of turbines; most models are more likely to predict sound to be in the 30-35dB range, the low and middle range of Thorne's, measurements, at a mile.)

How often will peaks occur?

There are no publicly-available, long-term noise monitoring records from operating wind farms that might give us a sense of how often peak sound levels caused by turbulence or unusually enhanced propagation may occur. But a study by Ken Kalisky gives us a clue about more generalized patterns of wind farm sound variations. Kalisky used meteorological records to model the sound levels likely to be generated by a wind farm over the course of a year, on an hourly basis. He found that sound levels would be within 5dB of the peak level (in this case, between 35 and 40dB) just 12% of the hours that turbines were operating:

Since turbines don’t operate all the time, the actual number of hours that turbine sound would approach its normal peaks is even less. A very conservative estimate would be that turbines operate a third of the time; using this adjustment factor, we’re down to just 4% of the hours of the year with near-peak sound levels. That sounds pretty reassuring.

But let's do some math: 4% of the hours in a year could mean 58 days with peak sounds for 6 hours. That’s two months of the year. Or, more days with shorter periods of peak sound; say, 116 days (a third of the year) for 3 hours. It’s likely that the louder times will cluster seasonally, when high winds or shear conditions or turbulence is more common; this would create longer periods in which the loudest times are a regular occurrence.
It’s not hard to see how any of these scenarios could create an experiential sense of fairly chronic peak sound. And this is likely a very conservative estimate; in fact, turbine capacity factors are generally 25-40%; this reflects the percent of power generated as compared to turbines operating at full power 24 hours a day. Much of the time they are turning, turbines operate at below peak power; thus the proportion of hours turbines operate are sure to be higher than the capacity factor. So it’s likely that the “peak hours per year” are somewhat higher than what we just figured. Consider as well that Hessler’s graph above suggests that in addition to the peak noise times, we’ll have fairly common times when wind speeds are moderate, but turbine sounds are prominent, even when not necessarily near their peaks. All this is not to overstate the severity of these peak noises; indeed, we’re talking here about routine turbine operations within regulatory limits. But it’s important to not slip too easily into complacency when we hear that peak sound levels are rare.

Low frequency noise and infrasound

I think it’s fair to say that the bottom line continues to be roughly the same as it’s been: wind turbines clearly produce much of their sound energy at lower frequencies, including the low end of the audible spectrum (20-250Hz) and the infrasonic range (below 20Hz, which is generally below the range humans tend to hear, simply because it has to be very loud to be perceptible). Conventional wisdom continues to be that the infrasound in wind turbine noise is well below human perceptual limits, even of the more sensitive fringe of the population.

However, some researchers who have looked more closely at sound in areas where complaints were especially severe are becoming more convinced that infrasound may be more of an issue than we’ve thought.

Bray/James, one minute of sound at a home in Ubly, Michigan, 1500 feet from the nearest turbine in low winds; human perception threshold generally considered to be 95-100dBG
Assessing sound measured in dBG, which includes both audible low-frequency sound and infrasound, and using equipment and filters designed to capture very short time segments – matching the time frame of human auditory responses – Wade Bray and Rick James have recorded rapid, extreme variation in intensity (high crest factors) and peaks of sound that come very close to standard hearing thresholds. (Wind farm noise typical distances for homes has been measured at Leq’s of 50-80dBG, well below the 95-100dBG hearing threshold. Hearing threshold curves are based on sustained pure tones at specific frequencies; there is some indication that our thresholds for hearing pulses of sound could be lower.) This is fascinating work, although so far data from only two or three sites have been assessed using these techniques; we’ll need more field measurements to get a better sense of how common these high peaks are, and the range of intensity of the peaks. Meanwhile, Alec Salt continues to investigate ways that our ears’ outer hair cells (OHC) may respond to much lower intensities of infrasonic sound than our inner hair cells, which drive actual perception; while intriguing, this line of research is so far coming out of just one lab, and are animal studies (albeit on animals widely used as proxies for human hearing), and the mechanisms by which OHC stimulation might relate to physiological responses still uncertain. These new lines of research are intriguing, and certainly worth pursuing; I look forward to further replication of these findings, and for the metrics and methods to be assessed more widely by the acoustics and auditory physiology communities. Only after this important line of inquiry is more thoroughly investigated will it be widely considered viable as a basis for setting policy.

Meanwhile, whether or not this new line of research succeeds in reframing the infrasound question, it’s widely recognized that low-frequency audible sound is a key factor in annoyance about wind farm noise, and several recent papers contain some good ways of looking at this. It’s important to not conflate infrasound and low-frequency sound; while the former is (always or mostly) imperceptible, the latter is clearly very audible in many situations, and indeed, is the dominant sound component of wind farm noise at moderate and larger distances.
A few things are worth noticing in this graph, from a report on low frequency noise commissioned by the Ontario Ministry of Environment. Most importantly, it shows lots of easily audible low frequency sound from 50Hz on up; it's likely that some individuals would be sensitive to the wind farm sound levels shown here at 30-50Hz. Note that even these lower frequencies are not infrasound (which is below 20Hz), but borderline-audible low frequencies. The data here is affirmed by field observations by the report's author of "strong, audible low frequency (but not infrasonic) tones from some turbines." Notice also that this graph affirms that there is indeed a lot of sound in frequencies below 20Hz, the typical human hearing threshold. Clearly, turbine noise does include infrasound, though here it is far below the hearing threshold curves for those frequencies.

Also, the two studies of wind farm noise plotted here show surprisingly little difference in overall sound levels between 305m/1000ft (purple line with triangles) and 650m/2100ft (black line with triangles) - this may reflect differences in the local topography or turbine size, or could be a reminder that our sound models (which would suggest that the black line should be routinely 3-6dB below the purple line) are not as reliable as we might wish (due to a confluence of factors, including the source sound levels of turbines varying from the ideal conditions used as a the starting point for models, and the variability of sound propagation due to transient meteorological conditions).

It's quite likely that much of the annoyance reported by neighbors could be triggered by very low frequency, moderately audible noise, which can be more ear-catching when it contains one or more dominant tones, fluctuates rapidly, or contains more intrusive knocking or banging sounds (which are likely caused by air turbulence increasing the sound level of the turbine in irregular patterns). Further, increasing evidence confirms neighbors' reports that moderate but hard-to-ignore low frequency noise can be more perceptible inside their homes than outside.

These elements are part of the reason that several of the papers summarized in the Appendix from relatively mainstream perspectives (and which consider infrasound a non- or minimal issue) recommend lower noise limits than the 45-50dB standard commonly used in the US; you'll see in these papers that 40dBA is becoming a common recommendation (usually averaged over a full 24-hour period). Most of the more cautionary acousticians tend to recommend 30-35dB (often using a shorter averaging time of ten minutes or less); it's striking to me that the gap between these two perspectives has narrowed considerably in the last year or so.

**More distant propagation of low frequencies**

Also of particular note are observations from multiple researchers which are relevant to two key aspects of sound modeling: surprisingly high variations in the source sound level being generated by turbines, and more distant propagation of low-frequencies than is often assumed.
Two of the papers featured in the Appendix, one from mainstream consultants HGC for a report to the Ontario Ministry of Environment\textsuperscript{78}, one by Danish researchers Møller and CS Pedersen\textsuperscript{79}, stress that lower frequencies appear to drop by more like 3dB per doubling distance (cylindrical spreading), rather than the 6dB (spherical spreading) as with most audible sound, and most dBA sound models. This, combined with atmospheric refraction creating a sound channel with the ground below, can create much higher sound levels than expected at distances beyond a few hundred meters. At greater distances, the sound that makes it that far will be mostly low-frequency, and will be at higher levels than typically predicted using spherical spreading models. As Møller and Pedersen note, "Cylindrical propagation may thus explain case stories, where rumbling of wind turbines is claimed to be audible kilometers away."

Several of the papers summarized in the Appendix address the challenges inherent in recording low frequencies. One researcher, David Hessler, maintains that most measurements of low frequency noise around wind farms are little more than records of the noise of wind on the mics. Others point to solutions to this problem, including wind screens designed specifically to protect mics from low frequency contamination, and measuring turbine sounds at times when the recording location is sheltered from wind. And the afore-mentioned Bray/James work suggests that it’s important to be attentive to the time period over which you are assessing low-frequency sound. It’s worth being aware of these questions as you consider low frequency monitoring data.

One other aspect of low-frequency noise that is noted in several recent papers is that it’s quite common that low frequencies are more noticeable inside a house than outside, after walls filter out the remaining, faint mid-frequencies. Thus, inside a bedroom, a faintly audible pulse of low-frequency noise can become a subtle yet inescapable presence. Both Thorne\textsuperscript{80} and Ambrose and Rand\textsuperscript{81} have measured such noise inside homes. Residents studied by Thorne often report that the low-frequency sound is noticeably worse in their homes than it is outside (Thorne’s studies have taken place at 1.5-2km, 5000-6500ft, from turbines). Even more surprising, and frustrating for some residents, "rooms in a residence can and will show significantly different characteristics. What may be inaudible or not perceptible in one room can be easily heard or perceived in another room on the same side of the house."

These are the “hot topics” in noise assessment for wind farms, the current lines of research that are attempting to both make sense of unexpected noise annoyance and to generate practical guidelines for use by regulators. Again, for those of you working more deeply on regulatory issues or community noise responses, I encourage you to read Appendix A on this topic to get a better picture of the current thinking of both mainstream and more cautionary acousticians.
Industry efforts to quiet wind turbines

See Appendix B for full paper, submitted for the proceedings of
Renewable Energy World North America, December 2012

As part of my ongoing coverage of wind farm noise issues, I regularly read several trade magazines that cover renewable energy and wind technology topics. In the past year or so, I’ve seen a marked increase in articles in the trade press about efforts to reduce the noise output of wind turbines. A good example is a July 2011 article in North American Windpower:

As the so-called “low-hanging fruit” of land with good wind and transmission access gets used up and wind turbines move closer to residential areas, noise concerns are expected to become more prevalent, according to wind turbine manufacturers.

“It’s on the top of the minds for all manufacturers,” said Paul Thompson, commercial director of Mitsubishi’s wind turbine group, “we’re all doing things to reduce the amount of noise that’s generated.”

GE’s Henrik Stiesdel stressed that wind turbines do “have a noise impact. The main remedy is to ensure that they are not sited to close to dwellings. If that’s not possible because you are in a densely populated area, then we have remedies where we control the power output when conditions are such that noise might be exceeding limits.”

Appendix B of this report contains a wide-ranging paper I wrote for Renewable Energy World North America’s December conference proceedings, detailing a range of quieting techniques and new research initiatives. Here, I’ll touch on the practical effects of these efforts while attempting to be quite brief.

For current projects, there are two primary approaches to reducing noise output of turbines, both of which have been used in projects where neighbors complained, and as part of initial project planning, in order to meet noise standards while building relatively close to homes.

Most widespread is Noise Reduced Operations (NRO) or Noise Reduction Systems (NRS), which lower turbines sound power levels by slowing them down and “feathering” the blades a bit (i.e., tipping them back so that wind flows past them more easily). Nearly all turbine manufacturers have proprietary NRO software and operational settings that can be triggered as needed; settings are usually available to reduce noise to the degree that is desired, from 1dB to 4dB. Generally, 1-2dB NRO settings don’t reduce electricity production very much (i.e., under 5%), while higher NRO settings can result in 10-25% reductions in power output.

Recently, turbine manufacturers have been experimenting with serrated trailing edges on turbine blades, either as retrofits where noise has become a problem, or as part of the
initial blade design. Of several different blade modifications being researched, serrations have the most extensive research track record, with overall dBA noise reductions of 2-8dB being reported\(^2\). However, many studies have found that these reductions are frequency-dependent, with reductions in low-frequency noise and increases at higher frequencies (over 2kHz). Serrations may also be less effective at low or moderate wind speeds; in some situations, this can be when neighbors find turbine noise most audible.

During its first summer in operation, the three Fox Islands Wind turbines on the island of Vinalhaven, ME, were retrofitted with serrated edges (above) as part of an effort to reduce noise impacts on neighbors, with the hope of achieving a 2-3dB decrease in sound levels. No formal study of the effects has yet been released\(^3\), though neighbors report that the serrations seemed to moderate the lower-frequency thumping element of the sound, while slightly increasing the overall whooshing aspects, as the studies summarized in Barrone might suggest. Interestingly, neighbors suggest the lower frequency improvements were most noticeable in low and moderate wind speeds, counter to the research findings.

The use of either serrated blades or NRO may be expected to reduce sound levels by 2-3dB, which is just barely perceptible. However, a combination of noise-reduction techniques that reduce the sound output by 6dB could double the distance at which turbines are heard at any given level, offering significant relief for nearby neighbors. For example, instead of homes at 1700 feet hearing 45dB, they would hear 39dB, with sound reaching 45dB only at 3400 feet. So while current techniques are just starting to be perceptible, this line of research could make a difference if we are able to continue building on it. In the meantime, even a 3dB reduction would sound slightly quieter at any distance, and would slightly increase the distance where any given sound level occurs.

**Longer-term research on quieter (but longer?) blades**

Several lines of research at Sandia National Laboratory and the National Renewable Energy Laboratory, and within the wind industry, offer promises of future noise reductions thanks to improved blade design and wind farm layouts. All of this research is focused on reducing the stresses on turbine blades caused by air turbulence. Sudden changes in wind speed and direction create stresses on blades, and by extension on all the inner components of turbines, and reduce power output significantly. This “in-flow turbulence” also triggers both increased broadband and pulses of low-frequency noise, and is quite likely responsible for some of the most intrusive knocking, banging, or “sneakers in a
dryer” sounds that are often reported by wind farm neighbors. While the researchers doing this work are not primarily investigating how turbulence and blade stresses influence noise levels, it’s likely that the acoustics of these dynamics will become an important secondary interest of many in the industry.

One line of research is developing blades that can flexibly respond to differences in wind speed and blade stress along their length. A Sandia NL paper summarized the situation thusly84:

“...greatest structural fatigue damage tends to occur during nighttime hours from coherent turbulence that develops in the stable, nocturnal atmospheric boundary layer. Under such conditions, intense vertical wind shear and temperature gradients create resonant flow fields capable of imparting short-period loading and vibrational energy as wind turbine rotor blades pass through regions of organized or coherent turbulence. This energy is subsequently propagated throughout the remainder of the structure...”

The leading-edge research now underway aims to reduce these load stresses in two ways85. First is “passive load mitigation,” including innovative materials (such as carbon fiber as a component in various places within the blade core) and blade geometries (one design reduces loads through a geometric sweep that allows “bend twist coupling” in which blade tips can flex in response to stresses). This is a step forward from simply trying to reduce stress by adjusting the pitch angle (which can only respond to average loads along the blade), but such passive mitigations cannot respond to local load variations as the blade sweeps through turbulent air. That’s where Active Aerodynamic Load Control (AALC) comes in: sensors along the blade that can instantaneously trigger small flaps along the trailing edge of the blade to relieve transient pressures.

So far, the primary thrust of this research is to reduce loads on blades (and thus on generators), in large part to facilitate the use of longer blades on larger turbines that can generate more electricity per cost of construction. Often, the benefit is seen as being able to build a bigger turbine that doesn’t make more noise than current ones, rather than in quieting current designs. It’s likely that these breakthroughs could be applied to smaller (i.e. current-size) turbines as well, in order to allow projects to proceed under local noise limits that are lower than what today's designs can achieve. In moving to larger turbines, whether quieter or the same sound output as today’s, we need to bear in mind that larger designs may exacerbate amplitude modulation triggered by wind speed differentials between the top and bottom of the rotor diameter, and may be associated with moderately increased sound levels at low frequencies, which can be the primary noise annoyance at greater distances, especially indoors86.

**Better understanding of wake turbulence and wind shear**

Two related lines of research at Sandia and NREL are also of interest. Again, the primary interest is reducing load stresses, but here, the goal is to learn more about wind flow patterns so to avoid the situations that cause the stresses – and the increased noise – caused by turbulence.
First is the study of **turbine wake interactions**. Turbines work best when the wind entering the blades is consistent, or “laminar.” Behind each turbine, the air is swirled into a tumbling mess, leaving downwind turbines struggling to extract energy from far more turbulent inflow. One recent study at an existing offshore wind farm found that **downwind turbines can produce 60-70% less power than the front row; it’s likely they’re also noisier (and, crucially, noisier than assumed by models based on the sound power level of turbines in an ideal laminar flow)**. The image below shows (a) instantaneous and (b) time-averaged wind velocity, clearly illustrating that only the front row operates at peak efficiency:

![Image of wind velocity](image)

The final area of ongoing research that is likely to pay dividends in noise reduction as well as in power increases is the **study of wind shear in far more detail** than typically found in current wind farm noise modeling and project design. As noted in a recent overview of current research, **we must look beyond “the narrow definition of shear (i.e., the change in wind speed with height). Wind direction can also change with height**. During the day, when there is strong mixing throughout the lower ABL (atmospheric boundary layer), this change is a few degrees throughout the typical 40m to 120m rotor plane. However, at night, as turbulent mixing decreases, directional shear can be 20-40 degrees or more, depending on how much temperature increases with height. Directional shear also has an impact on the power derived from the wind and can impart considerable stress on turbine infrastructure...” Indeed, while vertical shear (which is more apt to be relatively consistent) can increase power output, directional shear (which can change rapidly) generally leads to power losses and increased stresses (and again, perhaps noise).

For more on operational innovations and this leading edge research that could lead to quieter turbines and wind farm layouts that better minimize wake effects, see Appendix B.
Health Effects
See Appendix C for full research review, published online April 3, 2012

In February of this year, I wrote a column for Renewable Energy World⁹⁰ that addressed the recent increase in claims that wind farms are causing negative health effects among nearby neighbors. The column suggested that while many of the symptoms being reported are clearly related to the presence of the turbines and their noise, the relationship between wind farms and health effects may most often (though not always) be an indirect one, as many of the symptoms cropping up are ones that are widely triggered by chronic stress. In recent months, the dialogue around these issues has hardened, with both sides seemingly intent on painting the question in simple black and white—community groups assert that turbines "are making" people sick, while government and industry reports insist that there's "no evidence" that turbines can or do make people sick. The gulf between the conclusions of formal health impact studies and the experiences of some neighbors has widened to the point that both sides consider the other to be inherently fraudulent. I suggested that the rigidity of both sides' approach to this subtle and complex issue is likely increasing the stress and anxiety within wind farms communities that may in fact be the actual primary trigger for health reactions.

In an extensive summary of new research that is included as an Appendix here, I took a closer look at the few surveys and studies that have attempted to directly assess the prevalence of health effects around wind farms.

Even as the public becomes increasingly concerned about health effects, with a lot of focus on the role of inaudible infrasound, it's been striking to me that the researchers investigating health effects – even clearly sympathetic researchers – are not talking about infrasound much at all, and are instead focusing on stress-related symptoms. (Readers of the full Appendix C will see that this applies to researchers including Michael Nissenbaum, Daniel Shepherd, and Carl Phillips.) Drawing from studies done in areas where health concerns have been most widely reported, AEI's review found that most of the studies find little difference in overall health based on proximity to turbines, though they did find reductions in some specific measures of health, especially sleep quality, and overall local amenity or quality of life. (It should be stressed that these studies, using widely-recognized health rating systems, looked at average ratings in the vicinity of wind farms; the data as presented does not clarify whether an increased proportion of individuals – even just, say, 10-15% – closer to turbine reported lower health ratings, while the overall average remained relatively unchanged.)

And, where health effects are reported (primarily sleep disruption and stress-related symptoms), those who have been most diligent and open in assessing community responses estimate that health problems – whether direct or indirect – appear to crop up in no more than 5-15% of those living within earshot; this is a surprisingly small number, considering the central role health effects has taken in the public perception and debate about new wind farms. While we shouldn't discount the impact on these people, it appears that fears of widespread health impacts may be misplaced. Though impacts on even a few,
whether direct or indirect, are certainly a valid consideration in making wind farm siting decisions, it’s helpful to have a clearer picture of how widespread the issue may be.

Not too surprisingly, what these researchers are finding contradicts both the "all is well" literature survey findings, as well as the fear that worst-case scenarios – being driven from homes by lack of sleep, headaches, kids struggling in school – are likely to widespread.

The bottom line appears to be that this first wave of research, undertaken by relatively cautionary and empathetic researchers, is finding that just a small proportion of nearby residents are reporting actual health impacts, though far more report degradation of the overall quality of life and sense of place. These studies use a diverse range of approaches and criteria, so can’t all be directly compared, or compiled to suggest global patterns, but each of them offers a clear window into particular communities’ responses to wind farms in their vicinity. As noted earlier, while all of the papers reviewed here come from researchers with much interest in and empathy for reports from affected neighbors, none of them propose inaudible infrasound as the central factor in health effects; the first four papers all focus on stress and sleep factors, and the last two, while including infrasound in their discussions, focus mostly on other factors (one on pre-existing risk factors, and the other on pulses in the dBG level, which includes substantial audible low-frequency sound as well as infrasound). In particular, there are indications that people prone to motion sickness may be more sensitive to wind turbine sound (perhaps to the variability of low-frequency content), and that certain pre-existing conditions may be triggered or accentuated by turbine sounds, including susceptibility to migraines and inner-ear-related balance issues.

**Hearing the real stories through the noise**

I think it’s important to acknowledge a key factor that has hampered the ability of some within both the public and the industry to clearly address the possibility that neighbors have experienced legitimate changes in their health, whether by direct or indirect means. Many (though not all) of those most vehemently stressing the potential for health impacts in areas where wind farms are proposed are fundamentally anti-wind, anti-renewables, and anti-government incentives; health impacts are but one of a litany of arguments they make against new wind farms, and many simply dismiss all their claims as distorted rhetoric. This can too often blind us to the fact that nearly all of the individuals who are telling us about their actual health impacts have no dog in the energy-policy fight; their personal stories are often compelling and sober accounts of struggling with unexpected and disabling sleep issues, disorientation, and mood disorders. No matter how rare, or common, health effects may be, I’m more interested in understanding what’s going on around existing wind farms, than on the fears and opposition being raised in places where wind farms have yet to be built.

In my visits to wind farm communities, while many people spoke about annoyance, occasional sleep disruption, and dramatically changed sense of place, I also met individuals who have clearly faced new health challenges since turbines were built near their homes.
cannot know whether these health effects have been triggered by the noise itself, by the stress and sleep disruption the noise has caused, or by their own ways of responding to the change in their home place. But I can say that actually spending time with people who've been dramatically affected makes the magnitude of possible impacts far more real. Perhaps the saddest was a woman who's changed from an outgoing community member to a shell of her former self, dulled by newly prescribed drugs to control bouts of depression and anxiety. (Two acousticians doing a sound study at her home found themselves, for the first time in 30-year careers, having mental difficulties as they set up their equipment: unable to concentrate, confusion, and disorientation.) Several sleep in their basements to escape subtle (or not so subtle) pulses in their bedrooms, while two have abandoned homes they built themselves, chronically unable to get unbroken sleep; one of these had a heart attack, while speaking at a public meeting on the turbines. In one family, three children have been prescribed sleeping pills. A particularly stark account comes from Mark Cool in Falmouth, MA, as detailed in this October 2012 letter to the local Health Board:

“Wind 1 has been a neighborhood health issue since April of 2010. My last lodged noise complaint was August 29, 2012. I’ve been potentially exposed to Wind 1 daytime operations roughly 580 days. This means that during 8.4% of Wind 1’s potential daytime operations, I’ve suffered pressure headaches (one bout of vertigo), at my property. I have never experienced these type headaches, nor any vertigo, before April of 2010. A noteworthy fact is that on numerous occasions, I’ve left my property (exiting the wake effect of Wind 1) and gained relief. I’ve also noted, that upon returning to my property, all wind direction and velocities being constant, the same symptomatic pressure headache returned. The only change – my spatial relationship to the wind turbine.”

It’s these sorts of personal stories that lead me to look around my home valley and wonder who among my neighbors I’d feel OK about affecting, should turbines sprout on our ridges.

Much Ado About Nothing?

As mentioned earlier, local regulatory bodies and wind project planners often grapple with the idea that it’s impossible to avoid any and all negative impacts. Some people will always be annoyed by new public infrastructure, and some of these will experience increased stress that can trigger health consequences. The question really comes down to how extensive or how severe an impact a community feels is reasonable to expect and accept. Of course, it’s also possible, even probable, that simply keeping turbines a bit farther from non-participating neighbors would solve most or all of the problems.

Some observers suggest that if actual, acute symptoms appear in as few as 5-10% of the people living near wind farms, then we may simply be hearing from people who represent the normal baseline rates for conditions like headaches, dizziness, tinnitus, and insomnia. This is an important question to keep in mind as we move forward and have larger studies\textsuperscript{94} to draw conclusions from.
However, most health effects research and testimonies assess changes in health: typically, subjects report symptoms appearing, or increasing, after wind farms began operation, and decreasing when turbines are not operating or the subjects are away from the area. The fact that most of these studies use self-reporting of current health conditions, and retrospective reporting of earlier health status, is considered by some to be a weakness; memories can be distorted by recent upsets about the wind farm. Some of the studies now beginning will be attempting to redress this by doing health surveys before wind farms begin operation, and following up later with the same subjects. 

But again, for now, we start where we are, and these initial studies, while not ideal, can be assessed on their merits. The authors generally are quite forthright about their methods, making it relatively easy to see both the strengths and shortcomings of the data we currently have to work with.

Likewise, we should beware of settling too easily into the comfortable thought that health effects are all “simply” indirect consequences of stress. Even if the vast majority of reported health problems appear to be indirect, stress-mediated effects, it also appears that some people are being directly affected. Whether these people have a relatively common pre-existing condition (such as motion sensitivity), or are part of the very few on the perceptive fringe of the normal auditory perception curve, so that they actually do hear or sense some of the low-frequency sounds more readily than most, we need to be careful not to lump all reports into any easy-to-accept framework. This applies equally to those who seem to imply that all health issues are "merely" psychological, as well as to those who might fear that everyone near turbines will get headaches or vertigo. 

We might also bear in mind that in addition to the sound waves that are the focus of virtually all discussion of community responses and health effects, turbines also create air pressure vortices that travel in downwind (these are the wakes discussed above). Some of the reported turbine-related symptoms, including pressure in ears or chest, and a general sense of discomfort, could be related to these pressure waves. The only community response researcher to consider them that I am aware of is Bob Thorne, who feels these vortices may contribute to his observed "heightened noise zones," areas in which noise levels are noticeably higher, often at distances of 1-2km from turbines.

For those with an interest in the health effects research, I highly recommend you take the time to read through the full 26-page summary, included here as Appendix C. There, you'll find key excerpts from the studies, and detailed analysis of the data presented in each.

AEI has previously summarized most of the larger wind turbine and health literature reviews put together by industry groups and government agencies (including reports from AWEA/CanWEA, Ontario, Oregon, Massachusetts, Minnesota, and the World Health Organization). These can be accessed at AEI's Wind Farm Noise Resource page: http://www.acousticecology.org/wind/
Footnotes and References

1 Federal agency staff (NOAA, NMFS, DOE, NSF, MMS, NPS; Canadian DFO), state agencies overseeing wind energy (MA, RI, MI), US Navy, Alberta Energy Resources Conservation Board (provincial oil, gas, wind agency), Joint Industry Program (US offshore oil and gas companies), ocean noise, acoustics, and wildlife researchers at institutions worldwide, environmental organizations (including NRDC, Greenpeace, Winter Wildlands Alliance, Ocean Conservation Research), local and county boards of selectmen and commissioners.

2 See this October 2012 article, including that sentiment from Duke Energy Renewables: http://www.michigandaily.com/opinion/22-daily-support-wind-farms-michigan-15


4 Regarding Falmouth, I met with nearly the entire wind energy team at the Massachusetts Clean Energy Center (MassCEC), which supplied both the turbines and technical expertise to the town. Regarding Vinalhaven, I met with three staff at the Island Institute, a regional non-profit that championed the wind project as a path toward energy independence for the island community; I’ve also spoken by phone many times with George Baker, head Fox Islands Wind, the small company formed to own the turbines (in order to qualify for key tax credits not available to a non-profit), and I met with the town manager, who is also on the board of Fox Islands Electric Coop.

5 For records of this process, see http://cbuilding.org/falmouthwind

6 See http://aeinews.org/archives/1848


This paper includes Texas field measurements of 1.5 and 2.3MW turbines, from which several things stand out. First is that the sound emissions from the Texas turbines was incredibly consistent: moderate sound output periods were only 2-3dB lower than maximum periods, and in the low-frequency one-third octave bands, the standard deviation in sound levels was under 1dB across six measurement periods.

9 See http://www.acousticecology.org/wind/ for AEI’s archive of wind energy reports

10 This would be consistent with research on such serrated edges; often, lower frequencies are reduced, but mid and higher frequencies increase; the overall dBA rating generally is reduced by up to 2dB. See Appendix section below on “Addressing Wind Farm Noise Concerns” for more detail.


15 Iberdrola Renewables. Blue Creek Final Amendment 4/12/2011. Appendix T1c, Figure A1, Noise Contours Participating Residences.
17 CH2M Hill Memorandum. Acoustical Analysis of the Horse Creek Wind Project. January 27, 2011. Figure 1.
19 See AEI’s Wind Farm Noise 2011 report, along with the 2009 overview, and AEI’s other coverage of wind farm noise issues at http://www.acousticecology.org/wind/
20 AEI’s NEWEEP presentation: http://aeinews.org/archives/972
21 A milder interpretation of the nocebo holds that people blame turbine noise for things that happen anyway, whether it be sleep issues or headaches; this is somewhat more plausible, though most neighbor reports are quite clear about seeing changes after turbines began operating, and finding relief when they away from the turbines.
22 The full report can be downloaded at http://betterplan.squarespace.com/-health-and-safety/7.%20Lincoln_Township-full_moratorium_report.pdf
23 At closer ranges, willingness to host dropped dramatically: In Lincoln Township, after living with turbines for a year, of ten respondents within a quarter mile of a turbine, only 1 said they’d host another one, five said they would not, and four more chose to not provide an answer; only one landowner living that close did not participate in the survey at all. At a quarter to half mile, prospects improved slightly: 9 of 27 landowners (33%) would host a turbine; if the five landowners in this range who didn’t fill out a survey all were fine with hosting, then this would increase to 44%.
24 See http://aeinews.org/archives/465 for more on the Jonesburg survey
25 Craggy Ridge Homeowners Association, Wind Turbine Survey September 2012. 71 of 81 homeowners responded. The survey asked about a range of effects; in addition to those reporting health and well-being effects, larger proportions cited not liking how they look (30%), concerns about property values (64%), and “they don’t really impact me personally” (38%)
27 Zhenhua Wang, Evaluation of Wind Farm Noise Policies in South Australia: A case study of Waterloo Wind Farm.
Accessed 10/22/12
29 I have used basic math to flesh out the numbers of affected residents from the summary presented by Wang, which only presented percentage results among those who returned surveys; I have further done the calculations as mentioned to assess rates among the entire population using the extreme conservative assumption that all non-respondents are not affected.
31 Mary Morris. Waterloo Wind Farm Survey April 2012.
32 While Morris presented two sets of complete data, 0-5km and 0-10km, she did not separate out the 5-10km data for analysis. I did so using simple math.
33 TRUenergy Mid North Community Survey Summary. February 2012.
34 Clifford P. Schneider, Visual and sound impacts from the Wolfe Island Wind Project on residents of Tibbetts Point Road, Cape Vincent, NY. April 2010 presentation.
35 http://aeinews.org/archives/55
40 See http://dasam.dk/?q=node/62
43 Ibid.
Accessed 10/17/12
45 See, for example, Rand, Community reactions to noise. Report/letter submitted to Riga, Michigan Township Planning Commission, 2/5/11; and Rand, Wind Turbine Sound, An Independent Investigation: Siting to Prevent Adverse Noise Impacts. Powerpoint presentation to Informed Citizens Coalition, 2/5/11. See AEI Wind page (linked in page footers) for links to these; also please see full discussion of these issues in the AEI Wind Farm Noise 2011 annual report.
47 http://www.awea.org/sitinghandbook/download_center.html
48 Available at http://www.nrel.gov/docs/ft07osti/40403.pdf
51 Wind historian and booster urges remote locations for wind farms, http://aeinews.org/archives/1726
I'm not tracking wind bans with any real diligence, since I'm more interested in places where there's an effort to establish setbacks that reflect local noise tolerance. Among the places where bans have been implemented or proposed projects were turned down on generalized aesthetic grounds are Merritt Township, MI, Brookville, ME, Lake County, IL, Christchurch Borough, UK, and Mitchell Shire, UK.


Bangor Daily News, 1/24/12.

Bangor Daily News, 10/27/11.

For more on the various Goodhue setback rulings, see http://aeinews.org/?s=goodhue

http://thechronicleherald.ca/novascotia/119413-argyle-votes-to-increase-wind-farm-buffer
http://aeinews.org/archives/2025


Shorter story from October:
http://freepressonline.com/main.asp?SectionID=52&SubSectionID=78&ArticleID=22252


This was from Merrit Township, MI, which voted to deny a permit for 9 turbines in their town; this was part of a much larger wind project, and Merritt Twp did allow for siting of a substation, cables, and other elements of the project in town. Not surprisingly, the decision shocked the project developer: "Mary Wells, spokesperson for NexEra, said that officials were surprised and very disappointed by the decision. "It's astonishing," Wells said. "We showed them how we had adhered to all of the regulations of their ordinance, and they completely disregarded the rules that they had set in place." http://www.mlive.com/news/bay-city/index.ssf/2012/02/merritt_township_supervisor_lo.html


Please see the Appendix summary for full details; the researchers report on studies with individual turbines as well as a small wind farm, and used models based on pure spherical spreading, as well as ones shifting to cylindrical at 200m. They focused on 44dB thresholds at times (the Danish limit), and 35dB at times (Swedish quiet limit, and the level this research team recommends as "a very reasonable limit for wind farm noise," in part because of the variable propagation distances they found).


For more on the Pinnacle Wind Farm noise issues, including company efforts to quiet turbines, see AEInews coverage at http://aeinews.org/?s=pinnacle
At Hardscrabble, noise complaints cropped up shortly after operations began, and in late 2012, sixty residents sued the company for nuisance and negligence. Sound monitoring suggests that the project operates generally in compliance with the local 50dB limit, but occasional periods slightly over the limit were recorded. For more on Hardscrabble, see AEInews coverage at http://aeinews.org/?s=hardscrabble

Hessler 2011, p.15


See several papers in the Appendix on Low-Frequency Noise Research for the basis of this widespread understanding, especially:


One other research team has replicated this approach that I’m aware of: Ambrose and Rand found similar dynamic patterns of dBG-weighted sound, though the peaks they identified (around 65dBG, one peak to 75dBG) were significantly lower than those reported in the Wade and James work that introduced the technique (regularly 80dBG, and up to 94dBG).


A report on Vinalhaven noise reduction efforts, including both the serrated edges and use of NRO, is nearing completion, and will presumably soon be delivered to Island Institute, Fox Islands Wind, and Fox Islands Electric. I believe it's being done under the auspices of the Lawrence Berkeley National Laboratory (which did a preliminary study), though it may be coming out of the National Renewable Energy Lab.

85 Jose Zayas. Technology Innovation for Wind Energy: SNL’s SMART Rotor Program. Sandia National Laboratories. (No date on presentation; 2010 or later) sandia.gov/wind
jrzayas@sandia.gov


90 See www.renewableenergyworld.com/rea/u/AcousticEcologyInstitute/articles


94 Large-scale government-initiated studies are underway in Japan (see http://aeinews.org/archives/644 ) and Ontario (see http://aeinews.org/archives/1862 )


96 To repeat a well-worn AEI theme: Both direct and indirect health effects would be minimized by adopting local siting standards that prevent sleep disruption, high annoyance rates, and profound changes in the local sense of home and place, thus avoiding most stress-mediated effects. While some of those with pre-existing sensitivities may be affected at greater distances, I suspect that protecting sleep and avoiding stress for the many would also largely protect the few who are susceptible to the rare direct effects.

Appendix A: Turbine Sound Research

As published on AEInews.org on 12/31/11: http://aeinews.org/archives/1711
PDF version of this is available at http://www.acousticecology.org/wind/

Recent research on low frequency noise from wind turbines

If AEI were a mass media outlet, publishing this on New Year’s Eve would be considered an attempt to “bury” the story on a weekend when few people are following the news. But since our readership works on a longer time scale and are likely to find their way here over the next couple of weeks, I hope you'll instead consider this a New Year present! It's taken many (many...) hours of work, and I hope it helps all those working on wind farm noise issues - including local and state regulators, environmental consultants, wind developers, and community groups - to make sense of the insanely confusing world of low-frequency noise and infrasound. Here's to a constructive 2012 as we continue to work toward siting policies that protect residents from unwanted changes to their sense of place while encouraging responsible and widespread growth of wind energy!

Download this extended post as a 22-page pdf file

As regular readers will know, AEI's wind farm coverage has focused primarily on the ways that nearby neighbors respond to the audible noise from wind turbines, with far less emphasis on infrasound. However, given the ongoing public dialogue about the contribution of infrasound and low-frequency sound to the annoyance, sleep disruption, or health effects reported by some wind farm neighbors, I do like to keep abreast of research into the lower end of the sound spectrum. In this post, I'll be summarizing several papers that have appeared in journals and conference proceedings over the past several months. This will be a much longer post than normal, but I encourage you to take the time to read through it, and to download the source papers for further study. What you'll find here is a close reading of work from both mainstream and more cautionary acousticians, which I believe will help you to understand the subtleties of our current state of understanding in a new and clearer way.

I think it's fair to say that the bottom line continues to be roughly the same as it's been: wind turbines clearly produce much of their sound energy at lower frequencies, including the low end of the audible spectrum (20–250Hz) and the infrasonic range (below 20Hz, which is generally below the range humans tend to hear, simply because it has to be very loud to be perceptible). Conventional wisdom continues to be that the infrasound in wind turbine noise is well below human perceptual limits, even of the more sensitive fringe of the population. This summary doesn't directly challenge that idea, though as you'll see, there are some indications that we may have been a bit too quick to entirely rule out any perception of infrasound produced by wind turbines. Still, I hasten to stress that any possible connection between physically perceptible infrasound and health effects remains beyond the scope of most of these papers (with a couple of exceptions).

More importantly, though, it's increasingly being recognized that low-frequency audible sound could very well be a key factor in widespread annoyance about wind farm noise. It's important to not conflate infrasound and low-frequency sound; while the former is (always or mostly) imperceptible, the latter is clearly very audible in many situations, and indeed, is the dominant sound component of wind farm noise at moderate and larger distances. It's quite likely that much of the annoyance people report could be triggered by very low frequency, moderately audible noise, which can be more ear-catching (or perhaps even cause physiological reactions) when it contains one or more dominant tones or fluctuates
rapidly. Further, increasing evidence confirms neighbors' reports that moderate but extremely bothersome low frequency noise can be more perceptible inside their homes than outside. These elements are part of the reason that several of the papers here from relatively mainstream perspectives (and which consider infrasound a non- or minimal issue) recommend lower noise limits than the 45–50dB standard commonly used in the US; you'll see in these papers that 40dBA is becoming a common recommendation. Most of the more cautionary acousticians tend to recommend 30–35dB; it's striking to me that the gap between these two perspectives has narrowed considerably in the last year or so.

Among the highlights of the recent research is Møller and Pedersen's finding that larger turbines produce more low-frequency sound (especially audible low-frequency), and that in many atmospheric conditions, sound levels will remain annoyingly high for much farther than often assumed by more idealized sound modeling. Also of note, Bray and James' field measurements of wind turbine sound, using equipment designed to capture very short time segments, reveals a remarkable variability and surprisingly high peak sound levels in the low-frequency and infrasonic sound, to a degree that raises questions about our tendency to rely on longer-time-period averages that indicate infrasound is always well below perceptual limits. As we look more closely into low-frequency and infrasound data, both the mainstream papers and the more cautionary acousticians' work suggest that these questions are far from settled.

(I should clarify that my use of the word "mainstream" is meant to simply mean studies by folks working with techniques and perspectives on bothersome noise levels that have been standard in noise control assessment for many community noise sources. And conversely, the use of the term "cautionary acousticians" does not imply they are less qualified or biased in any way. Indeed, most of them have decades of noise control experience and have been drawn to the study of wind farm noise only because of the unexpectedly robust complaints that have arisen, and are professionally interested in trying to ascertain the reasons, either by using innovative measurement techniques or closely assessing annoyance patterns. They may be more "cautionary" in their recommended noise limits simply because they've looked more closely at specific problems, rather than keeping their distance and approaching the issue through standard noise modeling and analysis techniques.)

Some of the papers I'm summarizing here address aspects of annoyance and sound characteristics of wind farm noise that are not limited to low frequency and infrasound issues (especially including acknowledgement of the extreme variability of the overall sound levels); these papers provide important perspectives that may help us to understand why wind farms are producing more annoyance reactions than we might expect, considering their moderate sound levels.

For more (much more...but worth it!), click on through to read lay summaries of the following recent papers:

- Stephen E. Ambrose and Robert W. Rand. The Bruce McPherson Infrasound and Low Frequency
Let's start with a paper from Møller and CS Pedersen that got a fair amount of attention when it was published. The leading take-away from the paper in the popular and trade press was their finding that larger turbines (2.3–3.6MW) produce more low-frequency sound than smaller ones (below 2MW); specifically, the sound spectrum shifted downward by about a third of an octave. This has important implications moving forward, because of the push to increase turbine size in order to generate more electricity from each turbine; 3MW is becoming a common size in new wind farms. The increase in low frequency sound was moderate, just 1.5–3.2dB, but the authors remind us that at low frequencies, small dB differences are perceived as larger differences in loudness than at higher frequencies. And, the farther you go from the turbine, the more higher frequencies are dissipated while lower frequencies become the dominant component of the sound that remains.

But the Møller/Pederson paper is important for several other key reasons as well. Firstly, they stress that much of the information being promulgated by both sides of the wind turbine siting debate fails to distinguish between infrasound and low-frequency sound. As they say (parenthetical phrases are in the original, not editorial additions):

Infrasound and low-frequency sound are often not properly distinguished, and, as a peculiar consequence, low-frequency noise is frequently rejected as the cause of nuisances, just because infrasound can be discarded (usually rightfully). Infrasound is (still) often claimed inaudible, and sometimes even low-frequency noise, or it is reported that both can only be heard by especially sensitive people—which is all wrong. Weighting curves are misunderstood or (mis)used to give the impression of dramatically high or negligibly low levels. Sometimes, political utterances (from both sides) are disguised as scientific contributions.

Infrasound is addressed only briefly in this paper, but their treatment provides a good foundation for understanding other papers. They use G-weighted sound levels in their consideration of infrasound, which, unlike C or A weighting, includes sounds below 10Hz, while accentuating the frequencies from 2–70Hz (though still adjusted in a way that lets one final dB number reflect a combined contribution of different frequencies' sound levels). The human hearing threshold is 95–100 dBG, with anything below 85–90 dBG generally considered imperceptible. Their measurements of wind turbine sound at 90–525m were below 65 dBG; the highest measurements they found in the literature were 80 dBG at 360m, still below perceptible thresholds. The paper includes an unusually thorough survey of research into individual differences in hearing sensitivity at low frequencies (including
studies suggesting that we respond to peak sound levels when there are large fluctuations, a
precurser to the Bray/James study below which found peaks of over 90dBG), though the
authors conclude that except for the possibility of a very few people with anatomical
abnormalities in the hearing organs, the variation found to date is modest and so infrasound
is unlikely to be a contributing factor to wind farm annoyance.

But don't rest easy just yet: they also stress that downwind propagation of low-frequency
noise, and overall turbine noise, is often vastly underestimated using standard models.
Atmospheric refraction – sound bouncing back down from air density boundaries overhead,
and sometimes (especially with low frequencies) bouncing off the ground as well, so it's
channeled greater distances – can create much higher sound levels than we might expect at
distances of beyond a few hundred meters. Sound just below the border of low frequency
and infrasound (especially 8–16Hz) appears to dissipate much more slowly ("cylindrical"
instead of "spherical" spreading), dropping by only 3dB with each doubling of distance,
rather than 6dB as do most audible sounds. (Other papers included here, including the
HGC/Ontario MOE report, also stress this factor, which the Ambrose/Rand field
measurements confirm.) This means that at greater distances, the turbines noise that makes
it that far will sound lower in frequency, and be louder than predicted by spherical spreading
models.

Their measurements of actual wind turbines also led to some quite remarkable results. They
measured the sound power levels of 9 large turbines, then did two rounds of sound
modeling. The first assumed simply spherical spreading, sound dropping 6dB for each
doubling of distance. They measured how far they had to be from individual turbines in
order for the sound to drop to 35dB, the level above which E Pedersen and Persson-Waye
found annoyance begin to spike beyond 5–10% of the population, and also the level required
in quiet areas in Sweden. Because the nine turbines had distinctly different initial (source)
sound levels, the variation in distance was stunning, with this quiet sound level reached at
distances ranging from 629m (2063ft) to 1227m (4024ft). Interestingly, when modeling
small wind farms of 12 turbines, they found that sound levels of 44dB (Danish wind farm
noise limit at homes) were reached at a very similar wide range of distances, 530m–1241m.

But more striking still was the dramatic increase in setback distances necessary when they
considered atmospheric conditions with a sound–reflecting layer. Here, they joined an
emerging consensus in acoustics that propagation can be cylindrical beyond 200m, and
found that homes would need to be anywhere from 1414m (4600ft) to 3482m (11,421ft /2.16miles) in order for the sound to drop to 35dB. Again, they note that at these greater
distances, as higher frequencies are absorbed and lower frequencies are less impeded, the
sound becomes more dominated by lower frequencies, and that "Cylindrical propagation may
thus explain case stories, where rumbling of wind turbines is claimed to be audible
kilometers away." This also helps explain the fact, noted in both the Hessler and Thorne
papers below, that noise levels well above those predicted by noise modeling can be
expected to occur with some regularity.

Møller and CS Pedersen repeatedly stress that the audible low-frequency components of
wind turbine noise, especially as distance increases, are likely a key factor in reported
annoyance by neighbors. After modeling likely indoor noise levels, they note:

If the noise from the investigated large turbines has an outdoor A–weighted
sound pressure level of 44dBA (the maximum of the Danish regulation for wind
turbines), there is a risk that a substantial part of the residents will be annoyed
by low-frequency noise even indoors. The Danish evening/night limit of 20dBA

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for the A-weighted noise in the 10–160 Hz range, which applies to industrial noise (but not to wind turbine noise), will be exceeded somewhere in many living rooms at the neighbors that are near the 44dB outdoor limit. Problems are much reduced with an outdoor limit of 35dB.

Given all they found, Møller and CS Pedersen consider 35dB a "very reasonable limit for wind turbine noise," joining their Scandinavian colleagues TH Pedersen and Nielson, who recommend 33–38dB. As they also note, "A limit of 35 dB is used for wind turbines in Sweden for quiet areas... It is also the limit that applies in Denmark in open residential areas (night) and recreational areas (evening, night, and weekend) for industrial noise (but not for wind turbine noise)."

Note: If you, like I, have been wondering whether all these Scandinavian Pedersens citing each others' work are engaged in scientific nepotism, rest easy. I recently confirmed that none of them are related; they just share a common name (lots of family lines had Peder at the top of the lineage, I guess!)

A literature survey paper by Karl Bolin, et al, Infrasound and low frequency noise from wind turbines: exposure and health effects, generally affirms the conventional wisdom that infrasound is of minimal concern, but also includes several somewhat cautionary notes. The paper begins by focusing on the mechanism that creates the low frequency and infrasound components of wind turbine noise, zeroing in on inflow turbulence as the primary contributor in the 10Hz to several hundred Hz range, covering audible low–frequency noise and some infrasound. A quick look at measured low–frequency and infrasound levels finds them, per usual, well below typical perceptual thresholds. The authors twice note that studies cited by Salt et al to suggest that infrasound is commonly at high enough levels – 60dBG – to trigger outer ear hair cell responses took place at very close range (20–100m) from turbines, much closer than residential sites. (Ed. note: however, see two studies below at residences where peaks of 60–90dBG were observed.) The section of the paper on annoyance levels notes that the widely–cited E Pedersen–Waye et al annoyance surveys all focused primarily on outdoor annoyance, while the same studies found indoor annoyance levels to be about half of those found outside at each noise level.

Here, though, Bolin et al move toward a cautionary stance, summarizing annoyance studies as compared to other common community noise sources and concluding that today's 45–50dB turbine noise guidelines may be a bit too high:

Overall, these comparisons suggest that guidelines for wind turbine noise in the interval 35–40 dB would correspond to the proportion of annoyed persons comparable to the proportion annoyed by road traffic noise at a typical guideline value.

The final section of the Bolin paper surveys sleep disturbance and other health effects, reporting on the health findings in the big Pedersen surveys, which found that while annoyance and some sleep disturbance were reported, there was no consistent association between noise levels and specific health factors, including chronic disease, headaches, tinnitus, or tiredness. At the end of this section, the authors report that cardiovascular risk has been found to be elevated near road noise of 55dB or more, which is "significantly higher than typical exposure from wind turbine noise." However, noting that these cardiovascular

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risks are considered to be largely related to stress, annoyance, and sleep disruption (i.e., not from direct physiological effects of the noise itself), and that wind turbines tend to trigger stress and annoyance at lower levels than road noise (note: this is the basis for their suggestion of a 35–40dB guideline above), then "one cannot completely rule out effects on the cardiovascular system after prolonged exposure to wind turbine noise, despite moderate levels of exposure."

The most comprehensive look at low frequency sound and infrasound from turbines to come out in recent months appeared in the journal Noise Control Engineering, and was written by Robert O'Neal and two colleagues at Epsilon Associates, a consulting firm.

This paper includes an extensive literature survey, an indoor and outdoor field measurement program at a wind farm in Texas, and a comparison of the field measurements to several key noise control criteria. In short, they find that the low-frequency and infrasound components of the wind turbine sounds they measured meet all relevant standard criteria, including those from the International Standards Organization (ISO), American National Standard (ANSI), and UK and Japanese environmental agency guidance. Most of the findings are pretty straight-forward, as well as rather detailed, so I'll refrain from recounting them here, and encourage you to check out the paper yourself.

I'll note a few things that caught my eye as I read it through, though. Right off the bat, the authors stress that the widespread idea that sound below 20Hz or so is inaudible to humans "is incorrect since sound remains audible at frequencies well below 16 Hz provided that the sound level is sufficiently high....The division into 'low-frequency sound' and 'infrasound' should only be considered 'practical and conventional.'" (Ed. note: still, we need to be attentive to perceptual thresholds, which range as high as well over 100dB at the lowest frequencies.)

The discussion here of physical sensations in response to infrasound also shed some interesting light. The authors note that sensations in the chest, lower back, and thighs sometimes occur, but only at sound levels 20–25dB above the hearing thresholds (Ed. note: this is very high indeed at low frequencies, unlikely to occur near wind farms even considering the more cautionary field studies below); the ears are the most sensitive receptors even of sounds between 4 and 25Hz. Yet also, this observation may illuminate some neighbor reports: "Below 10 Hz it is possible to perceive the single cycles of a tone, and the perception changes into a sensation of pressure at the ears."

This paper relies on standard measurement procedures that average the sounds over relatively long periods of time (10 minute averages; sampling rate is not noted, though the "fast" rate typically employed is 125ms, with 1-second sampling also being common). As we'll see in the Bray/James paper below, this methodology may miss some of the dynamic, rapidly varying aspects of wind turbine noise. But for now, let's take this work at face value, and see that the authors note of ANSI outdoor criteria:

annoyance is minimal when the 16, 31.5 and 63 Hz octave band sound pressure levels are each less than 65 dB and there are no rapid fluctuations of the low frequency sounds.

And, that according to UK standards, "A low frequency noise is considered steady if either

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L10 minus L90 (i.e., the difference between the loudest and quietest times) is greater than 5 dB or the rate of change of sound pressure level (Fast time weighting) is less than 10 dB per second" in the most extreme third-octave band.

_Ed. note: Bear these caveats in mind as we move to consideration of the faster time-averaged measurements reported below by Bray/James and Ambrose/Rand, both of which found significant variation of sound levels and rapid fluctuations in low frequencies._

Turning to the Texas field measurements of 1.5 and 2.3MW turbines, several things stand out. First is that the sound emissions from the Texas turbines was incredibly consistent: moderate sound output periods were only 2–3dB lower than maximum periods, and in the low-frequency one-third octave bands, the standard deviation in sound levels was under 1dB across six measurement periods. (_Ed. note: This suggests that, following on the Bolin paper above, inflow turbulence was likely quite low at this site (flat open land); I wonder whether the results would be applicable to sites with more rolling landscape or other factors that could increase localized turbulence._)

Most of the Epsilon measurements came in well under the various criteria; this figure is representative of most of their results:

One measurement, however, was fairly edgy, bumping up against the "moderately perceptible" vibration level, as well as the ANSI standard that is modified for low-frequency noise (ANSI 512.9 Part 4); this one tracks sound only down to 16Hz, and one wonders what’s going on in the deeper infrasound range below:

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Overall, though, O’Neal and his Epsilon colleagues conclude that their measurements indicate:

Infrasound is inaudible to even the most sensitive people 305 meters (1,000 feet) from these wind turbines (more than 20 dB below the median thresholds of hearing). Low frequency sound above 40 Hz may be audible depending on background sound levels.

At present, this paper is the clearest summation of this widespread conventional wisdom.

Well, dear reader, you’re doing well to be hanging in this long! Your diligence will be rewarded, as the next few papers move the discussion forward in several interesting directions. We’ll see some intriguing – and possibly troubling – sound measurements in very short time scales, an innovative approach to predicting annoyance reaction to noise, and a critique of typical noise measurement metrics. Alright, then, on we go!

Probably the most provocative and ground-breaking paper among this batch of new research is the paper presented by Wade Bray and Rick James at Noise-Con 2011, the annual conference of the Institute of Noise Control Engineering (INCE).

For years, Bray has stressed the need to assess sounds at time scales that reflect human auditory perception, and James has in recent years been on the forefront of investigating the sound of wind farms in locations where people have been especially bothered by the noise. In their recent paper and presentation, they worked together to assess the sound at a home in Ubly, Michigan 1500 feet from the nearest turbine (wind speeds were low, under 10mph, with temperatures of 17–22 degrees F, overcast skies, and no precipitation).
Given the innovative approach this paper takes toward assessing noise levels, it's especially difficult to summarize briefly; here I'll mention the key concepts and findings, but I encourage you to read the full paper for a more complete context as to why the authors think this approach is an important adjunct to traditional assessment techniques.

Typical noise assessment focuses primarily on measuring the sound levels at the full range of frequencies, with an emphasis on very fine resolution between frequencies (one-third of an octave is the typical resolution; so that spectrograms present the dB level for each third-octave). This works fine at higher frequencies, but as you move down the frequency scale, a trade-off has been made for historic and technical reasons: several third-octave bands are combined into "critical bandwidths" forcing the time scale of the measurements to be extended far beyond the time scale of human perception. While we perceive and respond to low frequency (20–100Hz) sounds on a timescale of about 10ms (milliseconds; one one-hundredth of a second), most noise assessment standards use "fast" time weightings of 125ms, or even levels averaged over as much as 1–10 seconds. These longer averaging times hide the peaks and troughs of the sound that occur at very short time scales:

For the one minute of the Ubly data graphed above, the sound level averaged across the entire 60 seconds was 77dBG. When averaged every second, the red line shows levels ranging from about 62dB to 85dB, and when averaged every 10ms, it ranged from about 55dB to 94dBG. (The G-weighted sound level primarily emphasizes sounds from 10–30Hz, and only moderately reduces the emphasis on sounds from 2–10Hz and 30–70Hz. While still not reflecting the pure, un-adjusted sound spectrum, dBG provides a better focus on low frequency and infrasonic ranges than A or C weightings.)

*Ed. note: Because dBG weighting includes sound below 10Hz (unlike dBA or dBC weightings), some people tend to think this is a measure of primarily infrasound. Yet note that it actually includes a large chunk of audible low frequencies (up to 70Hz), while centering on that fuzzy transition between infrasound and low frequencies (10–30Hz).*

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A central point of this Bray/James paper is that human perception responds to the peak sound levels, rather than averages (as also affirmed in Møller/CS Pedersen’s paper, above). In addition, sounds that are highly variable in short time spans (called a "high crest factor") are also more perceptible than sounds at a steady level or closely varying around the average, because human ears are very attuned to patterns in sound. These two observations, combined with the fact that the measured peak levels approach much closer to the standard human perception curves than do the averages (which are typically used to assess likely perceptibility of low frequency wind farm noise), suggest to the authors that the low frequency and infrasonic components of wind turbine sound could be more readily perceptible than is normally assumed. (The standard human perception curves are derived by playing pure-tone sounds at carefully controlled dB levels; this method suggests a perceptual threshold for infrasound in the range of 95–100dBG).

In addition to the very rapid pulses of sound over 90dBG (and much more often over 80dBG), which occur over a span of about 60ms, Bray and James reported several other variations in sound levels that they suggest may aggravate or increase the annoyance responses in nearby neighbors. They found tone-like higher sound levels at 30, 75, and 150Hz, pulsing a bit louder once per second (which corresponds to the "blade-pass rate,” the rhythm at which one of the three blades either passes the tower, or sweeps across the top of its rotation, through higher wind speeds). And, they noted several other “periodicities,” or fluctuations in sound level, including periods of 6–9 seconds of higher sound levels that came and went unpredictably (Ed. note: perhaps corresponding to periods of high inflow turbulence) and blade-pass rate sound peaks that varied in several frequency regions over time periods of less than a second, several seconds, and several minutes. This variability in the audible sound levels is likely a key reason that turbines trigger more annoyance than other noise sources.

I’ll be very interested to see what other acousticians make of this new data, particularly the discovery of very rapid fluctuations and high peaks in the low frequency dB levels. It appears to my untrained reading that this is important new information, though I am far from conversant in the arcane details of short-time-period considerations of either human perception or sound levels. And while they didn’t find peak dBG levels above the classic perception curves (though they were close), these field measurements clearly confirm that infrasound is present at relatively high and very dynamic levels in wind farm noise. Time and further research will tell whether this is part of the reason why wind farm noise seems to trigger more annoyance than other sound sources at similarly moderate average dB levels. I should also note that this paper makes no claims about health effects being triggered by the infrasound levels; its focus is on the fine-time-scale structure and sound levels of the measured wind turbine noise and the relation of their findings to human perceptibility. (Ed. note: While Hessler, below, suggests all infrasound recordings are contaminated by wind on the mic, Bray notes that his binaural mics provide a means to identify wind noise, which would be subtly different on each mic; and, the pulses of sound in synch with the blade-pass rate are clearly not wind noise.)

Another study just released by two longtime noise control engineers, Stephen Ambrose and Rob Rand, offers a close look at noise levels and health effects, while also providing some detailed sound data that complements the Bray/James work.
This report is being circulated from Rand's consultancy website, so unlike the others here, is not peer reviewed, but the authors are operating exactly in the area of their decades of expertise, and the reporting is detailed enough to be worthy of full consideration. It presents a very short-term assessment of a particular location in Falmouth, Massachusetts where the resident was experiencing sleep disruption, headaches, and the like, located 1700 feet from a single operating turbine (a 2nd turbine nearby was shut down in high winds as a noise mitigation for neighbors). The authors were on-site for a bit under two days, and were surprised to experience the disorientation, difficulty in focusing, and sleep disruption reported by many Falmouth residents; they note that they are both prone to motion sickness, which may indicate some vestibular sensitivity. Since the authors had not experienced such reactions before in decades of noise control and monitoring work, they feel that their physical reactions give credence to the connection between health and focus/attention issues and exposure to the wind turbine's sounds.

Again, this paper contains much detail worth reading and evaluating for yourself, and I'll just mention several key points. They note a clear correlation between their physical symptoms and both the wind speed and the power output of the turbines; a correlation with the dBG sound levels is suggestive as well, with ill effects more prominent with higher dBG levels, and at times with dBG pulsations (they felt fewer ill effects when dBG variation was random). As interesting as their fatigue, headaches, and lack of appetite may be – especially since they occurred without the stress, anxiety, or other personal responses to turbines that are commonly posited as the sources of reported health effects – this is clearly a very short period of study with just two (unplanned) subjects. While providing a solid indication of the value of further similarly targeted research, this study alone is far from definitive proof of a direct health and turbine noise link at this point.

Near the end of their paper, however, the authors make an interesting observation. They note that the ramping–up onset of symptoms that they experienced, along with the more gradual dissipation of the symptoms after they left the site, both mimic a classic dose–response relationship; they suggest that the peak sound pressure events, which occurred on average once every 1.4 seconds, often over 60dBG (as reflected in their detailed measurements discussed below), can be considered the recurring "dose" that triggered their "response." They mention a standard dose–response equation for considering cumulative effects that could be used to explore this idea further.

Some of the actual sound measurements that were made are also particularly valuable. Their measurements found two tones with higher sound levels, at 22.9Hz and 129Hz; these are both low-frequency, not infrasound. The authors note that both tones exceeded the Outer Hair Cell stimulation threshold proposed by Alec Salt, both indoors and outdoors. They also point out that 22.9Hz lies at the high end of the range of the brain's "beta waves," which are associated with alertness, concentration, and active thinking.

Interestingly, a closer analysis of the 22.9Hz tone shows a high variability in peak levels as also found by Bray and James; in this case, the average sound level was 50dB (unweighted dB I believe, but unspecified in the paper), with faster time sampling showing sound ranging from 15 to 60dB over the course of just a second, with a rapid peaks occurring every 40ms or so. And, at this location, 1700 feet from the turbine, dBG levels were often over 60dBG indoors, and consistently over 60dBG outdoors. (Some critiques of Salt's proposed 60dBG threshold for hair cell response to infrasound, including O'Neal, above, point out that Salt's examples of turbines producing these levels were taken much closer to turbines, with the implication that 60dBG is unlikely at typical residential distances over 1200 feet or more).

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Finally, the authors made measurements at increasing distances from the turbine (268ft, 830ft, 1340ft, and 1700ft), and report that while the dBA decreased at a standard 6dBA for every doubling of distance (the assumption used in most sound modeling), the unweighted sound levels (dB) dropped at only 3dB per doubling distance, due to the slower dissipation of lower frequency components of the sound. And most interestingly, while at 1700 feet, the measured dBA was much lower indoors than out (43dBA outside, 21dBA inside), the unweighted sound level was actually higher inside than out (75dB outside, 79dB inside). This affirms many residents' reports that the low frequency sound can be more noticeable, and more bothersome, inside than outside their homes. As the authors note: "Despite the apparent increase in energy indoors, the wind turbine was almost inaudible indoors. The house envelope blocked most of the frequency content above 10 Hz, and amplified the remaining low frequency pulsations....The acoustic pressure swung from positive (compressed) to negative (rarified) 0.2 Pa peak–to–peak." As they note, residents often say they experience these low frequency pulsations as if they are living inside a drum.

A recent addition to the pile of papers was David Hessler's comprehensive guidelines for assessing sound emissions from proposed and completed wind farms, prepared for the Minnesota PUC and funded by the US DOE.

A few things stand out here. First and foremost is the claim that all low–frequency and infrasound recorded near wind farms is simply flow noise of wind on microphones. Again, I'm not an acoustician or engineer, so can only make a few comments on that; you may want to read his logic yourself. He notes that tests of wind screens in quiet wind tunnels show high levels of LF and infrasonic noise (up to 70dB, unweighted at the lowest frequencies); he likewise presents some data showing near–identical dB readings (averaging time not noted) at a residence surrounded by wind turbines and a location several miles from the wind farm, both of which vary with wind speed, and are seen by Hessler as further evidence that the dB readings are nothing but wind noise.

Ed. Note: I can't help but note that the dB levels reported by Hessler, as well as the dB and dB levels reported by Bray/James and Rand/Ambrose are well above the air–flow noise Hessler reports from the wind tunnel; this implies that there is additional low–frequency noise occurring above and beyond any microphone contamination noise. Also, much of the low–frequency and infrasonic sound measured at faster time scales (by Bray/James) show clear patterns in synch with the blade–pass rate, which would not be seen in air–flow noise on the mics. Finally, the problem of air flow on the mics can be bypassed by recording at times when wind is very low at the ground/recording level, and high at hub height. And, binaural systems (such as those used by Bray/James) allow a comparison of the two channels; wind noise will tend to be somewhat different at each mic, showing up as some incoherent measurements between the two, while turbine noise will be synched or similar in each mic (if the data shows perfect coherence between the two mics, you can be quite sure there is no wind noise contamination).

Beyond the low–frequency data and suggestions presented by Hessler, this set of guidelines includes several general recommendations for non–low–frequency noise that are worth noting. Most strikingly, the guidelines suggest keeping average dBA sound levels to 40dB at homes, and urges site plans that include many homes in the 40–45dB range to be adjusted to minimize the number of homes receiving more than 40dBA. They also stress that for locations with ambient levels over 35dB (which includes most rural locations during the day),

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it is important to keep turbine noise to no more than 5dB louder than ambient; this is in contrast to many locales where 10dB over ambient is allowed. Both of these recommendations are based on reported annoyance and complaints at existing wind farms; while not going “all the way” to a 30 or 35dBA limit as suggested by some, this downward shift from today’s norm of 45dBA or more is notable.

Relatedly, Hessler stresses that the use of a mean sound level (full day and full night, or perhaps even full day–night 24-hour averages) is necessitated by the fact that sound levels vary quite notably, making peak levels difficult to predict and peak limits difficult to enforce:

Extensive field experience measuring operational projects indicates that sound levels commonly fluctuate by roughly +/- 5 dBA about the mean trend line and that short-lived (10 to 20 minute) spikes on the order of 15 to 20 dBA above the mean are occasionally observed when atmospheric conditions strongly favor the generation and propagation of noise. Because no project can be designed so that all such spikes would remain below the 40 or 45 dBA targets at all times, these values are expressed as long-term mean levels, or the central trend through data collected over a period of several weeks.

Indeed, they also present some compelling graphs showing actual noise levels as the wind speed increases, which show that there is typically a 20dBA range of noise level at any given wind speed; this represents both variation in how strong the wind and ambient rustling of grass and leaves is when hub-height wind is creating turbine noise, and the impacts of various atmospheric conditions that change the noise level at the turbine and sound propagation in the surrounding environment.

Hessler notes that “the possibility, even likelihood, that project noise will occasionally spike
for short periods should be factored into regulatory limits....As a suggestion, it seems reasonable to conclude that a project is in compliance with an absolute regulatory limit if the measurements indicate that the project-only sound level is lower than the stated limit at least 95% of the time..."

_Ed. note: While this seems logical, we should note that 5% of the time over the limit can translate into a chronic experience for neighbors, and may create significant impacts when added to an already potentially marginal regulatory limit of 45dB or even 40dB, where "over the limit" can mean 10dB or more over background ambient. Five percent of the time translates to 72 days with 6 hours of excessive noise (20% of days), or 219 days with 2 hours of excessive noise (60% of days). For this reason, I’d lean to seeing this acknowledgement of the impracticality of 100% absolute limit be seen as a reason to set a somewhat lower average limit. If the limit were 30–35dB, it may be that we could tolerate more “over-limit” time, up to 10% or more._

The final take-away of note from Hessler’s assessment guidelines is the fact that Leq, or average sound levels, even at short 10-minute averaging times, is not appropriate for assessing existing background ambient noise levels or project sound levels; instead, Hessler stresses the use of the L90 level, representing the dB level that is exceeded 90% of the time, as more able to discern actual ambient levels and project noise levels (though again, he proposes long averaging times for the L90 noise criteria).

As I was completing this summary of recent low-frequency noise reports, a new one was released; while actually written in late 2010, in December 2011 the Ontario Ministry of Environment released a literature review on low frequency noise and infrasound written by HGC Engineering, a noise consultancy.

As usual, I urge you to check out the full report for more detail; the general tone and findings follows from most other similar overviews, concluding that while wind farms produce plenty of audible low-frequency noise, the infrasonic frequencies are below the levels necessary for human perception. _At the same time, though, the report contains a number of details that, to my eye, reinforce many of the other reports here in justifying the raising of a cautionary yellow flag, rather than relaxing into assurance that there are no low-frequency and infrasound issues to be further explored._ In particular, the literature references and recommendations dealing with low frequency sound inside homes, and the detailed references regarding wide individual variability in low frequency and infrasonic perceptual thresholds both bear close attention.

The Ontario report stresses the need to assess indoor low frequency noise, since many complaints come from folks who are more bothered inside their homes than outside. The Ambrose/Rand study (above) provides some initial data that confirms this experience. The HGC authors cite studies showing that transmission loss through walls is zero or near zero in low frequencies and infrasonic ranges (in contrast to the commonly assumed 15dB reduction in dBA full-spectrum sound). When combined with studies, also cited here, affirming just a 3dB reduction in lower frequencies with doubling of distance (rather than the 6dBA reduction presumed in most sound modeling, which focuses more on higher-frequency audible sound), the likelihood that neighbors at distances beyond 500m–1km may be experiencing elevated low-frequency sound in their homes becomes quite clearly understandable. Because of "the significant variation in sound impact from house to house as a function of
room layout and sound transmission characteristics," the HGC team recommends that MOE develop a protocol for assessing noise indoors. The report notes that best practices for indoor recording are still in development; it is challenging, since sound levels can vary by 20–30dB in different parts of a room (due to complex interactions of sound reflected from the walls, floor, and ceiling). One current best-practices approach is to average the sound of 4 points in the floor or ceiling corners of the room.

This report presents a good, clear graph of the various studies of perceptual thresholds for low frequency and infrasound:

![Graph of perceptual thresholds for low frequency and infrasound](image)

A few things bear noticing here. These curves show hearing thresholds only at very low frequencies (below 50Hz), and are measured in unweighted dB (which is sometimes called dBL and sometimes dBZ, and sometimes, just db). The authors note that some (few) individuals are expected to be more sensitive than these curves "by 10dB or more." You can see the 95–100dBL thresholds at 10Hz, which dominate the dBG levels that result in the same threshold; remember here the Bray/James data showing dBG peaks of over 90dB, and more often, over 80dB.

Remember that these curves are the average thresholds found in each of these 8 different studies, and that the studies use simple pure tones at each frequency, gradually increasing the volume/amplitude of the sound until the subject reports being able to hear it. Bearing this in mind, the HGC report has a good set of literature summaries that address the individual variability within each of these average curves.

Individuals' hearing thresholds tend to not be nearly as smooth as these group averages would suggest; in fact, these studies show "an extremely diverse range of individual responses to low frequency noise." In some individuals, the curves flatten out at some of the lower frequencies rather than rising so sharply. Several other studies (not hearing/threshold tests) found sounds being perceived at levels below these traditional thresholds, especially

**Appendix A**
when there is a combination of tones and frequencies more complex than the simple pure
tones used in the threshold studies. *(Ed. note: Of course, wind farm sounds are also far more
complex, with some tones and rhythms/pulses, and an overall sound that encompasses a
broad spectrum of frequencies.)* HGC cites another lit review, by Schust (2004), which
“highlights a few papers which identified possible effects ('somnolence, irritability, tiredness,
tense and restlessness') which were associated with infrasonic noise at levels below
(although close to) a level equivalent to the mean threshold of hearing less one standard
deviation.” *(Ed. Note: i.e., not just below the classic mean threshold, but just below a
standard deviation quieter than that...which may really bring the Bray/James data into play)*

In sum, the HGC/Ontario report stresses that "it is clear that some caution is needed when
djudging the audibility of sound which approach the mean thresholds of hearing." Yet they
also concludes that, below 20Hz, "sound pressure levels produced by modern upwind
turbines will be well below (on the order of 20dB below) the average threshold of hearing, at
the setback distances typical in Ontario." *(setbacks are 550m/1800ft; bear in mind that
beyond here, infrasound will drop by only 3dB per doubling distance, so that at
1.1km/3600ft, sound will be perhaps 23dB below the average thresholds).* *Ed. note: To my
eye, given the individual variability noted in this report and the emerging study of peak,
rather than average, infrasound and low-frequency noise levels, this relatively close gap
between (average) infrasonic and (average) hearing thresholds does suggest that peak
sounds could easily approach the average thresholds and be above some individuals' thresholds.*

This report also notes the infrasonic sound levels of other things people are commonly
exposed to, including riding in trains (with extreme infrasound, up to 150dB, as they enter
and leave tunnels), and riding in a car, which commonly exposes us to over 100dB of
infrasound. This may be reassuring, since even peak levels at homes near wind turbines are
significantly lower. *(Ed. note: However, these reassurances don't take into account the
difference between a few seconds of train/tunnel exposure, a few hours of being in a car
(which most of us can affirm leads to mental and physical discomfort/fatigue), and chronic
exposure at one's home. And more importantly, if the Bray/James and Ambrose/Rand data is
representative of other locations, the rapidly pulsing nature of the infrasonic sound from
turbines may well be of an entirely different nature, contributing to the fatigue and focus
issues reported by Ambrose and Rand, even at lower intensities than we experience in trains
or cars.)*

The HGC report also addresses the challenges of getting accurate low-frequency readings in
windy conditions, as Hessler stresses. But rather than joining Hessler in considering low-
frequency and infrasonic readings to be entirely unreliable or impossible around wind farms,
HGC notes several approaches, including a NASA-designed wind screen and an in-ground
system, both of which allow for accurate infrasonic readings, though they distort or miss
higher frequencies. Indeed, while the HGC report concludes that infrasound is unlikely to be
an issue, so need not be routinely measured as part of project permitting, they also note the
ongoing investigations taking place by acousticians (as well as the public apprehension), and
recommend that MOE adopt measurement procedures for infrasound, to be used in specific
situations – presumably, when complaints arise, and perhaps also to provide for better
comparison between studies that are performed in the coming years.

Finally, this graph presents a pretty good overview of the relationship between wind farm
noise and hearing thresholds:

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**Appendix A**
A few things are worth noticing here. The dotted lines show the same hearing threshold curves we saw in the previous graph, with an International Standards Organization standard overlaid on them; the two other curves, marked with triangles, are actual measurements of wind farm noise. The first thing I noticed was that the two studies of wind farm noise plotted here show surprisingly little difference in overall sound levels between 305m/1000ft (Kamperman and James) and 650m/2100ft (HGC) – this may reflect differences in the local topography or turbine size, or could be a reminder that simple sound propagation models (which would suggest that the darker triangles from HGC should be routinely 3–6dB below the purple Kamperman/James data) are not as reliable as we might wish. We can expect, once again, these low-frequency sound levels to continue to drop only 3dB at 4200ft, and 6dB at 8400ft.

The graph shows lots of easily audible low frequency sound from 50Hz on up, while it is likely that some individuals would be sensitive to the wind farm sound levels shown here at 25–50Hz. (Note that even these lower frequencies are not infrasound, but borderline-audible low frequencies.)

If we add to this graph the reminder noted by HGC of "strong, audible low frequency (but not infrasonic) tones from some turbines," it once again comes into clear focus that the lower frequency parts of the wind turbine sound spectrum are likely to be key factors in triggering annoyance among neighbors.

*Ed. note: While some reports, including this one, tend to suggest that leaf rustling and wind in trees and ears will mask these lower frequencies (which are not that much above our hearing thresholds), the experiential reality in most situations is that the turbine noise remains clearly audible at a lower frequency than the wind and rustling sounds in vegetation; while the absolute dB levels may match or suggest that the turbines would be masked, the higher frequencies of the leaves do not in fact mask the generally lower overall frequency*
content of the turbines.

Finally, I want to mention a brief summary included in the HGC report of a very interesting detailed study by Møller, CS Pedersen, and Persson-Waye, which investigated a randomly selected sample of 21 cases of low-frequency noise complaints from a pool of 203 cases (these were not wind farm noise locations; just homes where people reported a bothersome low frequency noise). The study involved making recordings of sound in the homes of the complainants, after which the subjects were exposed to the sounds in blind listening tests at a low-frequency test facility. The study concluded that some of the complainants were annoyed by physical sounds, and others were suffering from low frequency tinnitus. That is, this latter group did not hear or respond to the actual sounds recorded in their homes. The authors stressed that physical sounds in the infrasonic range were not found to be responsible for the annoyance in any of the cases, which means that the ones who did hear and respond to the sounds recorded in their home were in fact being bothered by low-frequency noise, rather than infrasound.

Ed. note: of course, this is not evidence that no infrasound-related complaints are valid, especially if considering the new measurement methods being used by Bray/James. But we also must be cautious not to simply assume that the Bray/James work, or the Ambrose/Rand work (where the infrasound peaks were significantly lower than Bray/James) can be instantly and broadly applied to presume that any situation reporting no infrasound issue is inherently invalid, just because these new methods were not employed. Science moves slowly, to be sure, but it does move as evidence accumulates and is affirmed elsewhere. It's important to note the newest studies, but there needs to be far more investigation, using similar methods in different situations, before these provocative new results could support widespread changes in policy or standards.

While supporting the current Ontario MOE approach to wind farm noise assessment, which relies exclusively on dBA measurements, with penalties for tones, "which often occur in the low frequency range," the HGC report stresses that "there is a degree of disagreement and uncertainty in the literature of some of the subjects discussed in this review, and research efforts are ongoing." They recommend that any low-frequency or infrasound policies adopted by the province of Ontario should have some built-in flexibility, so as to incorporate new research findings in the future.

Okay, almost there! Just three more, each much shorter summaries than those we've covered so far.

Knopper and Olsen's paper in Environmental Health, which is a literature review of health effects of wind turbines, affirms the conventional wisdom that the noise from wind farms is not loud enough to directly trigger physiological reactions.

They do note that annoyance and sleep disturbance "have been statistically associated with wind turbine noise especially when found at sound pressure levels greater than 40 dB(A)," which lines up well with the emerging consensus we see in the mainstream papers here, encouraging project planners to limit exposures above that level at nearby residences. This annoyance and sleep disruption is also correlated with visual impact and attitudes to the
local wind farm, as well as to general noise sensitivity. This literature review largely suggests that most of the annoyance reactions and health effects are caused indirectly, via anxiety or annoyance about the wind farm, citing a long history of studies of other community noise sources that show similar links between health effects and attitudes.

One key point in this paper caught my attention: this idea that most health effects are due to various cognitive stresses means to the authors that "it appears that it is the change in the environment that is associated with reported health effects, not a turbine-specific variable like audible noise or infrasound." What leapt out at me from this is that the change in the environment IS a "turbine-specific variable," the wind farm itself! Even if the sound is not directly triggering health issues (noting that these reviews of previous literature do not include any recent work on short time-averaging and higher peak levels), what we are seeing is that for many people, their sense of place and home is of such importance that the arrival of a wind farm in their rural landscape triggers a strong negative response that encompasses aesthetic, stress, sleep, and quality of life issues. Acknowledging that the change in the environment is a substantial impact in and of itself is an important insight to bear in mind.

A fascinating paper by Kroesen and Shreckenberg appeared in the Journal of the Acoustical Society of America in early 2011, which proposed a multi-faceted approach to understanding why noise can be annoying to people at their homes.

The paper focused on aircraft noise, but would seem to be applicable to our emerging inquiries into wind farm annoyance issues as well. Again, reading the paper itself is recommended, as it draws from rich research streams in psychological acoustics which cannot be adequately summarized here. The nut of it is the authors' suggestion that what they term a "general noise reaction" (GNR) can be calculated from assessing several different aspects of the individual's response to the noise source. "Residential satisfaction" and "perceived health" (both mental and physical health) are seen as being outcomes of the GNR, which has three main types of contributors: traditional noise annoyance, activity disturbance, and anxiety and fear related to the noise source. Activity disturbance can include specific activities such as relaxation, reading/concentrating, "domestic coziness or visitation," and sleeping. Anxiety and fear includes such factors as concern about stress-related health effects or impacts on property values. Overall, the authors found that mental health was more than twice as strongly affected as physical health, based on the GNR ratings obtained from their study, with direct noise annoyance and activity disturbance being the dominant factors, "while the anxiety and fear dimension operates at a more distant level."

This seems to be an important finding, for it is one of the more detailed investigations of the underlying factors in noise reactions; all too often, subjective factors such as anxiety, fear, and prior attitudes are assumed to be the primary drivers of negative reactions to wind farms, based either on assumptions or on simpler survey results. This study seems to point to more concrete experiences such as the noise itself being bothersome or intruding into valued activities as the core factors.

With the exception of the Pedersen non-clan in Scandinavia, most of the best-known research and reports on wind farm noise have come from the US and Canada. But a lot of important work is ongoing in Australia and New Zealand as well, where several large wind farms have spurred widespread complaints at greater distances than we commonly hear about elsewhere (2–4km). Bob Thorns is one one of the acousticians there who has

Appendix A
investigated wind farm noise in as much detail as anyone here; his Ph.D. thesis on perception and annoyance in response to moderate noise plowed some very fresh ground.

This year, Thorne published a paper that addressed *The Problems with "Noise Numbers" for Wind Farm Noise Assessment* that introduced a new hypothesis worthy of serious followup study: the concept of heightened noise zones (HNZ) as a key driver of unexpectedly high levels of annoyance.

Thorne predicates this paper on a key, fundamental observation:

Wind farms and wind turbines are a unique source of sound and noise. The noise generation from a wind farm is like no other noise source or set of noise sources. The sounds are often of low amplitude (volume or loudness) and are constantly shifting in character (“waves on beach,” “rumble-thump,” “plane never landing,” etc.). People who are not exposed to the sounds of a wind farm find it very difficult to understand the problems of people who do live near wind farms...

This paper includes much of interest (including some consideration of health effects), but again, I’ll focus in on just a few of its themes. There is a significant amount of focus here on the elevated low–frequency “thumps” experienced inside homes, generally 1.5–2km (5000–6500ft) from turbines. As Thorne notes, "Low-frequency sound and infrasound are normal characteristics of a wind farm as they are the normal characteristics of wind, as such. The difference is that “normal” wind is laminar or smooth in effect whereas wind farm sound is non-laminar and presents a pulsing nature." Residents studied by Thorne often report that the low-frequency sound is noticeably worse in their homes it is outside. Even more surprising, and frustrating for some residents, "rooms in a residence can and will show significantly different characteristics. What may be inaudible or not perceptible in one room can be easily heard or perceived in another room on the same side of the house."

Like many others, including the Hessler guidelines report above, Thorne stresses the wide variability in noise levels at different times, leading to his conclusion that "wind farm noise level predictions can therefore only be considered as approximations and cannot be given any weight other than this." More specifically, he notes that in sound modeling,

the predicted values are given as a range, ±3 dB(A) at 1,000 meters for the most common prediction method with the predicted value being the “middle” of the range. The uncertainty increases with distance and the effect of two or more turbines operating in phase with a light/strong breeze blowing toward a residence. A variation of 6 to 7 dB(A) can be expected under such adverse conditions. Thus, on any given day the wind farm background LA95 or “source” time–average (LAEq) sound levels—assuming the wind farm is operating—could vary significantly in comparison with the predicted sound level. This is without the additional effect of any adverse wind effects or weather effects such as inversions.

As noted by Hessler, when considering all such effects, peaks of up to 20dB over the predicted (modeled) levels can be expected.

Thorne has monitored sound levels at many homes around a mile from wind farms. He notes that "in 60 seconds the sound character varies regularly by more than 20dB" and that "Sound from wind farms can easily be heard at distances of 2000 meters (1.24 miles); such
sound was measured...over the range 29 to 40 dB(A) with conditions of calm to light breeze.
The sound was modulating and readily observed and recorded. The sound can be defined as
being both unreasonable and a nuisance.“ (Ed. note: it’s worth noticing these 40dB peaks at
over a mile away; most sound modeling will suggest that such levels are common only within
a third to half mile or so of turbines)

Thorne also notes that he has often observed what he calls heightened noise zones, which
"can be small in extent—even for low frequencies and infrasound—leading to turbine sounds
'disappearing' and 'appearing' in areas spaced only a few meters apart. The concept of HNZ
goes a long way in explaining the problem of wind farm noise and its variability on
residents." (Ed. note: I've heard similar anecdotal reports from many residents and visitors
to wind farms, though this is the first paper I've seen that's addressed this important and
confounding factor)

As an initial hypothesis, Thorne suggests that these HNZs are generated in part by the air
vortex traveling downwind from turning turbine blades, which "travels downwind in the form
of a helix, rotating about its axis with each vortex replacing the previous one in space at
approximately 1-second intervals." If they encounter another turbine within 10 rotor
diameters (1160m/3800ft for a 2.5MW turbine), these vortexes can cause turbulence that
increases the noise output of the second turbine; in addition, they continue downwind with
lesser power for much greater distances. Thorne hypothesizes that these vortexes and the
increased sound they trigger in nearby turbines interact with the less directional audible
sound waves emanating from each turbine, lensing in the air or ground, and interference
between turbines' noise (audible) and vibration causing very localized patches of heightened
noise and/or vibration. He reports that "the effect has been consistently measured at a
residence 1,400 to 2,000 meters (roughly three quarters of a mile to a mile and a quarter)
downwind from a row of turbines."

All of this leads Thorne to conclude that any compliance criteria based on a single value
(including a low 35dBA Leq, a higher 40dBA L95, or an ambient–plus 5dB) are ineffective and
"unacceptable" as protection from noise nuisance, because "current noise prediction models
are simplistic, have a high degree of uncertainty, and do not make allowance for" the sorts of
variables and effects reported above.

If all noise measurements are invalid, I'm not sure where that leaves us, in terms of
generating siting policies. Thorne suggests setting siting standards based on observed
reactions by residents, including sleep disturbance, anxiety, and stress, and suggests that
these reactions are likely to begin to crop up as sound levels rise above 32dBA (Leq) outside
homes, or above the individual's threshold of hearing inside. He concludes that setbacks of
up to 3.5km may be necessary to achieve these low sound levels at homes, though also
proposes that "no large-scale wind turbine should be installed within 2,000 meters of any
dwelling or noise-sensitive place unless with the approval of the landowner."

This latter proposal dovetails nicely with an emerging "cautionary" consensus of trying to
keep noise at non–participating neighbors homes to no more than 35dB. As AEI often
emphasizes, such limits need not preclude development if they also include provisions to
allow closer siting to neighbors who don't mind hearing turbines more often or more
noticeably.

Phew! We made it. I appreciate your diligence in reading all this through, and
hope you'll agree that the details found in this wide-ranging set of papers add some important and helpful perspectives as we try to understand why wind farms are triggering more annoyance than most other community noise sources.

While the possible role of infrasound in community responses remains highly contentious, I'm struck by the increasing acknowledgement of the importance of low frequency components of wind farm noise (especially inside homes), and the move toward lower (40dB) noise limits even among mainstream acousticians. It appears that the common U.S. regulatory standards of 45–50dB are no longer considered appropriate in many situations, especially because of the low frequency considerations. While many acousticians continue to recommend limits of 30–35dB to effectively eliminate noise complaints, I'm struck by how the gap between the mainstream and cautionary views is rapidly shrinking. This bodes well for a more positive dialogue on these subtle but important questions surrounding noise annoyance, quality of life, and wind farm siting guidelines.

Even 40dB standards will require a new level of collaboration between wind developers and host communities – and in this lies the possibility of a gradual move toward what AEI sees as the obvious win-win path forward: adoption of lower noise limits (which will likely vary by community, based on the local sense of place and tolerance for moderate noise), in combination with negotiated easements allowing closer siting to homes where the residents don't mind somewhat higher noise levels.

Time will tell how siting policy will evolve, but it's clear that the conventional wisdom is shifting. Ongoing research and more informed public debate are likely to keep the process of learning, listening, and experimenting very interesting in the next few years. Here's to a constructive dialogue in 2012 and beyond!
Appendix B: Addressing Wind Farm Noise Concerns

By Jim Cummings, for inclusion in the proceedings of Renewable Energy World North America, December 2012

In the past several years, as wind energy development expanded from the plains and west, into rural areas with fewer working farms and ranches and higher population densities, complaints about wind turbine noise have become more common. Initially, based on experience in ranching communities where sound levels of 50dB and more were easily tolerated, noise complaints were often seen as a surrogate for broader NIMBY attitudes or as the habitual response of local complainers. But over the past year or two, as it’s become clear that some residents are experiencing genuine annoyance and stress responses to “normal” wind turbine noise levels, developers have been seeking new ways of working with noise concerns. Paul Thompson, commercial director of Mitsubishi’s wind turbine group, has said, “It’s on the top of the minds for all manufacturers. We’re all doing things to reduce the amount of noise that’s generated.” (Beniwal, 2011)

At the 2012 AWEA Project Siting seminar, John Anderson (AWEA Director of Siting Policy) noted that siting controversies can damage “wind’s brand” and create attitudinal obstacles among citizens or political leaders. While bird and bat mortality have long been at the forefront of such challenges, concerns about wind turbine noise have rapidly ramped up in many areas where new development is proposed, to the point that in some types of communities, addressing noise concerns has become a primary consideration during planning, permitting, and operation of new wind farms. Wind farm operators are experiencing an uptick in the number of projects that trigger post-construction noise complaints in communities; often, the degree of annoyance being reported is unexpected at the distances where complainants live. Even more impactful, complaints at some wind farms have spurred a widespread rise in community resistance to many new projects. (It’s important to stress that post-construction noise issues arise in only a small minority of wind farms overall; such problems seem to occur more often around projects in areas with a significant population within earshot.)

Within this context, most project developers have moved past earlier assumptions (and public assurances) that turbines will be inaudible at nearby homes, or will always be masked by nearby wind-driven ambient noise in leaves, bushes, or ears. Efforts are increasing to better understand, predict, and communicate the variability in turbine noise output, as well as to reduce the noise generated by turbines. In addition, ongoing research is investigating the ways that turbine audibility may be experienced by nearby residents (how far, how often, the quality of the sound, annoyance rates). This paper summarizes current research aimed at reducing the community noise impacts of wind farms, including:

• Passive noise reduction blade design
• Active aerodynamic load control
• Noise-reduced operation protocols
• Conditional curtailments
• New research on inflow turbulence and turbine wakes
• Low-noise brake linings
• Cooling fan noise mufflers
• Adapting to variable levels of noise sensitivity in different types of communities
An extensive list of references will provide access to more detail on each of these ways that wind farm noise concerns are currently being addressed.

Turbine noise reduction as primary goal

Reducing the source level of the sounds made by wind turbines is the area in which the greatest strides have been made to date. The two primary lines of research and implementation have been in the evolution of equipment design to reduce mechanical noise and trailing-edge aerodynamic noise during normal turbine operation, and in the development of Noise Reduced Operation (NRO) protocols for use in situations where local noise standards cannot be met during full power operations.

Mechanical noise
Mechanical noise, primarily from gears and fans in the nacelle, has been largely addressed in the past two decades, to the point that it is rarely the source of noise complaints or siting limitations. However, continued improvement is always the name of the game, especially when siting relatively close to homes. A recent example is this past summer’s addition of noise-muffling louvers on the 23 turbines at the Pinnacle Wind Farm in Keyser, WV, after several neighbors along the road below the ridgeline complained of excessive noise. Likewise, several brake manufacturers are developing new linings that are being designed specifically for noise reduction in comparison with standard linings.

Aerodynamic blade noise
Aerodynamic noise from the trailing edge of turbine blades is the primary noise source of most modern turbines. This is generally a broadband noise, though most notable at frequencies of 700Hz to 2kHz. A range of design modifications are being developed by most turbine manufacturers, including shape of the airfoil, tip modifications, vortex generators along the fin’s crest, and porous or serrated trailing edges. Serrated edges appear to be the most widely studied, with overall noise reductions of 3-8dB being reported (Barrone, 2011). However, many studies have found that these reductions are frequency-dependent, with reductions in low-frequency noise and increases at higher frequencies (over 2kHz). Serrations may be less effective at low or moderate wind speeds; in some situations, this can be when neighbors find turbine noise most audible.

During its first summer in operation, the three Fox Islands Wind turbines on the island of Vinalhaven, ME, were retrofitted with serrated edges as part of an effort to reduce noise impacts.
on neighbors (photos above by Charlotte Goodhue). No formal study of the effects has yet been released, though neighbors report that the serrations seemed to moderate the lower-frequency thumping element of the sound, while slightly increasing the overall whooshing aspects, as the studies summarized in Barrone might suggest (personal communications, 2012).

Operational adjustments
In some situations, turbines operating at full power either cannot quite meet local noise criteria, or continue to trigger complaints even while in compliance. To address these cases, wind farm manufacturers have developed Noise Reduced Operations (NRO) or Noise Reduction Systems (NRS), which are software-driven operational protocols that aim to reduce noise with minimal reductions in power output. These systems typically combine changes in the pitch angle of the blades and reduction in RPMs, and can be set to achieve the desired noise reduction, often from 1dB to 4dB. Power losses are modest at moderate wind speeds when aiming for 2dB noise reduction, and increase with additional noise reduction and at higher wind speeds (Leloudas, 2007; see images below from NRO applied on a 2.3MW turbine). Such settings are often used to meet reduced nighttime noise criteria, or to adjust a few turbines within a larger wind farm that are closer to neighbors (for example, one of the three Fox Islands Wind turbines routinely operates in NRO 1dB mode).

During 2011, Fox Islands Wind experimented with NRO in addition to the serrated blades. A Lawrence Berkeley National Laboratory study of the relationship between NRO, noise levels, and neighbor annoyance is still being finalized; a preliminary analysis suggests a small but not statistically significant reduction in annoyance during NRO. During the summer and fall of 2012, Iberdrola’s Hardscrabble Wind Farm in upstate New York began experimenting with a new software package from Gamesa, the turbine manufacturer, in order to reduce instances of noise peaking over the local noise limit.
NRO can be applied in several ways: all the time, only at night, or only in certain meteorological conditions (e.g. particular wind speeds or directions that either increase noise output or direct sound to nearby homes). In practice, most use of NRO operates in one of the first two situations; research is ongoing to better understand specific conditions in which NRO could be effective in reducing the noise footprint of projects (see Bockstael 2012 for some of this research).

**Conditional curtailments**

Some projects have faced the more challenging prospect of full curtailment in particular situations. The town-owned turbines in Falmouth, MA, have been shut down at night for several months after several dozen neighbors raised issues about sleep disruption; prior to this, the Falmouth turbines were shut down in winds over 22mph (10m/s). However, to my knowledge no such noise-related full curtailments have been imposed on North American commercial wind farms.

**Turbine noise reduction as secondary benefit**

**Increased cut-in speeds as bat mortality mitigation**

One high-profile type of conditional curtailment may provide some degree of noise relief for neighbors: seasonal night-time operational adjustments designed to reduce bat mortality. As with conditional NRO, research is ongoing to better understand the conditions in which bat mortality may be most effectively reduced. So far, an increase in turbine cut-in speed appears to be the most likely path forward in areas with high concentrations of bats. Bats tend not to fly in high winds, so keeping turbines shut down (or fully feathered and freewheeling slowly) in light winds can reduce mortality to half or even a fifth of the rates measured under normal operations (Arnett et al, 2011). Since relatively little power is generated at the low end of operational wind speeds, an increase of the cut-in speed from 3–4m/s to 5m/s results in a reduction in total power output of only 1-3%. An earlier study (Baerwald, 2009) of similar moderate increases in cut-in speeds reduced total turbine operating time by 42% (in a season with a generally lower wind speeds, so this reduction would likely be less at other times). This was obviously great for bats, though it could be a worthy area of further research in community noise/annoyance mitigation (while turbines create less noise at these low wind speeds, it could be worth investigating whether such a noticeable reduction in turbine operations reduces the stress/annoyance that underlie many noise complaints).

**Inflow turbulence, directional shear, and turbine wake research**

More far-reaching and promising is a large body of ongoing research at the National Renewable Energy Laboratory (NREL), Sandia National Laboratories (SNL), and within the wind industry aimed at reducing turbine blade loads caused by turbulence. The primary goal of this line of research is to lower the overall cost of energy (COE) by both avoiding power output losses in turbulent conditions, and reducing structural stress enough to allow the use of longer blades that can capture more energy from the wind. Cost reductions are also achieved by reducing wear and tear caused by sudden, shifting blade loads; these stresses take their toll not just on blades, but on all turbine components.
However, blade load research may well turn out to be as effective in reducing community noise impacts as the explicit noise-reduction approaches that are already being pursued. Worn or damaged blades are not just less effective at capturing the wind’s energy – the loss of coherent laminar flow and increase in trailing-edge turbulence also creates more noise. Likewise, worn bearings and gears are often louder, or emit tonal noise. Note: Such noise benefits will of course be minimal if design innovations remain focused increasing size while maintaining current noise levels and/or stress tolerance; and, even if quieter, larger turbines are developed, increasing size may exacerbate amplitude modulation triggered by wind speed differentials between the top and bottom of the rotor diameter, and may be associated with increased sound levels at low frequencies, which can be the primary noise annoyance at greater distances, especially indoors (Moller and Pedersen, 2011)

Other aspects of this new research, especially the development of adaptive blade designs and incorporation of new insights about wake and other flow dynamics into wind farm layouts, offer even more promising possibilities for creating unexpected benefits in terms of community noise, because of the likelihood that turbulence in the blade-swept area is a key factor in the most problematic aspect of wind turbine noise: its extreme variability, in both amplitude (with peaks of up to 20dB above daylong averages) and in sound quality and intrusiveness.

While many of us think of wind turbine noise as a gentle whooshing, wind farm neighbors often speak about knocking, banging, and tumbling sounds that are especially disruptive, and of deep rumbling low-frequency sounds that, even when barely audible, intrude into their bedrooms. These are just the sorts of noises that are often associated with blades operating in the presence of inflow turbulence.

Research efforts are aimed at innovative new blade designs that can reduce the physical stress on blades and mechanical components that is caused by rapid variations in wind speed or direction along the length of the blade. A Sandia NL paper summarized the situation thusly (Wilson et al, quoting Kelly, 2005):

“…greatest structural fatigue damage tends to occur during nighttime hours from coherent turbulence that develops in the stable, nocturnal atmospheric boundary layer. Under such conditions, intense vertical wind shear and temperature gradients create resonant flow fields capable of imparting short-period loading and vibrational energy as wind turbine rotor blades pass through regions of organized or coherent turbulence. This energy is subsequently propagated throughout the remainder of the structure…”

The leading-edge research now underway aims to reduce these load stresses in two ways (Zayas presentation). First is “passive load mitigation,” including innovative materials (such as carbon fiber as a component in various places within the blade core) and blade geometries (one design reduces loads through a geometric sweep that allows “bend twist coupling”). This is a step forward from simply trying to reduce stress by adjusting the pitch angle (which can only respond to average loads along the blade), but such passive mitigations cannot respond to local load variations as the blade sweeps through turbulent air.
That’s where Active Aerodynamic Load Control (AALC) comes in: sensors along the blade that can instantaneously trigger small flaps along the trailing edge of the blade to relieve transient pressures.

Sandia’s Structural and Mechanical Adaptive Rotor Technology (SMART) blades are in an intermediate R&D stage, with 30-foot blades currently being tested (image left). Other active blade control approaches being studied include wings whose trailing edge can deflect either way, and flexing microtabs with the height of the boundary layer (Wilson et al. 2009; Zipp 2012).

Sandia National Lab is also on the leading edge of wake research. Their Scaled Wind Farm Technology Facility (SWiFT) facility, under construction near Lubbock, will feature an array of four turbines with 27m rotors to study wake interactions (Windpower Engineering, July 2012). Project lead Jon White affirms that they are expanding the original project design to perform a variety of acoustic measurements (personal communication, 8/19/12).

Researchers at NREL are also investigating wake interactions, with the goal of better assessing the power production and load effects of turbine wakes on downwind turbines. Early indications are that we have much to learn, and once again, the same power losses and physical stresses being studied here are very likely associated with some of the more troublesome turbine noise events.

One recent study found that in “perfect” worst-case, but typical average, wind conditions (wind head-on the rows in a 48 turbine wind farm of 2.3MW turbines with a spacing of 4.3 rotor diameter), there was a 60-70% decrease in power output behind the front row; their modeling matched the average power plant output well, but actually over-estimated the feeble power output of the turbines in the farthest back rows (Churchfield et al, 2012; image below shows (a) instantaneous and (b) time-averaged velocity, clearly illustrating that only the front row operates at peak efficiency). The authors note that “it will be an interesting future study to examine the structural response of the turbines in the plant.”

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Another NREL research team stresses that “the enhanced turbulence in turbine wakes increases the loads on downwind turbines. Furthermore, turbines located in the center of large arrays experience more faults and damaging loads than turbines located at the edge of wind farms.” (Lundquist and Clifton, 2012)

The final area of ongoing research that is likely to pay dividends in noise reduction as well as in power increases is the study of wind shear in far more detail than typically found in current wind farm modeling. As noted in a recent overview of current research, we must look beyond “the narrow definition of shear (i.e., the change in wind speed with height). Wind direction can also change with height. During the day, when there is strong mixing throughout the lower ABL (atmospheric boundary layer), this change is a few degrees throughout the typical 40m to 120m rotor plane. However, at night, as turbulent mixing decreases, directional shear can be 20-40 degrees or more, depending on how much temperature increases with height. Directional shear also has an impact on the power derived from the wind and can impart considerable stress on turbine infrastructure…” (Freedman and Moore, 2012) Indeed, while vertical shear (which is more apt to be relatively consistent) can increase power output, directional shear (which can change rapidly) generally leads to power losses and increased stresses (Wharton & Lundquist, 2012)

For the latest thinking from industry, agency, and academic researchers on many of these issues, the report of this year’s DOE Complex Flow Workshop is a great starting point (DOE Wind Program, 2012). Working groups summarized current knowledge, complicating factors, and desired next steps in great detail at three scales: regional atmospheric, wind-farm scale, and single-turbine scale (down to millimeter-scale wind interactions with blades!). Of special interest is this observation from their conclusion (emphasis added):

One of the largest obstacles to obtaining useful validation data for public use has been the inability of the research community to convince industry players to share their data. While this is entirely understandable given the competitive nature of the wind industry, future public R&D efforts must rely on such data. As such, it will be highly important to find ways to incentivize data owners and users to share their data and/or provide access to their assets for testing purposes. The idea is not to simply expect that these data should and would be provided, but rather that public research institutions need to find ways to bring value to the industry participants in exchange for their openness.

While several (workshop members from industry) commented that complex flow R&D is a high priority area for their respective companies, they also noted that the resources and access to data required are difficult to come by for a single company in the competitive wind industry. There seems to be a strong desire on the part of turbine manufacturer R&D groups to work together and share data; however, the management of these companies will still require convincing.
Mitigation of reported noise impacts (existing projects)
Reducing fear of noise impacts (proposed projects)

In addition to the physical and operational adjustments covered in the first section of this paper, several approaches have been taken to addressing homeowners directly about both existing noise complaints, and fears of noise impacts.

Home retrofits, including double-glazed windows and air conditioning systems, have sometimes been offered to mitigate intrusion from many community noise sources. Recently, residents near the Hardscrabble Wind Farm were offered white-noise machines to help mask turbine sounds (initial press reports suggest they did not fully mask the troublesome noise, perhaps because the turbine sounds, especially inside the house, were weighted heavily toward the audible low-frequency range and sometimes have a pulsing quality).

Very occasionally, homes of nearby residents are purchased by wind developers. Most often, this occurs prior to construction, and involves homes that are simply too close to the project site for noise standards to be met; for example, one such house was purchased in Vinalhaven, ME prior to Fox Islands Wind becoming operational. Rarely, homes are bought after complaints arise, and are generally then resold or used by the wind farm operator. Records are spotty on this, though it clearly happens in some situations (two Ontario projects are the best documented; see aeinews.org/archives/350 and aeinews.org/archives/1344 ).

The most constructive approach, and one pursued by many developers with varying degrees of commitment, transparency, and success, is engaging in open dialogue with community members. A leading player in such efforts has been the Cambridge, MA, based Consensus Building Institute (Raab and Suskind, 2009; Suskind, 1990), which stresses, among other things, developing trust and keeping multiple project siting options open. AWEA’s Siting Handbook also includes suggestions to help shape community outreach efforts, including fostering a sense of local ownership and empowerment along with proactively engaging allies in the local dialogue.

Once problems arise, things get more difficult, and all too often wind up in the courts (again, Ontario provides an instructive example: aeinews.org/archives/1432 ). The most intensive and constructive community engagement process to take place after noise issues cropped up seems to be the ongoing Falmouth, MA, Wind Turbine Options Analysis Process (WTOP), which includes a variety of local stakeholders including town officials, wind advocates, and affected neighbor who have been meeting since June and plan to offer the town a set of options for reducing the noise impacts of the two town-owned turbines in time for the spring Town Meeting. For records of this process, see cbuilding.org/falmouthwind

Bigger-picture considerations

My work over the past four years has largely been about developing an understanding of the points of view and experiences that underlie both the current project design and siting of wind energy in America, and the ways that the resultant changes in local soundscapes have spurred a
push-back in some areas. I am a member of both AWEA and the American Society for Acoustic Ecology. While this has involved a great deal of research, reading, listening, meeting, and talking about a wide variety of specific and detailed information, it has also helped me to come to some larger framings that are clearly relevant to moving forward constructively in a way that fosters the continued expansion of wind energy while being empathetic and respectful of the varied character of host communities.

So I’d like to close with a couple of bigger-picture considerations that might help everyone involved to understand each other’s point of view a bit better, one technical and one sociological: first, a look at how the use of average sound levels can be confusing, and second, a consideration of place identity as a clue about why wind farms are more easily accepted in some areas than in others.

Average and peak sound levels
We all know that it can be hard for people to really know what a particular decibel level will sound like. Yet even once a noise limit has been agreed upon, the necessary use of averaging sound levels over time only adds to the confusion. Of course, wind farm sound emissions vary greatly, as do background sounds, with transient noises moving through as well; this is why we need to use time-averaged sound metrics. Yet it is often far less clear to community members that this is how it works. In my work monitoring contentious local situations, it’s increasingly common to hear wind farm operators struggling to communicate the fact that they are operating within compliance conditions even though sound levels occasionally exceed the stated limit. For example, the Pinnacle Wind Farm in Keyser, WV, operates under a state noise limit of 55dBA Ldn – the noise is averaged over a full 24-hour period. Thus, it’s not surprising that neighbors may occasionally record sounds of 65dB or even more; such peaks alarm residents, while being a natural consequence of a project operating in compliance.

As David Hessler stresses in a recent “Best Practices” report prepared under the auspices of the National Association of Regulatory Utility Commissioners:

It is important to note that the…suggested sound level targets discussed above are mean, long-term values and not instantaneous maxima. Wind turbine sound levels naturally vary above and below their mean or average value due to wind and atmospheric conditions and can significantly exceed the mean value at times. Extensive field experience measuring operational projects indicates that sound levels commonly fluctuate by roughly +/- 5 dBA about the mean trend line and that short-lived (10 to 20 minute) spikes on the order of 15 to 20 dBA above the mean are occasionally observed (emphasis added) when atmospheric conditions strongly favor the generation and propagation of noise. Because no project can be designed so that all such spikes would remain below the 40 or 45 dBA targets at all times, these values are expressed as long-term mean levels, or the central trend through data collected over a period of several weeks.

Hessler observes that “the threshold between what it is normally regarded as acceptable noise from a project and what is unacceptable to some is a project sound level that falls in a gray area ranging from about 35 to 45 dBA (Ldn). Below that range the project is so quiet in absolute terms that almost no adverse reaction is usually observed and when the mean project sound level exceeds 45 dBA a certain number of complaints are almost inevitable.” Citing the classic
Pedersen, et al studies, he notes “relatively high annoyance rates of around 20 to 25%” among residents living in areas with project sound of 40-45dB. He thus currently recommends a mean (Ldn) sound level of 40dB at residences in most cases, or 45dB “as long as the number of homes within the 40 to 45 dBA range is relatively small.” He stresses, “It is important to note that a project sound level of 40 dBA does not mean that the project would be inaudible or completely insignificant, only that its noise would generally be low enough that it would probably not be considered objectionable by the vast majority of neighbors.” (Hessler, 2011)

While Hessler’s recent work seems to point to a lower noise standard than has been typically used in projects up until now, we must bear in mind that he is working with the full day-night average, rather than an hourly or ten-minute average threshold. The lower long-term average takes into consideration the likelihood of frequent periods of 5dB higher (and lower) sound, fairly regular peaks of 10dB higher, and rare peaks of 15-20dB higher.

It appears that project managers are increasingly aware of the divergence between expectations based on averages and experiences based on peak sound levels; several projects have implemented noise-reduction efforts over the past couple of years, even when operating in compliance with the time-averaged standards. As Charley Parnell, vice president of Public Affairs for Edison Mission Group, owners of the Pinnacle Wind Farm, said in regards to the addition of noise-muffling louvres, “We believe Pinnacle is operating in a manner that meets the requirements of our permits, but taking additional steps to mitigate noise is an important part of our commitment to be a responsible corporate citizen of the communities in which we operate. We look forward to many years of providing clean energy generated by Pinnacle, and we intend to work in good faith to address local concerns.” Likewise, at the Hardscrabble Wind Farm, where new NRO software is being tested, Paul Copleman, Iberdrola Communications Manager concurred: “While our studies do not show turbine sound levels by themselves exceeding the permit limit, we do acknowledge we have received complaints from some of the residents and we are working diligently to address the situation.”

Hessler’s 40dB Ldn recommendation, coming from a stalwart of mainstream acoustics assessment, is moving closer to the recommendations of the more cautionary acousticians, who have been recommending targets of 30-35dB in some types of communities, in order to reduce nearby annoyance rates to near zero (though they often are speaking of shorter-term averages). Both approaches acknowledge that whatever averaging period is used, there will be peak events above the perceived “limit.” This crucial point needs to be more clearly communicated, in order to better manage expectations.

Place Identity and Expectations Regarding Local Soundscapes
Over the past five years, the wind industry has been faced with more widespread questions about noise impacts than it had been used to. For many years, wind farms built in either remote locations in the west, or in farming and ranching communities in the great plains, had been operating with virtually no noise problems. Suddenly, in Wisconsin, Maine, Ontario, New York, and Massachusetts, among other places, small local communities were in an uproar about perceived noise intrusions. Initially, industry representatives were taken aback, assuming the noise complaints were rooted in simple NIMBY sentiments, since we “knew” from experience
that 50-60dB wind turbine noise was easily accommodated in other places. Over time, though, it’s become more clear that different types of communities have different noise tolerances.

Many rural communities have begun seeking a balance that represents their self-perceived willingness to live with wind farm noise, adopting a wide range of noise and setback standards, ranging from the effectively exclusionary (1 mile is often impossible, 2 miles nearly always is), to attempts to find a happy medium, such as nighttime noise limits of 35 or 40dB and setbacks of 2500-4000ft. Other communities have adopted more familiar and accommodating standards, such as 45-50dB daytime average sound levels, or setbacks of 1200-1800ft. The era of “one size fits all” siting (which was commonly in the 900-1200 feet/50-60dB ballpark) is clearly coming to a close.

The best assessment of what is going on here comes from the Scandinavian team responsible for the only in-depth, peer-reviewed community annoyance research to date. In one of the most fascinating side studies from that body of research, Eja Pedersen and her collaborators dug more deeply into the paradoxical polarization of responses to very similar noise levels. They conducted in-depth interviews with survey subjects who rated their annoyance at the opposite extremes of the scale, and the results shed some much-needed light on what we’ve been seeing in communities over the past few years (Pedersen et al, 2007). It applies both to varied responses in any given community, and to the larger differences between types of communities.

They found that annoyance levels tracked closely with two very different ways of viewing the rural lifestyle and landscape, a differentiation that they termed “place identity.” For some, the countryside is a place for economic activity and technological development/experimentation. These people like new machines and technology, are glad to see a new use for the land (and wind!), and easily accept local disturbances (flies, odors, sounds). They let others use their land as they see fit, and consider turbine sounds as both relatively insignificant compared to the machinery they use every day, and also as outside their territory. Conversely, many other rural residents see the countryside as a place for peace and restoration, a tranquil refuge (or retirement) from their busy life of work in town. For them, turbine sound, especially at the times when it’s the loudest element in their soundscape, intrudes on what they see as their space and privacy, disrupting their enjoyment of their backyards, porches, and living rooms (see Cummings, 2010, for an overview of community response studies, including the full body of Pedersen et al research).

It’s not hard to see that in farm and ranch communities, the “economic activity” place identity will dominate, and that in the northeast and upper midwest, there is a higher proportion of residents who live in pastoral landscapes with a “peace and restoration” approach to place and home. A broad-brush look at projects around the country certainly can fit this framework: In Texas and Iowa ranch country, very few problems arise even in sprawling wind farm complexes such as those around Sweetwater, TX. In Wisconsin and New York state, though, some wind projects in farmland where there is a mix of these place identities, such as Blue Sky Green Field (WI) and Tug Hill (NY), revealed a vocal minority that is very clear about the disruption of their sense of place that wind farms created. At the other end of the spectrum, a few wind farms placed in areas with virtually no working farms, and where landowners are predominantly seeking peace and quiet, ran into substantial local uproar (e.g., Mars Hill, ME), as have some
municipally-owned turbines placed in towns with higher population densities, such as Falmouth and Fairhaven, Massachusetts. In Falmouth, 45 residents, about a quarter of homeowners within a half-mile downwind of the three turbines, have filed formal complaints with local authorities, a remarkably high number.

Still, it’s not as simple as this brief sketch may imply. Many wind farms in relatively rural, non-farming country don’t seem to trigger an outcry. The Massachusetts Clean Energy Center has conducted some preliminary studies, attempting to discern what the differences may be between places where projects go online with little fuss, and places where significant community reaction occurs (personal communication, June 2012). Much more needs to be done along these lines, in order to help clarify the factors that contribute to project success or a rocky road.

It could be, as Hessler suggests, as simple as population density; it’s quite likely that some version of place identity and expectations about natural quiet play into it; generic psychological noise sensitivity could be a factor (with the likelihood that fewer noise sensitive people are ranchers, and more noise sensitive people choose to live outside of towns in search of relative tranquility). There’s much to learn, and a few well-designed, comprehensive surveys in a well-selected variety of types of communities would go a long way toward helping the industry to plan future projects in ways that will be in synch with differences in local sense of place.

Paths Forward

Looking a decade or so down the line, we can expect that current research efforts will lead to the development of new blade designs and wind farm layouts that greatly reduce the significant impacts of chaotic air flow on the intrusice sorts of noises that underlie many of the noise issues among the more noise-sensitive neighbors of wind farms. We can also hope and imagine that more new development efforts will be located offshore, including deep-water floating offshore installations in relative proximity to coastal urban centers, taking some development pressure off the “nearby” rural landscapes in the more densely-populated states of the east and upper midwest.

In the meantime, though, current and near-future project planning will occur in three rather distinct paths, each of which is likely to be pursued vigorously. Perhaps some companies will choose to focus on one or another of these paths, though most will likely make do as they can with projects in all three as needed and as possible.

- Continue current siting practices (e.g. 1200-1800 feet; 45-55dB). Be prepared to spend the time/money to engage in proactive pre-proposal work in communities, and in some cases, to respond to heated resistance. Even when there is little pre-construction resistance, be prepared to apply post-construction mitigations in response to noise complaints at the margins of the regulatory criteria. 
  
  Examples: BP has been planning the Cape Vincent Wind Farm (NY) for several years, in the face of strong local resistance; this fall, they began the process of seeking state-regulated “Article X” approval. Previous examples at Pinnacle and Hardscrabble wind
Appendix B: Addressing Wind Farm Noise Concerns

Farms illustrate willing application post-construction mitigation after noise concerns arose post-construction.

- Continue current siting practices, and focus efforts only or mainly in communities where there is little or no objection, as well as low population densities (to minimize risk of post-construction surprises).
  Examples: The majority of current new wind farm construction, taking place as it always has in the great plains and intermountain west. As Clipper Windpower Vice President told wind historian Robert Righter, “If people don’t want it, we’ll go someplace else.” (Righter, 2011)

- Avoid community conflict and reduce noise impacts by prioritizing sites with few non-participating homes within a mile, and/or by working with communities or states that adopt larger standard setbacks to minimize or nearly eliminate audible noise at homes (e.g., 35-40dB, half-mile or mile setbacks,), along with easy-to-obtain waivers or easements for closer siting to willing neighbors.
  Examples: Most wind project in the State of Oregon are developed under a 36dB standard with easements available for construction closer to willing neighbors, which has minimized neighbor noise problems (and when they occur, issues tend to be moderate, with noise levels of under 40dB, far less likely to cause the severely distressing reactions that are sometimes reported with 45dB or louder noise). The site of the Record Hill Wind Farm in Roxbury, ME, was selected because there were only a handful of homes within a mile; these became project participants, while concentrations of homes at a mile and a quarter to mile and a half report they can hear turbines regularly when it’s very still, but that their lives are not disrupted by the sound (though some do still resent the lights reflecting in the lake and/or the ridgetop construction). The project developer was careful to not promise the turbines would be inaudible even at those distances, which helped manage expectations.

In conclusion, I’d like to recommend Robert W. Righter’s recent history of wind energy in America (Righter, 2011). Within a context of full support of the increasing role of wind in our energy future (and his longtime work on NIMBY reactions), he makes a strong case for pursuing the second two options above. He’s unusually sensitive to noise concerns, while affirming that not everyone will be pleased with any public infrastructure development. He notes, “When I first started studying the NIMBY response to turbines I was convinced that viewshed issues were at the heart of people’s response. Now I realize that the noise effects are more significant, particularly because residents do not anticipate such strong reactions until the turbines are up and running – by which time, of course, it is almost impossible to perform meaningful mitigation….Good corporate citizens must identify potential problems and take action.”

Righter’s conclusion offers a ready path forward: “Most developers understand that it is in their best interest to operate openly and in good faith with the local community. More problematical is the question of landscape….Wind developers should take to heart geographer Martin Pasqualetti’s advice: ‘If developers are to cultivate the promise of wind power, they should not intrude on favored (or even conspicuous) landscapes, regardless of the technical temptations these spots may offer.’ The nation is large. Wind turbines do not have to go up where they are not wanted. We can expand the grid and put them where they are welcome.”
References

Note: the Powerpoint version of this paper, presented at Renewable Energy World North America, 12/12/2012, included a slide referencing content (re: surveys of noise annoyance near wind farms) not included in this text. This content is covered, with references, in part in Cummings (2010) below, and also in AEI’s Wind Farm Noise 2012 annual report. In addition, the Powerpoint version includes a Kalisky 2010 graph of noise levels over a year that is discussed in more detail, and referenced, in AEI’s Wind Farm Noise 2011 annual report (the interpretation here is more accurate; previous interpretation did not account for hours in the year turbines are not operating) See http://www.acousticecology.org/wind/ for these and other AEI documents

Papers and Presentations


Jose Zayas. Technology Innovation for Wind Energy: SNL’s SMART Rotor Program. Sandia National Laboratories. (No date on presentation; 2010 or later) sandia.gov/wind jrzayas@sandia.gov

Media Coverage, Books, and Articles


Windpower Engineering and Development. National lab plans turbine array, reports on 100m blade, and more, July 2012, p 10-11.


Windpower Engineering and Development. Trends in simulation software, May 2012, p.70-72


In February of this year, I wrote a column for Renewable Energy World\(^1\) that addressed the recent increase in claims that wind farms are causing negative health effects among nearby neighbors. The column suggested that while many of the symptoms being reported are clearly related to the presence of the turbines and their noise, the relationship between wind farms and health effects may most often (though not always) be an indirect one, as many of the symptoms cropping up are ones that are widely triggered by chronic stress. In recent months, the dialogue around these issues has hardened, with both sides seemingly intent on painting the question in simple black and white—community groups assert that turbines "are making" people sick, while government and industry reports insist that there's "no evidence" that turbines can or do make people sick. The gulf between the conclusions of formal health impact studies and the experiences of some neighbors has widened to the point that both sides consider the other to be inherently fraudulent. I suggested that the rigidity of both sides’ approach to this subtle and complex issue is likely increasing the stress and anxiety within wind farms communities that may in fact be the actual primary trigger for health reactions.

Here, I’ll expand on that shorter column by taking a closer look at the few surveys and studies that have attempted to directly assess the prevalence of health effects around wind farms.

Even as the public becomes increasingly concerned about health effects, with a lot of focus on the role of inaudible infrasound, it’s been striking to me to that the researchers investigating health effects – even clearly sympathetic researchers – are not talking about infrasound much at all, and are instead focusing on stress-related symptoms. Drawing from studies done in areas where health concerns have been most widely reported, we’ll see that while some types of health problems may be more common near

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\(^1\) See www.renewableenergyworld.com/rea/u/AcousticEcologyInstitute/articles
wind farms, most of the studies find little difference in overall health based on proximity to turbines.

And, where health effects are reported (primarily sleep disruption and stress-related symptoms), those who have been most diligent and open in assessing community responses estimate that health problems (whether direct or indirect) appear to crop up in no more than 5-15% of those living nearest; this is a surprisingly small number, considering the central role health effects has taken in the public perception and debate about new wind farms. While we shouldn’t discount the impact on these people, it appears that fears of widespread health impacts may be misplaced. Though impacts on even a few, whether direct or indirect, are certainly a valid consideration in making wind farm siting decisions, it’s helpful to have a clearer picture of how widespread the issue may be.

Just last week, a news report about a public presentation by Carmen Krogh of Ontario’s Society for Wind Vigilance, one of the major voices in the health-effects debate, starkly illustrated the disconnect between public fear and the message actually coming from the voices of caution. I was struck to see that even as “the main concern” of the audience was the invisible dangers of infrasound and stray voltage, Krogh “focused on the stress affects of exposure and clinical annoyance. ‘We find that the number one complaint that people come forward with is sleep disturbance,’ she explained to the crowd.” While including the audience’s concerns in her assessment of five contributing factors, “Out of the five causes, Krogh focused on amplitude modulation (or the "swooshing" sounds) and audible low frequency...” As you’ll read here, this is no anomaly; nearly all the sympathetic experts have a similarly grounded focus on audible noise, sleep disruption, and stress. While some researchers continue to investigate questions around infrasound levels and perception, the public focus on infrasound as a primary or central contributor to reported health issues is not reflected in the actual findings of those studying the issues most diligently.

With this in mind, I hope that this detailed look at recent papers on health effects near wind farms will help to clarify the scope of the issue, and to provide useful context for decision-makers who are struggling to make sense of the complex and contradictory information that advocates on both sides of the issue present to them.

Investigating the health questions

Increasing public concern about health impacts has spurred a slew of reports over the
last three years from government entities and industry trade associations. Most of the official health impact studies have actually been literature reviews of previous research on noise from many sources, and have focused on questions such as whether inaudible infrasound around wind farms is strong enough to cause a direct physical reaction in neighbors (and just in case you've been out of the loop: they universally find that it's not). I will not be summarizing these reports here; they've all been summarized previously by AEI, and as just mentioned, they generally steer clear of attempting to assess actual reported health effects, preferring to stay in the presumably more objective realm of published studies relating to noise and health in general. To the degree that they include studies of on-the-ground responses to wind turbines, they tend to note that the early studies are limited by relatively small sample sizes, which is true. Still, we need to start somewhere, and as in most inquiries, the first investigations will tend to be smaller and more tentative. In any case, the omission of detailed analyses of these literature reviews should not be viewed as an attempt to skew the evidence presented here, since AEI has covered them in depth, affirming their value while also noting their limitations.

Meanwhile, a few acousticians and epidemiologists have begun taking a look at what is occurring in communities where health impacts are being reported, and this paper will summarize the recent findings of these attempts to dig into actual community responses. It should be noted that a few governmental entities, including the nation of Japan and the Province of Ontario, have initiated larger scale studies that will likely provide more comprehensive and statistically robust results over the next few years. But for now, we do have several worthwhile papers that examine actual reported health effects that can begin to help us move beyond the current quagmire.

Not too surprisingly, we'll discover that what these researchers are finding contradicts both the "all is well" literature survey findings, as well as the fear that worst-case scenarios — being driven from homes by lack of sleep, headaches, kids struggling in school — are likely to occur. Rather, these studies take us beyond the cartoons of sunshine and disaster, and drop us right down into an uncomfortably murky zone in which the answers are no longer presented in easily-understood black and white, but rather in harder-to-decipher shades of grey.

The bottom line appears to be that this first wave of research, undertaken by relatively cautionary and empathetic researchers, is finding that just a small proportion of nearby residents are reporting actual health impacts, though far more report degradation of the overall quality of life and sense of place. These studies use a diverse range of approaches and criteria, so can't all be directly compared, or compiled to suggest global

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5 See http://aeinews.org/archives/644
6 See http://aeinews.org/archives/1862
patterns, but each of them offers a clear window into particular communities’ responses to wind farms in their vicinity. As noted earlier, while all of the papers reviewed here come from researchers with much interest in and empathy for reports from affected neighbors, none of them propose inaudible infrasound as a central factor in health effects; the first four papers all focus on stress and sleep factors, and the last two, while including infrasound in their discussions, focus mostly on other factors (one on pre-existing risk factors, and the other on pulses in the dBG level, which includes substantial audible low-frequency sound as well as infrasound).

**Seeking a clear path through murky ground**

In the face of the growing clamor about health impacts, taking a direct, clear look at these studies may help to local and state regulators to step out of the confusing cross-fire of opinions, and to focus on the task at hand: designing siting standards that reflect the local best sense of how to balance the potential local economic and national climate change benefits with the likelihood of a diminished rural quality of life for some local citizens, and possible or likely health effects for a few. There is no one "right answer" to these questions, though wind promoters will suggest we must accept that we can’t expect everyone to be happy, and wind opponents will say that any new illness is one too many. Both have a point, and some towns will set standards that allow relatively close siting in the name of money for local schools or other priorities, while others will establish large setbacks that effectively keep wind development away. Meanwhile, many towns or counties will aim to find a middle ground that tries to minimize impacts while leaving some avenues for development to occur, either at a moderately greater distance or by encouraging or requiring developers to make agreements with neighbors before building.

I think it’s important to preface our consideration of these studies by acknowledging a key factor that has hampered the ability of some within both the public and the industry to clearly address the possibility that neighbors have experienced legitimate changes in their health, whether by direct or indirect means. Many of those most vehemently stressing the potential for health impacts in areas where wind farms are proposed are fundamentally anti-wind, anti-renewables, and anti-government incentives; health impacts are but one of a litany of arguments they make against new wind farms, and many simply dismiss all their claims as distorted rhetoric. This can too often blind us to the fact that nearly all of the individuals who are telling us about their actual health impacts have no dog in the energy-policy fight; their personal stories are often compelling and sober accounts of struggling with unexpected and disabling sleep issues, disorientation, and mood disorders. In my work with the Acoustic Ecology Institute, and in the papers that follow, the focus is on better understanding what’s going on with those reporting health effects around existing wind farms, rather than on the fears and opposition being raised in places where wind farms have yet to be built.
Alright then, let's dive in. The approach here will be similar to the one I took in AEI’s late 2011 summary of ten papers on low frequency noise; I'll address one paper at a time, while pointing out connections and contradictions between them. We'll be looking closely at the following seven publications, in addition to referring to several others in the final sections of this post:


Nina Pierpont. Presentation to the Hammond (NY) Wind Committee, July 2010


The famous “Overwhelming evidence (of) serious health problems” paper


The online version of this article can be purchased at: http://bst.sagepub.com/content/31/4/303

This paper is one of the "crown jewels" for community activists who have raised health impacts into prominence in the public policy debate over wind farm siting. Phillips' paper was one of several on wind farm siting policy published last summer in the Bulletin of Science, Technology, and Society, thus breaking through the invisible, and

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7 http://aeinews.org/archives/1711
8 Many of these papers can be downloaded from AEI's wind noise resource page at http://aeinews.org/archives/category/wind-turbines
(as Phillips himself points out) somewhat illusory, threshold of appearing in a "peer-reviewed journal." Most of the paper is devoted to detailed epidemiological critiques of the arguments that deny the validity of any evidence of health effects among wind farm neighbors; much of this material is effective and well worth taking into consideration, though some of it is less sharp or relevant, and at times, rather vitriolic. But this paper's claim to fame is its oft-quoted opening phrase: "There is overwhelming evidence that large electricity-generating wind turbines cause serious health problems in a nontrivial fraction of residents living near them." That phrase, touted as published in a peer-reviewed journal, shows up as Exhibit A in more than a few letters to the editor in towns considering wind farm proposals.

Yet, while the paper does make a strong case for disregarding easy dismissals of the problem, it does not provide any concrete data to suggest just how widespread health impacts actually are. The closest it comes to quantifying is to note, "Since several research groups and nongovernmental organizations have collections (of reported health effects, or "adverse event reports" that number in the three-figure range, it seems safe to conclude that the total number published or collected in some form is in the four-figure range, and it is quite conceivable that the total numbers of adverse event reports are in five figures." I would probably grant him that there may well be over a thousand clear reports of health impacts worldwide at this point; the very existence of so many people making such reports can justifiably be considered reason enough to dig deeper and find out what's going on. Yet this doesn't get us any closer to assessing whether these impacts are rare, or common; even his conceived-of 10,000 such reports would represent a small proportion of residents living within a mile or so of today's several thousand large wind farms worldwide.

But those who hold up Phillips' paper as clear published evidence of the vast scope of an insidious hidden health risk (most commonly tied in public imagination to

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9 Setting aside for the sake of celebration the fact that within the scientific community, the 20,000+ refereed or peer-reviewed journals represent a spectrum of reputation and quality that might be compared the spectrum within culinary arts, from chefs whose work is respected in kitchens around the world, to a local Denny's, both of which can boast of passing their local health inspections; still, wind proponents had harped on the lack of peer-reviewed input from the cautionary perspective, despite the fact that most of their "conclusive" reports were also white papers published outside the peer-reviewed journal process, so this became a big deal.

10 To those who may consider unsolicited reports of problems to be meaningless "self-selection," Phillips says: "In cases of emerging and unpredictable disease risk, adverse event reports are the cornerstone of public health research. Since it is obviously not possible to study every possible exposure-disease combination using more formalized study methods, just in case an association is stumbled on, collecting reports of disease cases apparently attributable to a particular exposure is the critical first step. The most familiar examples of hazards revealed by adverse event reporting are infectious disease outbreaks or side effects from pharmaceuticals, but the case of turbines and health also fits the pattern. Pharmaceutical regulators rely heavily on clearinghouses they create for adverse event reporting about drug side effects (and often become actively concerned and even implement policy interventions based on tens of reports). The WindVOIcE report collection is an example of this same well-accepted kind of active-recruiting data collection system."
physiological reactions to inaudible infrasound) conveniently overlook the second sentence in his paper, the one following his incendiary opening salvo: "...many people living near them have reported a collection of health effects that appear to be manifestations of a chronic stress reaction or something similar."

Indeed, Phillips goes even further in this direction, in a critique of the claim that health effects should be dismissed because they are "subjective" responses. He notes that such arguments "seem to be confusing 'subjective' with 'psychologically mediated,' which most of the observed effects might well be (though there are hypotheses about nonpsychological pathways)."

Phillips then offers his most valuable contributions to this discussion: "Being subjective or psychologically mediated does not mean that these effects are minor or less real. Indeed, there is a case to be made that such diseases (i.e. psychologically-mediated ones), which include everything from transient headaches to chronic pain and depression, account for the majority of the total burden of disease in our society."

On a similar note, Phillips stresses that the lack of an officially recognized labeled disease (ala "wind turbine syndrome") should not be reason to discount the health effects being reported: "...the individual diseases people are suffering from, such as chronic stress and sleep disorders, are often well defined (they are just not defined in terms of a specific cause)....There is no epistemic significance to the health outcomes in question having or not having a label."

And, he also points out, convincingly, that while not everyone who hears turbines gets sick, those who do get sick uniformly report some sensory experience of the turbines that's clearly not imaginary (ed. note: and, being sensed, are thus apparently not related to inaudible infrasound), and further, that:

"It is, of course, possible that some personal characteristic sensitizes them to be more bothered by the sensory effects, increasing the psychologically-mediated effects. But it is inevitable that some personal characteristics will be causal cofactors (factors that, along with the turbine, are part of the necessary constellation of causes for there to be a disease effect). This is true for every exposure-disease combination: Some exposed people get the disease and some do not, and sometimes we can identify other differences between the two groups."

While this paper makes no attempt to quantify just what the asserted "nontrivial fraction of residents" who experience health effects may be, Phillips did offer an estimate during a presentation to the Lee County (IL) Zoning Board of Appeals in late 2011. When asked what percentage of residents report health problems, he told the Board that there have not been solid studies of that, but that his best guess, based on what research has

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11 See http://aeinews.org/archives/1591
been done, is about 5 percent of those within a mile or so, with some reports of health effects out to two miles.

While this low estimate may surprise some, we'll see that other cautionary researchers also come to generally similar conclusions (estimates range from 5-15% of those close enough to hear turbines regularly). This more dramatically affected (and indeed non-trivial) minority may be those who are more sensitive in some way – to sound, air pressure fluctuations, or annoyance-induced stress. These relatively low percentages may also remind us of the need to separate the equally important, and more widespread, impacts on quality of life and sense of place from the more dramatic but apparently less widespread question of acute or chronic health impacts.

Health Related Quality of Life (HRQOL) Survey in New Zealand


Our second paper offers an interesting contrast and complement to the first – a contrast in that it's a rigorous field research project, and a complement in that it highlights the quality of life element that plays such a big factor in community responses to wind farms. A team researchers from New Zealand led by Daniel Shepherd conducted a comprehensive survey of residents living within 2km of a wind farm in the Makara Valley, just west of Wellington, with a comparison group of residents at least 8km from any wind farm. The survey was given a generic title, and included no questions specifically asking about wind turbines, in order to mask its intent to compare health-related quality of life (HRQOL) in two areas where the only substantial difference was the presence or absence of turbines.

The study utilized a well-known protocol, the health-related quality of life survey, which uses a series of questions to rate HRQOL in Physical, Psychological, and Social domains, while also assessing many specific sub-factors that contribute to these three main overall HRQOL scores; additional sections addressed general health, Environmental quality of life, neighborhood amenity, and annoyance. The authors note that "A variety of outcome measures have been proposed to assess the impacts of community noise, including annoyance, sleep disturbance, cardiovascular disease, and cortisol levels," and that the World Health Organization "recommends the use of HRQOL measures as an outcome variable, arguing that the effects of noise are strongest for those outcomes classified under HRQOL rather than illness."

The local wind farm consisted of 66 turbines running along a ridgeline, with homes
mostly in the bottomland of the river valley below; as in many locations, field measurements indicate that the turbines are generally compliant with their consent conditions, but complaints have been widespread nonetheless.

One of the most striking findings in this study was that 23 of the 39 respondents in the group living within 2km of turbines (59%) wrote in a comment that turbines were a noise source that bothered them, and rated it as extremely annoying, with a mean of 4.5 on a 5-point scale (the noise annoyance questions included only two noise sources, traffic and neighbors, with a space to specify an "other" source if they chose; no "other" source besides turbines spurred notation by more than 3 people). Also of note is that "scrutiny of the comments provided by the turbine group revealed no mention of the impact of turbines on the landscape, reinforcing suggestions made by other (researchers), that wind farm noise is more dominant than their visual aspects."

The HRQOL ratings that showed the strongest impacts among the turbine group were reductions in Physical quality of life (with sub-factors of sleep quality and energy level being the primary contributors), as well as Environmental quality of life. There was no statistical difference between the groups in Social or Psychological quality of life, or – notably – in the self-rated general health scores; this lack of a difference in average self-reported health is replicated in some of the other surveys we'll address here.

It's worth noting that these are overall averages; the data as presented does not clarify whether an increased proportion of individuals (even just, say, 10-15%) closer to turbine reported lower health ratings, while the overall average remained relatively unchanged. In both this study and the one that follows, researchers chose to use standard, widely-recognized health-related rating systems, rather than to detail specific complaints. This may allow the moderate sample sizes to be assessed in ways that are less prone to distortions by a few individuals, while also having the benefit of matching well-established protocols.

In this study, the most dramatic difference was in the separately-assessed Amenity score, where the turbine group scored dramatically lower (this is where the very high annoyance at turbine noise factored in, in stark contrast to finding no differences between the two groups in annoyance at other noise sources). Amenity is a term used in environmental planning in Australia and New Zealand, which correlates closely with what we would tend to call "sense of place," relationship with home and landscape, or perhaps overall quality of life. Those living near turbines reported much lower overall Amenity scores, indicating a substantial decrease in rural quality of life.

The authors also note a strong correlation between self-reported noise sensitivity and annoyance in response to the turbines in that group. In the paper we'll briefly discuss next, Shepherd stresses this factor, suggesting that rural areas attract a higher proportion of noise-sensitive individuals, and that this should be factored into permit conditions.
In conclusion, the authors of this paper suggest (based largely on the high levels of annoyance, decreased sleep quality/energy level, and reduced amenity) that "night-time wind turbine noise limits should be set conservatively to minimize harm," and that "setback distances need to be greater than 2km in hilly terrain."

We'll turn briefly now to another contribution from Daniel Shepherd, a statement submitted to a 2011 Environmental Review Tribunal considering an appeal to the permits issued to a wind farm in Ontario.

Here, Shepherd repeats from the above paper a constructive contribution to the discussion: a flow chart illustrating the complex pathways by which wind turbine noise can lead to "primary health effects" of annoyance and sleep disturbance, and on to "secondary health effects" of quality of life and stress-related disease:

![Flow chart](image)

**Figure 1:** A schematic representation of the relationship between wind-turbines and health in a rural setting such as that proposed with the Kent Breeze Wind Farms. Arrows represent cause-and-effect relationships, which maybe bidirectional. The multiplicity of relationships emerges due to variability in the response of individuals to noise.

He also stresses the finding from many other studies, that noise annoyance is not readily correlated with noise exposure; only about 20-25% of the annoyance effect can be explained by the noise level itself. While some claim that visual impact or general attitude toward the wind farm drives annoyance, Shepherd stresses the inherent complexity of individual reactions to any noise source. As noted above, visual/landscape impacts did not seem to be a factor in the annoyance reported in the...
Makara Valley; and further, Shepherd stresses individual psychological factors, as did Phillips. In particular, Shepherd puts forth the high proportion of noise-sensitive individuals in rural areas (roughly 20%, about twice the proportion found in cities) as an indicator that annoyance rates will be at least that high, leading to associated stress-related effects in 10-15% of residents who can hear the proposed wind farm.

Sleep quality survey in Maine

Nissenbaum, Aramani, Hanning. Adverse health effects of industrial wind turbines: a preliminary report

This paper, presented at the 2011 ICBEN Noise as a Public Health Problem conference, like the Shepherd study above, uses widely recognized standard assessment questionnaires to assess mental and physical health, sleep disturbance, and sleepiness in two sets of residents in rural Maine, one living within 1.5km (just under a mile) from wind turbines, and the other 3.5-6km from any turbines. About two-thirds of adults living within 1.5 km of the Mars Hill wind farm participated, along with about half of the adults within that distance of the Vinalhaven turbines; the near-turbine group was about evenly split between those within a half-mile and those between a half-mile and mile. The total number of participants (38 near turbines and 41 at a greater distance) is slightly smaller than the Shepherd survey; both would benefit from larger sample sizes, especially in the measures that show no statistical difference. However, both also boast a very good response rate among the local residents, adding to confidence in the validity of the findings.

Also as in the Shepherd survey, the results are presented as overall averages, contrasting near and far groups, so, again, there is no direct reporting of the proportion of either group reporting any particular health effects. In addition, in the categories where a significant difference was found between the groups, the results were presented on graphs scaled over the full range of distances.

Following on a preliminary survey at Mars Hill that found "sleep disturbance was the main health effect," this larger study also found that the sleep measures showed "a clear and significant relationship, with the effect diminishing with increasing distance" from the turbines. The Pittsburgh Sleep Quality Index and Epworth Sleepiness Scale both showed significantly worse sleep for the turbine group; likely following from this, the most statistically significant result was a dramatically lower SF36 Mental Component Score (MCS) for the turbine group, indicating worse mental health (the MCS includes vitality, social functioning, and emotional health) – MCS scores dropped rapidly within the turbine group with increasing proximity to the turbines, especially moving in closer than a half mile. The authors note that this "first controlled study of the effects of IWT noise on sleep and health shows that those living within 1.4km of IWT have suffered sleep disruption which is sufficiently severe as to affect their daytime functioning and
mental health." They note that "while not proven, it is highly likely that IWT noise will cause arousals (brief lightening of sleep which are not recalled) which may prove to be the major mechanism for sleep disruption."

Notably, given concerns about physical health effects, the SF36 Physical Component Score (PCS) showed no difference in average overall physical health between those close to turbines and farther away; the PCS assesses physical functioning, bodily pain, and general health perceptions.

The results here closely parallel those reported above by Shepherd in New Zealand, where the Physical sub-factors of sleep quality and energy level were one of the strongest differences between those close and far from turbines, while neither study found a measurable difference in general health ratings. By contrast, Shepherd did not find the dramatic impact on psychological measures resulting from the sleep issues that were found in Maine; instead, his study saw a similarly dramatic increase in annoyance and decreased Amenity.

The study design used here does not provide any data on individual reports of specific health or annoyance reactions, so we can't speculate on what proportion of the turbine group may have experienced any given health or sleep impacts; likewise, this study does not assess annoyance rates. (The introduction to the paper suggests that such questions were included in the questionnaire, but this paper presents only results from the more standardized assessment instruments.)

The earlier preliminary study (shared in public forums by Nissenbaum during 2009 and after; currently submitted for publication), which included just under half of the Mars Hill residents living within 3400 feet, indicated that the majority of those surveyed were experiencing sleep disturbance on most nights (which is likely directly related to 40% reporting new onset of headaches); 20% or less reported specific symptoms such as dizziness, tinnitus, or unusual sensations in their chest or ears. These figures are a notch above the 5-15% estimated by other investigators, but we may do well to remember that Mars Hill could be a worst-case scenario: ridgetop turbines close to sheltered valley homes, operating with a state-issued exception that allows them to run at 5dB louder than state regulations otherwise require (ie 50dB at night, rather than 45dB).

**Comprehensive guidelines proposal aims to reduce 5-10% health effects rate near wind farms**


In this comprehensive 116p document, Thorne, an acoustician who has specialized in human responses to moderate noise, reviews basic acoustics as well as field
measurements made at operating wind farms, and assessment of previous research into health effects. For these review qualities, it deserves a place in any basic wind farm noise document library. Of particular note — though unrelated to our purpose here — Thorne stresses that noise models cannot account for all the transient atmospheric factors that routinely increase temporary noise levels well above the average levels that the models predict reasonably well; he includes his field observations of "heightened noise zones" which match observations often made by people living around wind farms. For more on this, see the paper, or AEI's recent summary of low-frequency noise research.

Thorne’s conclusions are straightforward:

It is concluded that, based on professional opinion, serious harm to health occurs when a susceptible individual is so beset by the noise in question that he or she suffers recurring sleep disturbance, anxiety and stress. The markers for this are (a) a sound level of LAeq 32 dB outside the residence and (b) above the individual’s threshold of hearing inside the home.

It is concluded that there are sufficient credible observations, measurements and peer reviewed research papers and affidavits indicating that for 5% to 10% of the individuals living in the vicinity of a large rural wind farm its operation will cause serious harm to their health.

It is recommended that no large-scale wind farm or large turbine should be installed within 2000 metres of any dwelling or noise sensitive place unless with the approval of the landowner.

(Ed. Note: it appears that Thorne’s 32dBA threshold is chosen because as sound levels rise past this point, audibility increases in quiet rural areas, so that negative responses begin to be reported; or, to look at it from a slightly different perspective, 5-10% of those hearing noise levels above 32dB are likely to experience negative health affects (the current state-of-the-art large community response surveys, from Pedersen et al, show annoyance rates in rural areas of around 5-12% at 30-35dB, rising substantially as noise increases to 40dB and beyond). It also appears that Thorne is especially concerned about the fact that peak noise levels are often quite a bit louder than average (Leq) noise levels; he makes it clear that 40dBA (Leq) is not likely to prevent a significant number of amenity complaints and health changes, so it’s probably safe to presume that he feels that 32dBA (Leq) is a low enough average to assure that transient peaks and heightened noise zones do not cause widespread problems.)

Thorne’s conclusion, which is based on both the possible health effects on this 5-10% of neighbors, and on his studies of reduced rural amenity in a much larger proportion of residents around two existing wind farms, is shared by regulators in at least two Australian states (New South Wales and Victoria), where a 2km buffer has been proposed, with provisions to allow closer siting to willing neighbors. These much more stringent standards are designed to minimize the audibility of wind turbines in otherwise quiet rural areas, thereby largely preventing annoyance and health reactions. As Thorne
Wind farms are now causing concerns regarding noise, especially from those residents immediately near to the turbines. In this regard, the Board of Inquiry into the proposed Turitea (New Zealand) wind farm is important, as it is the outcome of nearly two years’ deliberations. The Board, in its draft decision of February 2011, says:

"Creating an environment where wind farm noise will be clearly noticeable at times of quiet background sound levels is not an option the Board condones, especially where large numbers of residents are affected. It is the Board's view that energy operations in New Zealand will have to learn not to place wind farms so close to residential communities if they are not prepared to accept constraints on noise limits under such conditions."

The decision highlights the duty of care that decision-makers, developers, acoustical consultants and regulatory authorities have to themselves and potentially affected communities.

**What Nina Pierpont really found:**

*pre-existing conditions underlie most health impacts*


Nina Pierpont, Presentation to the Hammond (NY) Wind Committee, July 2010

Even Nina Pierpont, the godmother of wind farm health concerns, does not suggest that the problems she documents in her *Wind Turbine Syndrome* book are common; she affirms that her research gives no indication of how widespread the issues are (while recognizing ways others researchers might begin to find out), and has suggested that the same 5-15% estimation we've seen from others here is a likely range.

Regular readers of AEI's wind farm noise materials may have noticed how rarely I reference Nina's work, other than defenses of the value of case series studies as a first step, in the face of unwarranted attacks on the work for not being something it isn't designed to be. This has partly been because of what a hot button her research has become (especially as others make more of her results than even she does), and partly because I've been put off by some of the over-reach in the narratives that Nina and Calvin (her husband and website editor) have themselves used, both in the book and their website. But that has not affected my ability to listen to what she and her

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12 See [http://aeinews.org/archives/298](http://aeinews.org/archives/298)

13 Such narrative over-reach includes sections of the book itself, which while calling the "low-frequency/infrasound" and vestibular effects connection a "hypothesis," read as if they are presenting proof, rather than conjecture. More egregious has been the tendency of the website to underplay the point of the book, which is about "risk factors" and instead to foster the impression that health effects are very common among the population at large. For example, the website routinely trumpets outside
Interviewees have to say about their actual experiences. The case histories in the book, and the interviews she has done with Falmouth residents, are most often compelling and sober testimonies, from grounded citizens who are not out to "get" wind power, but simply were shocked at the ways their bodies reacted to the nearby turbines. In the book, and in later case studies conducted by Pierpont, not all family members had health impacts; a key part of the initial study was aimed to begin to understand why some people reacted more dramatically than others.

In the book itself and several other documents, the actual findings of the "Wind Turbine Syndrome" research are quite simple, and perhaps even reassuring to many: As Pierpont has written:

> Not everyone near turbines has these symptoms. This does not mean people are making them up; it means there are differences among people in susceptibility. These differences are known as risk factors.

Centrally, she found that common WTS symptoms are most apt to occur in people with particular pre-existing conditions; specifically, she found "strong and statistically significant relationships" between three pre-existing conditions and the likelihood that residents would report new or aggravated health responses when turbines are operational nearby:

- Pre-existing motion sensitivity appears to be make it more likely to experience symptoms of waking in alarm and/or a sense of internal pulsations in the chest or abdomen
- People with migraine disorders report even more severe headaches than they're used to when turbines are operational
- Residents with previous inner-ear damage from noise or chemotherapy are more apt to report new onset of tinnitus.

Similar to the findings of all of these studies, chronic sleep disturbance is the most common symptom Pierpont has identified. Exhaustion, mood problems, and problems with concentration and learning are natural outcomes of poor sleep. She also often stresses that her work suggests that older people and young children are more at risk than adolescents and young to middle-aged adults. (Ed. Note: The very young and the

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14 See http://www.windturbinesyndrome.com/articles.html
16 Nina Pierpont, Presentation to the Hammond (NY) Wind Committee, July 2010
old are well known to be more sensitive to sound/noise in general, as highlighted by WHO noise guidelines)

As for how common any of this may be, her most specific statements on that question basically build from the risk factors identified above:

I estimate the proportion of the population likely to be susceptible to the symptoms of Wind Turbine Syndrome to be in the range of 20-30%, including the 12% of the American population with migraine disorder, older people with age-related problems with inner ear function, children with disabilities (especially autism spectrum disorders, of which a common attribute is auditory oversensitivity and scrambling of incoming auditory signals), and some proportion of people with noise-induced hearing loss.  

Note that this "susceptibility" estimate does not imply that all of them will fall ill; this is the population with what Pierpont suggests are the possible risk factors.

Ambrose/Rand: Acousticians experience health effects


A recent report from acousticians Stephen Ambrose and Robert Rand provides both the first case study of health effects involving trained acoustics professionals, and some affirmation of Pierpont's risk factor associated with motion sensitivity. Within a half hour of arriving at their study site (a home in Falmouth, MA), both Ambrose and Rand experienced disorientation and a difficulty in concentrating on the routine task of setting up their equipment. Both of them have a history of being prone to motion sickness. The authors note:

This research revealed that persons without a pre-existing sleep deprivation condition, not tied to the location nor invested in the property, can experience within a few minutes the same debilitating health effects described and testified to by neighbors living near the wind turbines. The debilitating health effects were judged to be visceral (proceeding from instinct, not intellect) and related to as yet unidentified discordant physical inputs or stimulation to the vestibular system.

They elaborate:

As is our custom on field surveys, we were enthusiastic and ready to begin our work. It was a beautiful spring afternoon, warm with a strong westerly wind aloft

at the wind turbine blade height. We observed that there was a soft southeasterly wind extending from ground level to tree top (about 60 feet). Within twenty minutes of being inside their house, while setting up our instruments, each of us started to lose our initial enthusiasm and actually started to feel less well. As time went on, we got progressively worse. We each experienced unpleasant symptoms of motion sickness, including ear pressure, headache, nausea, dizziness, vertigo, especially when moving about. We had a sense that the room was moving or slightly displaced from where it appeared. We experienced a loss of appetite, cloudy thinking, fatigue, some anxiety and an inexplicable desire to get outside; similar to motion sickness we have experienced on a boat or plane. We felt slightly better when we did go outside.

On the morning of the second day we left the house to go out for breakfast. About 30 minutes later and a few miles away we shared a light conversation about the night before... We talked about the difficulties we had staying motivated and the challenges we encountered performing our usual work. As time went we started to feel better, and then by the contrast in our state of mind, it hit us. We realized and understood the true extent of the debilitating symptoms expressed by neighbors; we had experienced many of them the previous evening.

As this was a short (just over two days) study, it is impossible to draw definitive conclusions from the results, though there appear to be correlations between higher winds and the appearance and disappearance of the symptoms in these two unplanned subjects. In addition, their noise measurements and analysis, following on some innovative techniques recently developed by Wade Bray, revealed the presence of rapidly pulsing low frequency sound. Using the dBG weighting, which is centered on 10-30Hz (the frequencies at the very low end of the normal "audible" range and the higher end of infrasound) along with considerable contribution from frequencies up to 70Hz and down to 2Hz, the authors report dramatic fluctuations of dBG levels, with peaks over 60dBG. Their symptoms appeared to worsen when the dBG levels varied in a regular pulse, and to be ameliorated when dBG levels varied in a more random fashion.

I will refrain here from detailed discussion of low frequency perceptual thresholds, which has been subject to some debate within the acoustics community over the past year or so. The key new factor is the contention by some acousticians that rapidly pulsing sound, with peaks much higher than the levels measured using longer time-averaging techniques, can be perceived at lower dB levels than is indicated by standard hearing threshold curves, which are generated using simple, pure-tone sounds. For much more discussion of these questions, including Wade Bray’s rapid timescale measurement techniques, see AEI’s lay summary of recent low-frequency noise research.18

18 http://aeinews.org/archives/1711
Ambrose and Rand conclude their paper with the observation that the ramping-up onset of symptoms that they experienced, along with the more gradual dissipation of the symptoms after they left the site, both mimic a classic dose-response relationship; they suggest that the peak sound pressure events, which occurred on average once every 1.4 seconds, can be considered the recurring "dose" that triggered their "response." They mention a standard dose-response equation for considering cumulative effects that could be used to explore this idea further.

You may have noticed that this paper stands apart from the others reviewed here, in that it involves reported health effects that are presumably NOT stress-mediated or related to sleep disruption. That is, Ambrose and Rand may indeed have experienced an effect triggered directly by the noise exposure itself. They cannot, and do not, claim to have proven that in this short study, but their experience is an important reality check that even if the vast majority of reported health problems may be indirect, stress-mediated effects, it is also likely that some people are being directly affected. Whether these people have a pre-existing condition (such as motion sensitivity), or are part of the most perceptive fringe of the normal auditory perception curve, so that they actually do hear or sense some of the low-frequency sounds more readily than most, we need to be careful not to lump all reports into any easy-to-accept framework. This applies equally to those who seem to imply that all health issues are "merely" psychological, as well as to those who might fear that everyone near turbines will get vertigo. While it appears to me that many, likely most, of the health effects being reported are stress-related, I do not for a minute presume that they all are.

We might also bear in mind that in addition to the sound waves that are the focus of virtually all discussion of community responses and health effects, turbines also create air pressure vortices that travel in the downwind direction (turbine spacing is carefully designed to avoid having downwind turbines impacted by these significant pressure differentials). Some of the reported turbine-related symptoms, including pressure in ears or chest, and a general sense of discomfort, could be related to these pressure waves. The only community response researcher to consider them that I am aware of is Bob Thorne, who feels these vortices may contribute to his observed "heightened noise zones."

A few more things to keep in mind

Much Ado About Nothing?

Some observers suggest that if actual, acute symptoms appear in as few as 5-10% of the people living near wind farms, then we may simply be hearing from people who represent the normal baseline rates for conditions like headaches, dizziness, tinnitus, and insomnia. This is an important question to keep in mind as we move forward and
have larger studies to draw conclusions from.

However, the papers considered here are assessing changes in health: typically, subjects report symptoms appearing, or increasing, after wind farms began operation, and decreasing when turbines are not operating or the subjects are away from the area. The fact that most of these studies use self-reporting of current health conditions, and retrospective reporting of earlier health status, is considered by some to be a weakness; people’s memories can be distorted by recent upsets at the wind farm. Some of the studies now beginning will be attempting to redress this by doing health surveys before wind farms begin operation, and following up later with the same subjects.

But again, for now, we start where we are, and these initial studies, while perhaps not ideal, can be assessed on their merits. The authors generally are quite forthright about their methods, making it relatively easy to see both the strengths and shortcomings of the data we currently have to work with.

Other surveys old and new

Scandinavia
As further evidence of the trend suggesting that health effects may occur in just 5-15% of the nearby population, we can also look to the three seminal Scandinavian surveys by Pedersen et al. These are much larger than the recent papers considered here, ranging from 350 to 750 people each. They were primarily assessing annoyance levels, but also asked some questions about health and sleep.19

The studies found that in rural areas, annoyance ranged from 5-12% at 30-35dB, 15-20% at 35-40dB, and 25-45% at 40-45dB. These annoyance rates dropped by half when inside homes, decreasing the stress-related risk group dramatically. And, relevant to our inquiry here, less than a third of those reporting outdoor annoyance reported any physical/health effects at all...bringing us right into the 5-10% range for people hearing 35-45dB, which generally coincides with living between a third of a mile and a mile of modern wind farms. For more on these studies, see AEI’s presentation to the webinar presented by the New England Wind Energy Education Project in the summer of 201020.

19 In considering the results of these surveys, it is important to keep in mind that the first two focused on sites that generally had only one turbine nearby, most of which were relatively small by today’s standards (hundreds of kW); only the third centered predominantly on wind farms, and included some turbines up to 3MW. In addition, about half the respondents lived in “suburban” areas in which existing noise levels and noise tolerance were notably higher than in most rural areas. Still, the detail collected in these studies provides a valuable grounding for discussions that are more often based on vague impressions of annoyance rates.

The Scandinavian data has also provided raw data that has been analyzed in two recent papers. Both of these focused on a statistical analysis of many factors, rather than on rates of any specific factor; both suggest that annoyance is a better predictor of negative effects than are noise levels. Eja Pedersen found that several measures of stress were associated with annoyance due to wind farm noise in all three studies, specifically, feeling “tense” and “irritable.” Headache was associated with annoyance in two of the studies, and undue tiredness in one. Pedersen points out, however, that we should not assume that this is clear evidence of even an indirect causal relationship between turbine noise and stress, mediated by annoyance; she points out that people already under stress may be more apt to attend to turbine noise as an additional contributor to their pre-existing discomforts.

Roel Bakker is lead author of a forthcoming paper that was summarized in the 2011 book Wind Turbine Noise, and is just about to be published in the journal Science of the Total Environment. This analysis looked at sleep disturbance and psychological distress (as measured by a 12-item questionnaire). Here, too, the effects were related to annoyance levels, rather than noise levels. Perhaps most importantly, sleep disruption and psychological distress was far more significantly related to annoyance among those living in quiet rural areas than in more built up areas, where the relationships were weak or non-existent.

Australia
The most recent survey to address annoyance and health effects comes from South Australia. It’s part of a Masters dissertation by a Zhenhua Wang, student at the University of Adelaide; a few-page summary of the results was publicly released in early 2012, with the full dissertation to follow. There are several wind farms in Australia and New Zealand where complaints are numerous at distances much greater than those we generally hear about in the US, Canada, and Europe – many complaints beyond 2km (1.25mi), and quite a few at 3-4km, with a few scattered complaints out as far as 10km (over 6 miles). I’m not sure whether this reflects wind farms being built in areas that are otherwise particularly pristine and quiet, or a different cultural attitude toward outside noise Down Under. It appears that most of these wind farms are on ridges, with homes below; some have suggested that the landscape in some of these areas may funnel the sound further than normal, as well; such topographic factors could be responsible for the higher annoyance rates.

This new survey was returned by 64% of the residents living within 5km (3.1mi) of the

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Waterloo Wind Farm, and in keeping with the apparently greater annoyance levels Down Under, its results are striking: 70% of respondents said they’d been negatively affected by noise, including 54% who rated themselves moderately or very affected. Of those affected, 38% reported health effects (i.e., 26.6% of the total number of respondents); i.e. about half of those moderately or very affected by noise. Even if the entire 36% of local residents who did not respond to the survey were totally unaffected, those reporting effects in the survey represent 32% of all residents within 5km being moderately or very affected by the noise, with 18% reporting health effects. Huh.

For reference on the other end of the spectrum, the Netherlands surveys suggest that just 8% of those within 2.5 km (1.5mi) of turbines are “rather” or “very” annoyed with wind farm noise. This has become a commonly referenced “general” annoyance rate; though the Pedersen studies (which this one builds on) also tend to show substantially higher annoyance in rural areas than in suburban ones (these overall averages include about half suburban respondents; see also footnote 20).

van den Berg “Effects of sound on people” chapter
Likewise, Frits van den Berg’s chapter in *Wind Turbine Noise*\(^{25}\), which was also presented as a paper\(^{26}\) at the Wind Turbine Noise 2011 meeting in Rome, provides a detailed overview of earlier and more recent studies of looking at annoyance, sleep disruption, and health effects around wind farms (it includes the Shepherd and Hanning papers summarized above). Rather than repeat much of this here, I encourage you to read the chapter or paper; the latter will be available on AEI’s wind farm noise resource page\(^{27}\). I will note that van den Berg manages to summarize the essence of each paper’s findings far more concisely than I have!

But for now, our focus is health effects, rather than annoyance; look to the AEI Wind Farm Noise 2012 annual report (forthcoming, summer 2012) for more comprehensive summaries of annoyance rate surveys, including summations in the van den Berg chapter and paper.

**Meet the New Stress, Same as the Old Stress**

Geoff Leventhall, a British acoustician who’s become one of the most widely-cited critics of the idea that infrasound and low-frequency sound from wind farms is strong enough to cause health problems, has also been quick to acknowledge that noise-related stress is likely to be a significant factor in community responses to wind farms.

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\(^{27}\) See [http://www.acousticecology.org/wind/](http://www.acousticecology.org/wind/)
In a detailed article in Engineering and Technology Magazine\textsuperscript{28}, published in 2009 just prior to the publication of Nina Pierpont’s Wind Turbine Syndrome book, Leventhal opined, “The wind developers are going to rubbish her book, and quite rightly so, but what must be accepted – and developers don’t want to accept this – is that yes, people are disturbed. If people are consistently disturbed, and their sleep is consistently disturbed, then they will develop some very ‘unclever’ stress symptoms. That will lead to stress-related illness.”

Elaborating in a white paper he wrote entitled, “Wind Turbine Syndrome – An appraisal,” Dr Leventhall critiques Pierpont’s approach and conclusions, but says of the identified stress symptoms:

“I am happy to accept these symptoms, as they have been known to me for many years as the symptoms of extreme psychological stress from environmental noise, particularly low frequency noise. The symptoms have been published before…The so called “wind turbine syndrome” cannot be distinguished from the stress effects from (any) persistent and unwanted sound. These are experienced by a small proportion of the population and have been well known for some time.”

In other words, Leventhall believes that the stress-mediated health effects we’re hearing about around wind farms are not due to any special qualities of turbine noise, but rather simply to people dealing with unwanted turbine noise in their environment and homes.

\textbf{Doctors Down Under urging people to move from homes?}

While most of my energy and attention has been focused on community responses in the U.S., along with following the publications in journals and conferences and press reports worldwide, I should mention at least in passing that I’ve come across several news reports from Australia that mention doctors urging patients move from their homes after they experienced negative health effects. This is not something I’ve found any solid studies on, but it has stood out in my ongoing monitoring of wind farm siting; I’m not aware of other regions in which doctors have made such recommendations (update: I just came across reference to an initiative in Quebec that was signed on to by 40 physicians\textsuperscript{29}). Two General Practitioners are seen in a short video by the Waubra Foundation\textsuperscript{30} on health issues near wind farms, as are two apparently hearty men who

\textsuperscript{28} See \url{http://eandt.theiet.org/magazine/2009/17/quiet-revolution.cfm}

\textsuperscript{29} See \url{http://terrecitoyenne.qc.ca/?p=325}

\textsuperscript{30} The Waubra Foundation is closely associated with Landscape Guardians, which is widely seen as a climate-change denialism organization, with significant ties to the oil and gas industry. Dr. Sarah Laurie, who spearheads their health-related efforts, affirms in personal communication that some board members have a broader agenda, but says she was strongly pro-wind until 2010 when she began hearing from GPs about patients with health issues, that her sole concern is health of neighbors, and that board members “respect each others’ differences.” As suggested above, and as studied by Robert Thorne, reports of both quality of life impacts and health effects are more commonly reported at relatively large distances in Australia and New Zealand, with many complaints at 2km, and quite a few out to 3-4km. Waubra
had to move from their homes after wind farms became operational nearby; the video can be viewed at http://www.youtube.com/watch?v=IEh3sooKU8A

The Waubra video is actually a perfect example of the difficulty we confront in considering the health effects issue. The testimonials are heartfelt and compelling; as I mentioned, I wouldn’t wish this on any of the folks living in my valley. Yet also, the end of the video highlights that after years of working on this issue, the Waubra Foundation has identified 90 people in four southeastern Australia states who are struggling with health effects (and that “over 20 families” have abandoned their homes across the country). I think it’s safe to say that those 90 people once again represent 10% or less of the total population living within earshot of the thirteen wind farms they list as locations of issues, and certainly of the thirty wind farms operating in the four states (though it would be interesting to know if the bulk of those 90 families live around just a few of the thirteen).

So again, I find myself turning to the Thorne and Shepherd studies from Australia and New Zealand that focus on the much higher rates of severe annoyance and impacts on rural quality of life and amenity. And again, I find myself wondering how we can begin to discern the differences between the few wind farms triggering widespread noise issues – the 13 in this region – and the 17 others where even Waubra hasn’t heard of any problems. In the US, it’s likely that the proportion of “problem wind farms” is even lower, since most of our installed capacity is still in the wide-open spaces of the west. What are the indicators that might clue us in to where we need to be more sensitive to more significant community reactions to wind farm noise? Looking at typical setbacks, population density, or community make-up of places with lots of complaints, as compared to places with few or no noise issues, might help us to move forward in a way that both protects rural quality of life and maintains our momentum toward increased wind energy generation.

Conclusions

So, what have we found? Remembering that to get a full picture of health impacts research, you should also be familiar with some of the larger literature reviews published by government entities and industry trade associations, this overview of direct research in communities where health impacts are being reported suggests a few things:

- First, health effects may be more common in a relatively small subset of the population that have pre-existing conditions that could make them more

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Foundation appears to take an especially hard line, urging setbacks of 10km, since that’s the greatest distance they’ve heard of problems. This extreme position raises questions about whether Waubra’s goal is simply health, or effectively stopping wind development.

31 See http://ramblingsdc.net/Australia/WindPower.html
susceptible to being affected by noise, perhaps especially low-frequency noise.

- Second, those who are noise sensitive (roughly 20% of the population, especially in rural areas) are more likely to be annoyed by sound in general, and wind turbines in particular. This annoyance, and/or a related increase in sleep disruption caused by turbine noise, can lead to stress-related disease symptoms.

- Third, among the rest of the population, especially among the 30-50% who are neither especially noise sensitive nor extremely noise tolerant, those who are annoyed by wind turbine noise (due to being woken, or simply because they resent the new noise intrusion in their rural landscape) may also develop some stress-related responses. This group is also more likely to simply resent the new noise intrusion in their community, even if they are not experiencing any health effects.

The evidence currently available from community surveys suggests that while in some types of communities, a quarter to half of those close enough to turbines to hear them at 40dB or more may find them particularly annoying and unwelcome, a much smaller proportion of the nearby population is actually reporting negative health effects. (For more on rural annoyance rates, see AEI's Wind Turbine Noise 2011 report32, and the upcoming 2012 version, which will summarize all known community response surveys.)

If this inquiry is being undertaken in order to inform decisions about siting standards, then it will always be important to look at both annoyance rates and health impact rates among those closest to the turbines. It tells us nothing to hear that, say, 95% of community members feel fine about a wind farm, when most in the community live miles away from turbines. Analysis of annoyance (as a possible precursor to stress-related health effects) and of reported health changes needs to consider rates within a half mile or kilometer, as well as rates between a half mile and mile or 1-2km, in order to provide useful information for deciding what setback between wind turbines and neighbors is appropriate.

But however we analyze these questions, we will be left with a social choice. Some people will be negatively affected by almost any new noise source or change in the local landscape. A tiny proportion of the population could well experience authentic health effects from turbine sounds that are over a mile away and just barely audible; at the other end of the spectrum, in some types of communities, a large proportion of those hearing nearby turbines regularly may hate the new noise and become quite worked up over it.

Communities will need to decide what level of impact is acceptable. Some may decide that they don’t want to subject any neighbors to even occasionally audible wind turbine noise (some such communities have adopted large setbacks, up to 2km or even 2 miles). Others might feel that contributing to a national push toward renewable energy

32 See aeinews.org/archives/1393
is worth the trade-off of knowing that 5-10% of those within a mile may have more headaches, or sleep disruption that leads to poor concentration and work performance (such communities, aiming for a "happy medium," have chosen setbacks of a mile, or sometimes 3000 feet). I suspect that few would welcome the thought of half of the nearby neighbors feeling that their homes were far less welcoming and relaxing than they used to be (which has been the experience in some of the communities that adopted setbacks of a third of a mile or less). But the question will always be there: where do we want to draw the line?

I would be remiss if I didn't also stress here that the annoyance rates and health effects rates reported in communities with strong negative reactions to wind farms are not representative of all wind farms. By contrast, it's notable that in ranching country, where most residents are leaseholders and many live within a quarter to half mile of turbines, health and annoyance complaints are close to non-existent; some have suggested that this is evidence of an antidote to wind turbine syndrome: earning some money from the turbines. More to the point, though, the equanimity with which turbine sound is accommodated in ranching communities again suggests that those who see turbines as a welcome addition to their community are far less likely to be annoyed, and thus to trigger indirect stress-related effects. Equally important to consider, ranchers who work around heavy equipment on a daily basis are also likely to be less noise sensitive than average, whereas people who live in the country for peace and quiet and solitude are likely more noise-sensitive than average. And, there are some indications that in flat ranching country, turbine noise levels may be more steady, less prone to atmospheric conditions that make turbines unpredictably louder or more intrusive. When considering the dozens of wind farms in the midwest and west where noise complaints are minimal or non-existent, it remains true that the vast majority of U.S. wind turbines are built either far from homes or in areas where there is widespread tolerance for the noise they add to the local soundscape.

Here we find ourselves once again at the crux point that needs to be factored in to wind farm siting standards: not every community will respond similarly to the new noise that wind farms undeniably add to the local soundscape. Siting standards need to be flexible enough to recognize these differences; one setback, or one dB limit, clearly does not fit all. Let's not forget, either, that a large proportion of US wind farms are still being built in the vast expanses of the Great Plains and intermountain west. Many of these, likely still representing the majority of US wind generating capacity, are miles from any home. This is clearly the best place for them to be, as recently stressed by wind historian Robert Righter.

One of the purposes of this summary is to ease the fear that health impacts will be widespread around any new wind farm. But I certainly am not implying that the 10%, or 5%, who are suffering, should be disregarded. To make it personal, if faced with

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possibility that two of the forty families in my valley would likely experience substantial health effects (whether because they were prone to motion sickness or just hated the sound enough to rile them up) from a wind farm on the ridge that sits – as indeed one does – a third to half mile from our homes, I would likely not want to trade their well-being for a few megawatts of green energy, despite my commitment to a renewable future.

Of course, the simple solution for communities would be to keep turbines farther away; opinions differ, but somewhere in the half mile to mile or so range is likely to greatly reduce audibility, annoyance, stress, and stimulation of pre-existing conditions. Some suggest 1.25 miles, or 2km, in order to be more sure that peak sound levels, triggered in worst-case atmospheric conditions, remain barely audible.

It’s not my intention or my place to pick a solution to this quandary, especially given the clear differences between communities as to what is likely to be the best choice. My goal is simply to help clarify what has been found by those looking most closely at these questions in communities where it has become an issue.