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Distributed Wind Market Applications

T. Forsyth and I. Baring-Gould

Technical Report
NREL/TP-500-39851
November 2007

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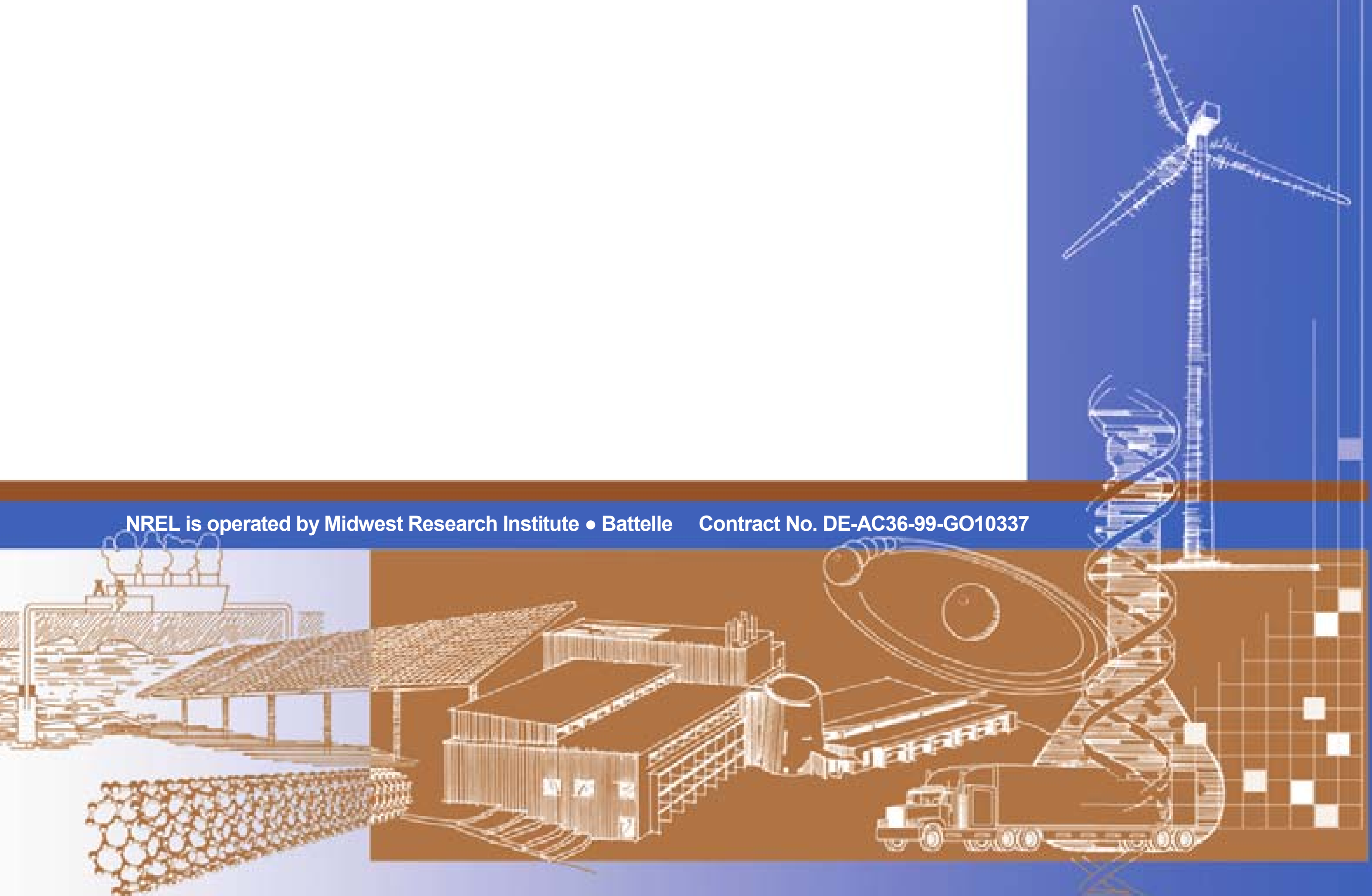

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Chapter 1. Executive Summary

The Executive Summary will discuss the distributed wind market potential from a domestic and international perspective with greater confidence in the number of units installed for the domestic market. The market potential discussion will be followed by a summary of information provided in each chapter, including regions of market interest for both the domestic and international market, key market and technical barriers, time-critical issues for market development, technology adoption timeframe, and recommended areas of concentration.

Distributed wind energy systems provide clean, renewable power for on-site use and help relieve pressure on the power grid while providing jobs and contributing to energy security for homes, farms, schools, factories, private and public facilities, distribution utilities, and remote locations. America pioneered small wind technology in the 1920s, and it is the only renewable energy industry segment that the United States still dominates in technology, manufacturing, and world market share.

The series of analyses covered by this report were conducted to assess some of the most likely ways that advanced wind turbines could be utilized as an option to large, central station power systems. Each chapter represents a final report on specific market segments written by leading experts in each sector. As such, this document does not speak with one voice but rather a compendium of different perspectives from the U.S. distributed wind field.

For this analysis, the U.S. Department of Energy (DOE) Wind and Hydropower Technologies Program and the National Renewable Energy Laboratory's (NREL's) National Wind Technology Center (NWTC) defined distributed applications as wind turbines of any size that are installed remotely or connected to the grid but at a distribution-level voltage.

Distributed wind systems generally provide electricity on the retail side of the electric meter without need of transmission lines, offering a strong, low-cost alternative to photovoltaic (PV) power systems that are increasingly used in urban communities. Small-scale distributed wind turbines also produce electricity at lower wind speeds than large, utility-grade turbines, greatly expanding the availability of land with a harvestable wind resource. These factors, combined with increasingly high retail energy prices and demand for on-site power generation, have resulted in strong market pull for the distributed wind industry, which is poised for rapid market expansion.

Seven market segments were identified for initial investigation. These market segments, documented in this report, include small-scale remote or off-grid power; residential or on-grid power; farm, business, and small industrial wind applications; and "small-scale" community wind. A summary of the market for remote wind-diesel applications is also included in this summary, although a full report was never completed. The remaining two market segments, water pumping for large-scale irrigation and water desalination, are currently being assessed as part of other program activities and are not included at this time. While some of these market applications have existed for some time, others are just beginning to emerge as part of distributed wind power. A short introduction to each of these assessments is provided below.

- **Small-scale remote or off-grid power (residential or village):** Supplying energy to rural, off-grid applications in the developed and developing world. This market encompasses either individual homes or small community applications and is usually integrated with other components, such as storage and power converters and PV systems.

- **Residential or on-grid power:** Small wind turbines used in residential settings that are installed on the house side of the home electrical meter using net metering to supply energy directly to the home. Excess energy is sold back to the supplying utility.
- **Farm, business, and small industrial wind applications:** Supplying farms, businesses, and small industrial applications with low-cost electric power. The loads represented by this sector are larger than most residential applications, and payback must be equivalent to similar expenditures (4 to 7 years). In many cases, businesses are not eligible for net metering applications; thus the commercial loads must use most of the power from the turbine.
- **"Small-scale" community wind:** Using wind turbines to power large, grid-connected loads such as schools, public lighting, government buildings, and municipal services. Turbines can range in size from very small, several-kW turbines to small clusters of utility-scale multi-megawatt turbines. The key, defining factor is that these systems are owned by or for the community.
- **Wind/diesel power systems:** Providing power to rural communities currently supplied through diesel technology in an effort to reduce the amount of diesel fuel consumed. The rising cost of diesel fuel and increased environmental concerns regarding diesel fuel, transportation, and storage have made project economics more sensible.
- **Irrigation water pumping:** Using wind turbines to supply energy for agricultural applications. Current applications are powered by grid electricity, diesel, gasoline, propane, and particularly natural gas. Wind or hybrid systems allow farmers to offset use of high-priced fossil fuels.
- **Water desalination:** Using wind energy to directly or indirectly desalinate sea or brackish water using reverse osmosis, electrodialysis, or other desalination technologies. The economic and technical performance of wind-powered desalination depends on the configuration and placement of wind resource with regard to the impaired water and existing energy resources. Water desalination works well with the wind resource found in coastal or desert environments.

In these analyses, the DOE Wind and Hydropower Technology Program is assessing two new segments that have not historically been classified under the distributed wind banner: farm/ commercial and the "small-scale" community wind market. Both of these markets struggle to find commercial turbines to meet their needs, demonstrating opportunity for the development of U.S. turbines.

These two emergent market segments combined with the existing small wind market result in three conglomerated turbine capacities. The first is the residential and smaller business sector at roughly 0 kilowatt (kW) to 100 kW capacity. The second sector is the farm/commercial market sector that includes farm, industrial, and wind/diesel from 100 kW to 500 kW. The last market sector for distributed wind is the "small-scale" community wind sector, which has been estimated to be 500 kW to 1 megawatt (MW). Although not covered specifically within this analysis, there is also likely a need to develop methodologies to lower the cost of power from large, multi-megawatt turbines that are installed in distributed community applications. Further hardware development in all of these sectors would help meet the desires of Americans to provide their own electricity, whether for a residence, farm, or business in rural America where zoning challenges are minimized.

This study identifies and describes how the distributed wind industry can overcome long-standing barriers and play an important role (in the United States and the international arena) in supplying power near the point of end use or behind the meter.

I. Summary of Market Potential

Authors were asked to conservatively assess the potential market size for the five market segments in terms of the number of units expected to be installed in 5-year increments through 2020. Additionally, authors were asked to recommend the expected turbine size that would be most applicable to meet the proposed markets. Figure E.1 shows an overview of the different market segments, the kilowatt capacity of the turbines for each market segment, and the existing turbines available within each distributed market segment.

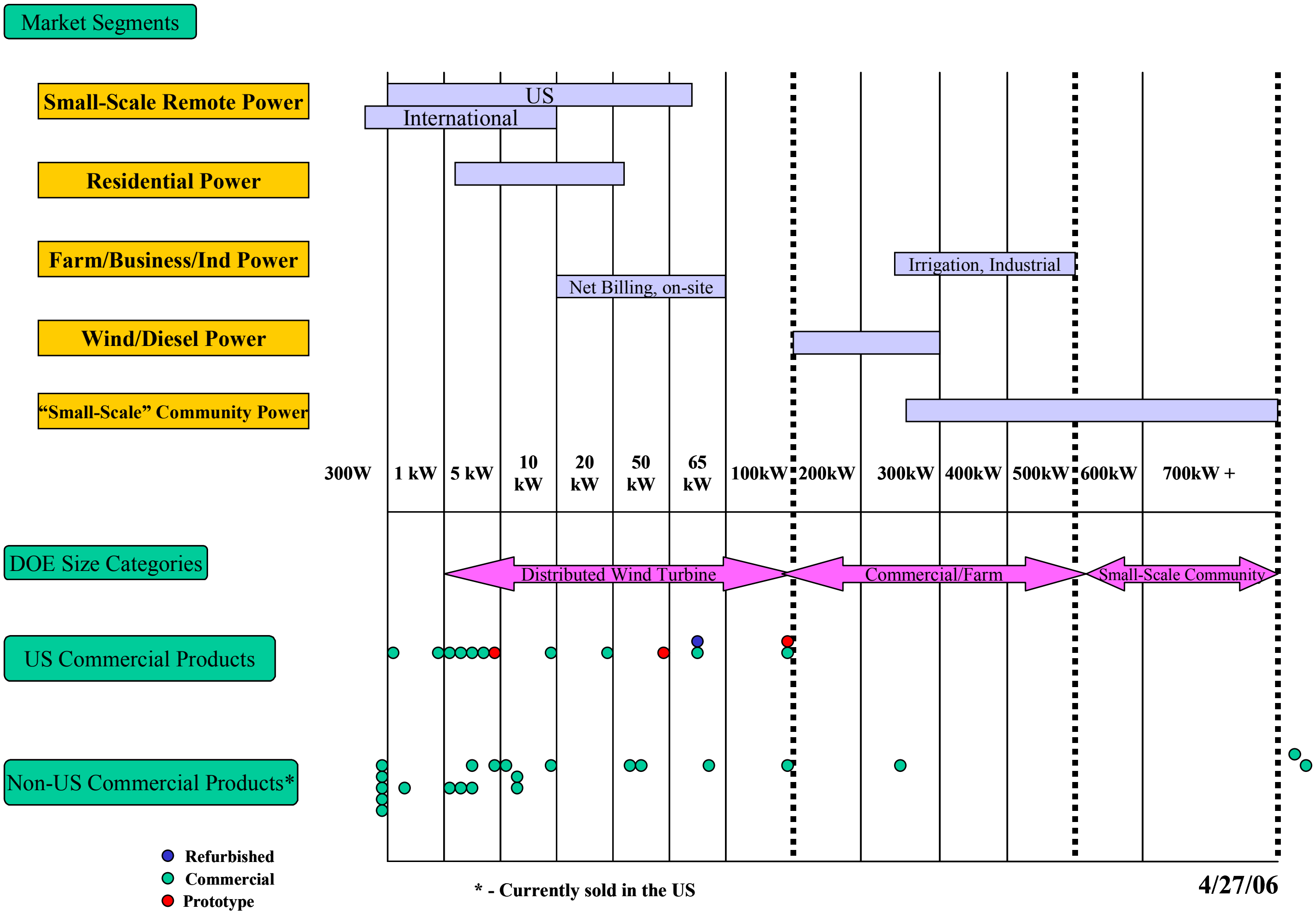

Figure E.1. Overview of market segments and commercial wind turbines

From a manufacturing perspective, the strongest market segment is turbines smaller than 10 kW in size, with 20 domestic or internationally manufactured turbines to choose from. The number of turbine choices between 20 kW and 100 kW is quite limited, and turbines between 100 kW to 1 MW are practically nonexistent.

It should be noted that the re-powering of wind farms in Europe and the United States has made available re-manufactured turbines that are being used to supply many current distributed applications. Although generally inexpensive compared to existing new turbine models, most of these are based on significantly outdated technology. Turbine design, reliability, and energy capture have been improved over the intervening time, resulting in current projects with reduced energy capture than would be expected from projects with turbines incorporating current technology and design practices.

II. Summary of Domestic Markets for Distributed Wind Technologies

Teams of technical experts with knowledge of their market segments provided the market projections summarized below. Each of these experts was asked to provide a conservative estimate to ensure the report validity in retrospect. It should be noted that NREL did not attempt to validate the expected market data from these market summary reports.

The benefits from distributed wind projects are minimized when quantified using total megawatts of installed capacity, especially for the smaller distributed turbines. However, the use of a simple number of units produced reduces the visibility of the mid-size turbines used in the farm/commercial, wind/diesel, and "small-scale" community wind segments. For this reason, the summary results are presented in terms of both the number of units and total installed capacity. It should be noted that the estimates of the number of units and thus the total installed megawatts are very rough and should only be considered in relative terms. The DOE Wind and Hydropower Program is in the process of conducting more detailed market assessments for the segments that show the most promise.

Table E.1 summarizes the cumulative number of expected domestic turbine sales over the five market segments. Note that the table also presents the turbine size for each market segment. Currently the largest sector in terms of the number of installed units is the small-scale remote or off-grid power market segment. The majority of these off-grid units have a lower capacity, with a typical turbine size in the range of a few kilowatts or less. All market segments combine to a potential total of 680,000 installed units by the end of 2020.

There are several market niches within the domestic off-grid segment, specifically in Alaska and Native American communities. An example is the Navajo Nation—approximately one-third of the 250,000 people on the reservation lack electricity.

The estimated market growth across 15 years to 2020 is 11% per year for the small-scale remote or off-grid market segment; 22% per year for the residential or on-grid segment; 48% across the farm, business, and small industrial segment; 26% per year for the wind/diesel segment; and 23% per year for the "small-scale" community segment.

Table E.1. Market Projections of Domestically Installed Units

	Off-grid	Residential	Farm, Industrial & Business	" Small Scale" Community	Wind/Diesel
Turbine size	300 W - 60 kW	1 - 25 kW	Large: 250-400 kW Net Bill: 10-60kW	100 - 1000 kW	100 - 300 kW
2005	125,700	1,800	20	150	65
2010	219,450	6,250	1,270	360	565
2015	455,450	14,000	4,270	1,010	1,565
2020	631,450	36,500	7,395	3,235	2,190

These data are shown graphically in Figure E.2. The off-grid market segment is excluded due to its dominance of the graph, which reduces the reader's ability to see the effects of other market segments. With the off-grid data removed, the residential market segments show that on a unit-production basis, residential leads the distributed market segment. From a manufacturing standpoint, in which high volume can reduce cost, the high number of units should be attractive.

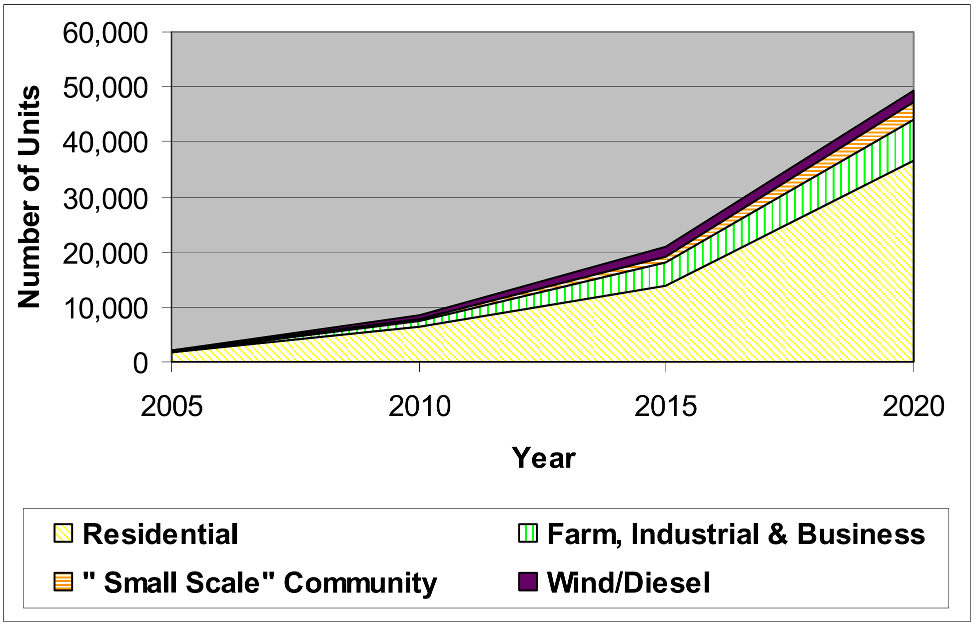

Figure E-2. Market projections using number of units installed in the United States

Table E.2 and Figure E.3 show these same data based on the expected cumulative installed domestic capacity of the turbines in these market segments. This figure provides a different view of the markets in that although fewer turbines will be installed in either the farm or community wind markets, their capacity (in terms of rated kilowatts) is much larger than the cumulative sum of the smaller residential and off-grid market segments.

It should also be understood that the "small-scale" community wind market was arbitrarily capped at a maximum turbine size of 1 MW. It is quite clear that a vibrant community wind market exists that uses turbines greater than 1 MW in size, with multiple installations reaching up to 20-MW sites. Further DOE market assessment activities will likely extend this size range of turbines to be considered to include turbines up to 1.5 MW in size.

Table E.2. Projected Domestic Installed Capacity (MW) by Sector through 2020

Year	Off-grid	Residential	Farm, Industrial & Business	" Small Scale" Community	Wind/Diesel
Turbine size	1 kW	12.5 kW	Large: 325 kW Net Bill: 30 kW	750 kW	200 kW
	Cumulative installed capacity (MW)				
2005	126	23	4	113	13
2010	219	78	260	270	113
2015	455	175	875	758	313
2020	631	456	1,516	2,426	438

Table E.2 shows the market segment with the largest installed capacity as “small-scale” community wind, followed by the farm, business, and small industrial market segment. Note that the farm, business, and small industrial market segment shares the same size turbine capacity as the wind/diesel market segment. Technological solutions would likely address both market segments. And combining the total projected market capacity of the farm, business, and small industrial segments results in approximately the same total as the “small-scale” community segment.

To date, approximately 270 MW of community wind projects are installed in the United States, representing $250 million in investment in rural communities. Of those, 110 MW would meet the “small-scale” community wind definition of 1 MW or less. At least 440 MW of new community-owned wind projects are in the advanced planning states in the United States; however, project developers expect to utilize turbines larger than 1 MW for nearly all of this future capacity (due to their better economics and availability).

Figure E.3 shows the total of all five market segments, resulting in 5.4 gigawatts (GW) of projected capacity by the end of 2020.

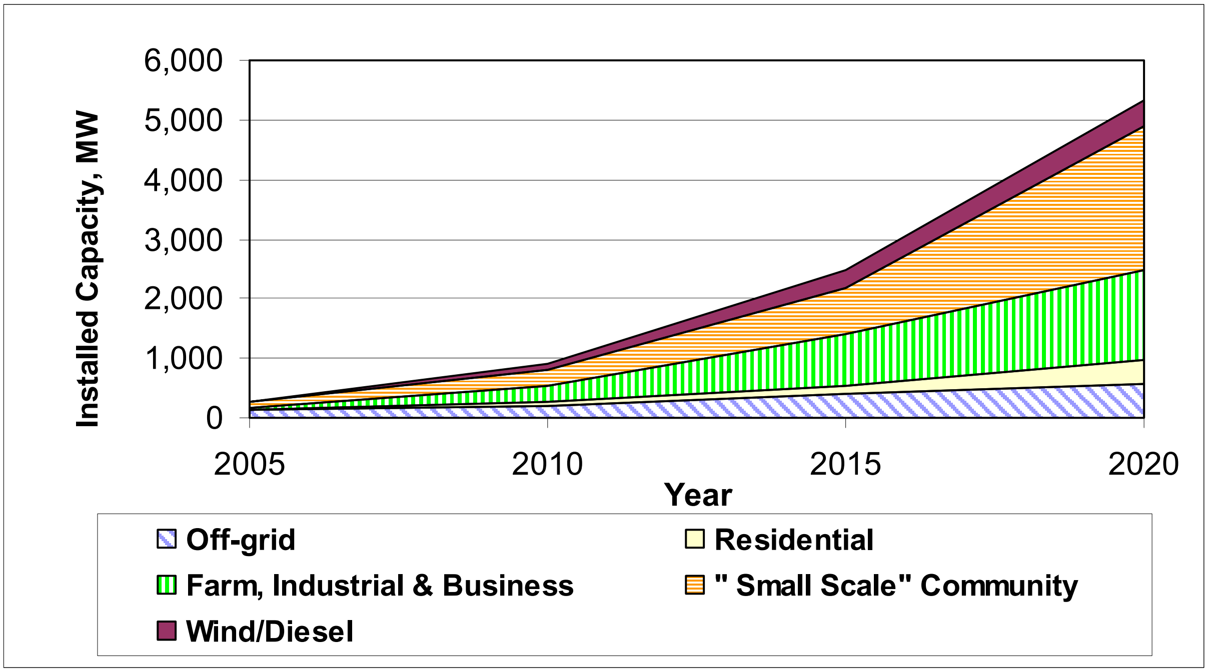

Figure E.3. Incremental domestic installed capacity by sector through 2020

A number of capacities were presented for each market segment, as shown in Tables E.1 and E.2. Each market segment chapter provides a range of market potential for 2010, 2015, and 2020 (found in each chapter's Summary Information Table). Based on those data, we evaluated the total market potential assuming *minimum* values of capacity and market potential, *likely* values of capacity and market potential (as shown in the above tables and figures), and the *maximum* value of capacity and market potential. Figure E.4 shows the bars, which represent the *likely* value of installed capacity in megawatts. The lines for each bar show the minimum and maximum for future years.

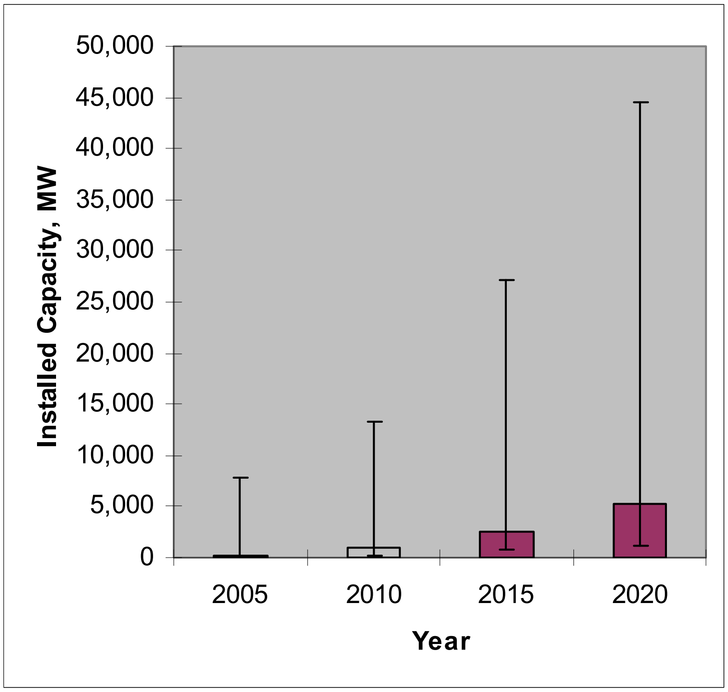

Figure E.4. Potential capacity variation for all domestic market segments

A large variation exists between the minimum and maximum value for the year 2020. This is due to several factors, including uncertainty about the optimum turbine size for each market segment, uncertainty in the removal of market barriers that are needed to propel the market forward, and uncertainty in the technology cost and the competitiveness of new products in the marketplace.

III. Summary of International Market for Distributed Wind Technologies

Although not the focus of this work, each of the market segment authors was asked to estimate the international market for distributed applications. It should be noted that international market information is notoriously difficult to measure, and the scope of these documents only allowed a cursory investigation.

The international market is of special interest because unlike the market for large wind turbines, U.S. small wind turbine manufactures currently hold a dominant market share. U.S. manufacturers of small and distributed wind turbines represent the most diverse and internationally recognized industry in this technology area.

Table E.3 provides a summary of the international market potential as identified in the market segment reports. Note that the table also presents the turbine size for each market segment. The largest sector in terms of installed megawatts is the community wind market segment. Historically, the European Union has been the leader in community wind, with about 80% of all the installed wind turbines considered community applications. This market is currently estimated to be 8.2 GW of installed units under 1 MW.

In comparison to the domestic market, three international market items stand out. First, "small-scale" community wind becomes a more dominant player in the world wind market, replacing the substantially increased off-grid market. Second, wind/diesel applications become a stronger market element. Finally, residential wind diminishes in importance. The off-grid market, although not as large as "small-scale" community wind, still offers a huge potential. Although most of this market potential is outside the developed world, China has a current installed capacity of 170,000 mini wind turbines (60 to 200 W).

Table E.3. Cumulative Installed International Capacity in MW by Sector through 2020

Year	Off-grid	Residential	Farm/Industrial/Bus	Community	Wind/Diesel
Turbine size	5 kW	12.5 kW	Large: 325 kW Net Bill: 30 kW	750 kW	200 kW
2005	2,361	14	0	8,250	10
2010	3,118	36	154	17,250	310
2015	6,275	99	410	40,125	1,810
2020	10,693	286	666	95,625	3,810

Table E.3 summarizes the cumulative capacity of expected international turbine sales over the five market segments. Note that the table also presents the turbine size for each market segment while Figure E.5 shows the expected number of installed units of each market segment, excluding the off-grid or small-system segment, which is expected to grow at more than 150,000 units per year in 2020, and distorts the impact of the other market segments. The largest sector in terms of the number of installed units is the off-grid or small-scale remote power market segment; however, the majority of these off-grid units will have a lower capacity, with a typical turbine size in the range of a few kilowatts or less. All market segments combine to a potential total of almost 1,500,000 installed units by the end of 2020. The total year-over-year international market grown is estimated at about 20%. It should be noted that due to the limited data available to support these estimates, the range between *minimum, likely,* and *maximum* values of capacity is quite large (Figure E.6).

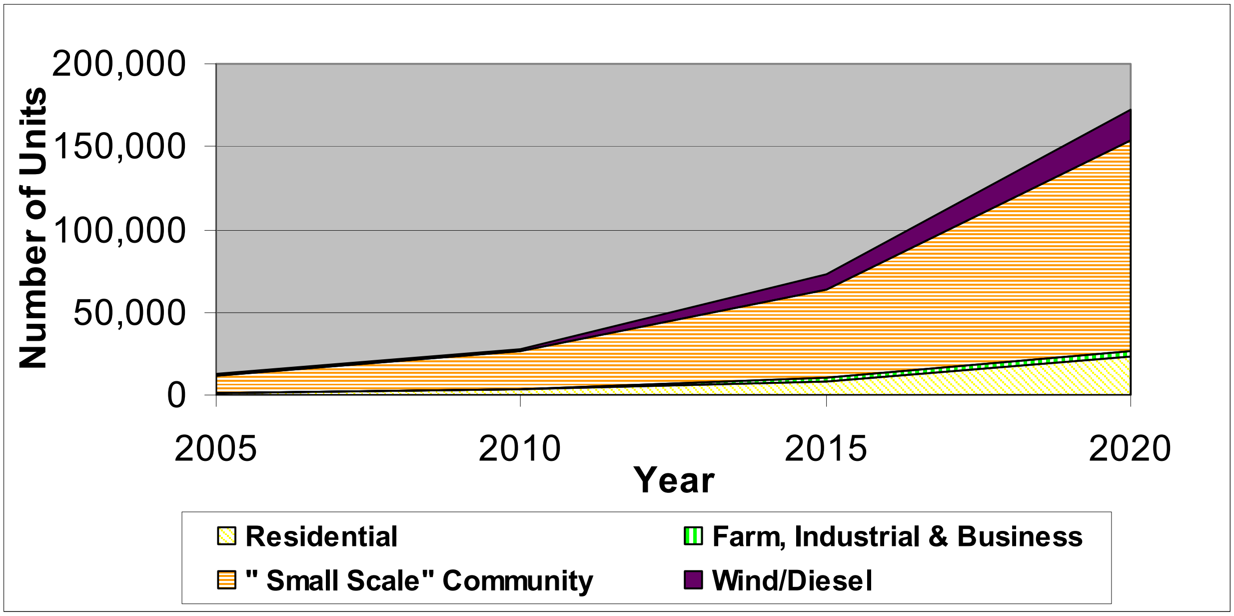

Figure E.5. Incremental international installed capacity by sector through 2020 without data for off-grid or small-system segment (which is too large to show graphically)

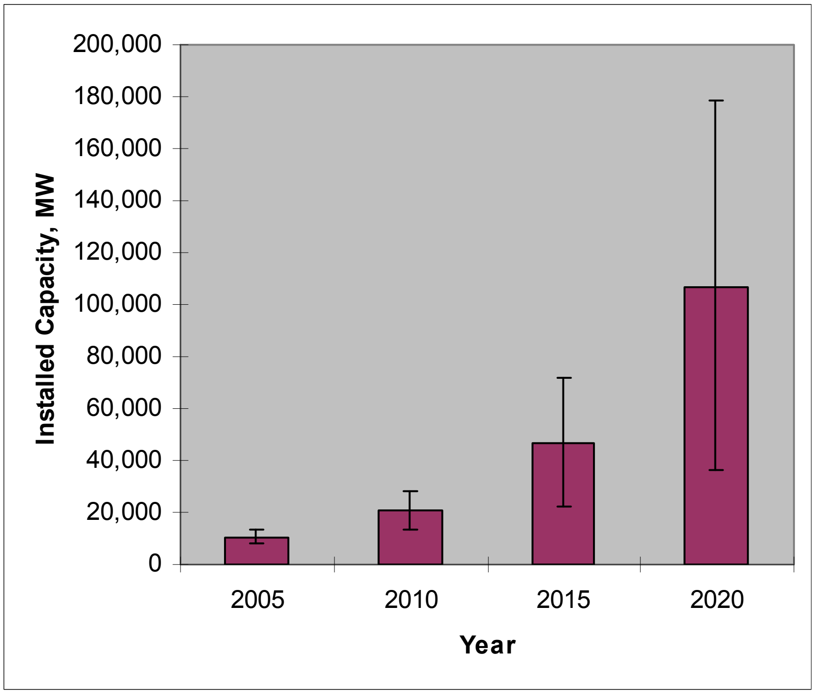

Figure E.6. Potential capacity variation for all international market segments

A robust market potential is estimated for the farm, business, and small industrial segment due to strong economic policy (for example, the German "feed in" tariffs, in which high economic value is given to the production of kilowatt-hours based in part on higher electricity rates). China also has aggressive renewable energy goals, and there is already proven use of mini turbines.

IV. Market-Based Barriers to the Distributed Wind Market

Through this market analysis, several market-based barriers were identified that hinder the development of the distributed wind applications market. Unless otherwise noted, many of the barriers, which are described in basic rank order of importance, were found to be casual factors in multiple market segments.

- **Technology not quite cost competitive:** Although markets exist in which incentive programs can be combined to give consumers 50% cost-sharing of their turbines, further cost decreases through volume manufacturing will be needed to allow appropriate payback periods for most American consumers. (Markets in which distributed wind technologies are cost effective exist in Class 3 to 4 wind resource areas and locations with high electricity costs, such as remote diesel stations.)
- **Turbine availability:** In the current market, turbines sized between 100 kW and 1 MW to serve farm, business, small industrial, wind/diesel, and small-scale community loads are not produced. There is also a shortage of turbines sized greater than 1 MW because of pre-purchases by wind developers using the Production Tax Credit. There are also opportunities for turbine development in the 5-kW to 15-kW range to meet needs in the residential market segment.
- **Zoning/permitting restrictions or complications:** Zoning remains a large issue for distributed applications, specifically for individual home or business owners seeking to install a small wind turbine on their properties in suburban America. The permitting costs and zoning requirements can greatly increase the overall cost, lead time, and complexity of installing even the smallest wind turbine. In most locations across rural America, zoning and permitting are not an issue for smaller turbines, but those locations don't typically have the incentives in place to compel the purchase of a distributed wind turbine. Model zoning ordinances for mid-size turbines currently do not exist, and there is a need for them. These ordinances should consider proper setback for sound levels and safety, as well as avian and other wildlife issues.
- **Interconnection to the grid, including standards and defined requirements:** Turbine grid interconnection is a complex issue that varies from state to state and generally from utility service provider to service provider. This creates a number of complexities, both from a technology perspective and an information outreach perspective. With such a wide range of requirements, it's almost impossible for the industry and other supporting organizations to provide informative assistance to interested homeowners.
- **Lack of consistent incentive policies across markets:** The lack of clear, consistent, and economically motivating incentives complicates and distorts markets for small wind systems. More systematic market incentives, such as "feed in" tariffs, a national investment tax credit for distributed wind applications, and state-based rebates for all distributed applications would expand the technology adoption.
- **Poor image due to past small wind experiences:** The historical performance of some distributed wind turbines has resulted in a somewhat persistent belief that small wind turbines are noisy, unsafe, and unreliable. Outreach activities addressing previous market issues and some of the largest preconceived notions of modern small wind turbines are needed.

V. Technical Barriers to the Distributed Wind Market

In addition to market barriers, technical barriers were also identified. A summary of these barriers, all of which are discussed in greater length in each of the chapters, is provided.

- **Product reliability and performance:** Turbine and system reliability, especially in distributed applications where service personal are less readily available, hinder the adoption of wind systems. Performance is typically over-predicted (usually due to a poor understanding of the wind resource, the micrositing of the turbine system, and insufficient tower heights).
- **Limited size choices using older designs:** The limited number of commercial turbines 50 kW and greater, combined with non-optimized turbine efficiency and design, result in missed market share. Many technological advances have been made on residential turbine designs and multi-megawatt turbine designs, and these technological advances could be applied to distributed turbines.
- **Availability of maintenance support:** By definition, distributed applications will not be installed in organized wind farms where field support is readily available. The lack of or additional cost of field support undermines technology acceptance.
- **Lack of performance standards, testing, and ratings:** The lack of industry-accepted standards undermines the credibility of performance estimates for wind turbines. In many cases, incentive organizations are unsure of which products to endorse and incent, limiting the available product with good economic value.
- **Technologies for low-wind regimes:** Most mid-size wind turbines used in the distributed market were designed before recent advances in low-wind-speed technology. However, a large number of sites where distributed applications will be applied are not in high-wind-speed regimes and would receive the most advantage of low-wind-speed designs.
- **Turbine noise:** Although distributed turbines are becoming quieter with each successive generation, some are still considered too noisy to be used in residential settings. Further technical advances to reduce noise will allow turbines to operate in a wider variety of settings.
- **Lightning susceptibility and grounding:** The susceptibility of distributed wind turbines to lightning and the cost of lightning protection increase the cost and technical complexity of wind systems.
- **Grid interconnection and integration:** The technical complexity and cost of interconnection of small wind systems to the electric distribution grid require further advancement, standardization, and testing. Distributing turbines through the use of more sophisticated remote-monitored controllers can allow the turbine to support the weak rural distribution systems, providing grid stability.
- **Tower options for larger wind systems:** Most towers are currently designed around wind turbines for central station wind farms. To allow for more cost-effective installation and maintenance, distributed wind turbines must be developed with towers and systems specifically designed for the distributed wind market, such as self-erecting towers or lightweight, tall towers for small turbines in rural low-wind-speed applications.
- **Energy storage for remote power systems:** Remote, non-grid-connected power and water irrigation applications require some form of energy storage to supply consistent, grid-quality electrical service. Energy storage is currently the highest life-cycle cost

component of a remote power system. Improving the cost and technical performance of energy storage will increase the applicability of wind-driven remote power systems.

VI. Acknowledgements

The following people and organizations completed the work summarized in this document:

The residential and “small-scale” community wind reports were written by a team led by Heather Rhoads-Weaver of eFormative Options LLC. The residential market team includes Amy LeGere, Brian Antonich, Johnny Holz, Steve Grover, Craig Hansen, Mick Sagrillo, Ed Kennell, Thomas Wind, Ron Lehr, Meg Gluckman, and Thom Wallace. The “small-scale” community wind team includes Brian Antonich, Lisa Daniels, Jonny Holz, Steve Grover, Craig Hansen, Mick Sagrillo, Ed Kennell, Thomas Wind, Ron Lehr, Amy LeGere, Meg Gluckman, and Thom Wallace.

The small-scale remote power report was written by Robert Foster and L. Martin Gomez Rocha from New Mexico State University – Southwest Technology Development Institute and Ken Starcher and Vaughn Nelson from West Texas A&M University – Alternative Energy Institute.

The farm, business, and small industry report was written by Ken Starcher and Vaughn Nelson from West Texas A&M University – Alternative Energy Institute and Robert Foster and Luis Estrada from New Mexico State University – Southwest Technology Development Institute.

Additional reports were completed by Dustin Gaskins, Steve Amosson, Thomas Marek, DeDe Jones, Bridget Guerrero, Lal Almas, and Fran Bretz of the Agricultural Research and Extension Center, Texas A&M University; and James Janecek, Tom Acker, Abe Springer, Jan Theron, Mark Manone, Grant Brummels, and Sean Martin of the Sustainable Water Resource Alliance and Sustainable Energy Solutions Group at Northern Arizona University. Jesse Stowell of Northern Power Systems also contributed to this report.

All of these teams have significant experience dealing with the market sector that they reported on and have provided potential market growth estimates based on their experiences. Their reports include a description of the market today, current market and technical barriers, their associated time frames, and projected market growth for the domestic and international markets.

The authors would also like to thank the U.S. DOE Wind and Hydropower Technologies Program for its support of this work.

VII. Conclusion

Distributed wind technologies provide an avenue for Americans and people from across the globe to economically take part in the determination of the world’s energy future. Until recently, most of the world’s population was dependent on outside forces to provide energy services, primarily through large central-station power generation. Although individuals with adequate financial resources have been able to rely on personal energy sources, such as photovoltaic panels or small fossil-fueled generators, these personal energy sources have been out of reach for many. The dramatic reduction in the cost and availability of distributed wind technologies, combined with new policy incentives in many parts of the world, has started to change this dynamic. This report documents a substantial market for distributed wind applications and, although some technical and market-based barriers exist, none of them are insurmountable. The report also indicates that there is much to be understood about this market and that further analysis will be required in areas of specific interest. As the nation moves toward a posture of energy independence using more environmentally friendly energy technologies and away from large, central-station power generation and the large transmission lines that these will require, distributed wind applications—from residential wind turbines connected to our homes to large distributed wind and wind/diesel applications—can play a greater and significant role in our energy portfolio.

Chapter 2. Small-Scale Remote or Off-Grid Power

Prepared by:

Robert E. Foster and L. Martín Goméz Rocha, New Mexico State University – Southwest Technology Development Institute
Ken L. Starcher and Vaughn C. Nelson, West Texas A&M University – Alternative Energy Institute

I. Executive Summary

This section evaluates the key market and technical barriers faced by wind energy technology for the small-scale remote or off-grid power (residential and village) market sector. Market and technical questions posed by the National Renewable Energy Laboratory (NREL) are discussed to identify promising priority areas for U.S. Department of Energy (DOE) wind program research and development activities.

Small-scale wind energy systems employing renewable energy offer an attractive and practical approach to meet electrical power needs for individual households and rural communities around the globe. Small wind turbines are a distributed energy source with good potential for rapid growth in the next 20 years. The key to long-term success for any small-scale wind energy system is to install a well-designed energy system while keeping in mind the institutional framework and structure needed to provide long-term operation and maintenance for the system.

The small wind turbine industry is already a sustainable market around the globe. With about 1.7 billion people without electric grid power, the village electrification market is estimated to be at least 26 GW [1]. Remote village power can be designed as a complete system with options of wind, photovoltaics (PV), batteries, and diesel generators. The major challenges are system costs, sizing system components, and establishing high-volume production of systems with a corresponding price reduction.

II. Application Background

Small wind energy systems come in many sizes to fit the need for energy and the resources available to the end users. This market encompasses single-home or small-community applications by supplying electricity to rural, off-grid applications in the developed and developing world. Sizes range from simple home-sized systems (60 W and up) to larger, village-scale systems with hundreds of kilowatts of wind added to the generation mix. In the United States, most consumers want to use wind energy to meet their energy needs at remote sites away from the grid or to make themselves energy self-sufficient. Developing countries desire small wind energy systems to supply energy for remote homes and villages without increased infrastructure demands on the limited resources of the central governments.

Wind power can provide significant amounts of energy to rural households and communities currently supplied through diesel technology and reduce consumption of diesel fuel. Small wind offers capabilities for individual loads or a collection of loads to be met.

In some villages, positive exposure to the first small wind energy systems predictably has led to an overall increase of energy use. Load management needs to be considered for each wind system installation because system designers cannot plan for unlimited growth in their initial system designs. Enforcing payments from the energy users seems one way to curb the exponential growth in system load, but it is feasible only if the costs are kept low so that energy value remains affordable.

High penetration for wind/diesel is defined as the wind providing at least 75% of the current load. For high-penetration, wind/diesel power systems without energy storage, there are three operating stages: (1) diesel only, (2) wind/diesel, and (3) wind only. The transition between these three separate operation stages is the most difficult part of system control. Both the wind and the load will fluctuate over short time periods.

III. Current Status of Small-Scale Wind

Small wind energy systems have been around for many decades and are a mature technology, initially gaining popularity in the early 20th century for small farms and ranches in the Midwest. Most of these farms and ranches were already accustomed to using wind-powered mechanical water pumping systems. Before the large U.S. rural electrification programs, many rural farms installed small wind electric systems to supply energy (e.g., Jacobs units). However, small wind popularity waned as the large rural grid-electrification programs were initiated during the Depression and after World War II. But the small wind industry has once again gained popularity in recent years as more people move to rural, off-grid areas and most states offer net metering. Net metering allows utility customers to use their wind generation to offset their power consumption over an entire billing period.

The small wind turbine industry is consistently growing, but not as rapidly as the large wind turbine industry. To date, more than 430,000 small wind units are installed worldwide, representing about 110 MW of installed capacity. The most successful turbines for the small-scale industry are the smaller units, usually only a few hundreds Watts in size. The largest market for these small turbines is overseas, in places such as China and Mongolia. The turbines are most often used to power individual households. There are also about 150 wind-hybrid power systems installed around the globe, using larger wind turbines (typically ranging from 1 kW to 50 kW). For these larger hybrid systems, institutional management issues are key to their long-term success. Likewise, a similar number of telecommunication systems around the world use small wind technologies to help power microwave repeater stations, etc.

The leading U.S. and world manufacturer of small wind turbines is Southwest Windpower (SWWP) in Flagstaff, Arizona, which has sold nearly 100,000 units to date. SWWP has roughly half of the world market share for small wind turbines, with 40% sold domestically and 60% overseas. The market that includes turbines for sailboats is shrinking and represents 15% of SWWP's sales. In 2006 (SWWP's best sales year to date), sales sometimes surpassed 1,000 units per month and, at the time of this writing, were expected to be about 12,000 for the year. High-volume production has allowed SWWP to sell a competitive-priced unit [2]. Other key manufacturers are Marlec from the UK (more than 50,000 90-W units produced) and Bergey Windpower in Oklahoma (more than 4,800 units produced, both 1-kW and 10-kW units).

IV. Market Barriers Issues and Assessment

Expected United States Market

In the United States today, there are an estimated 35,000+ kW of installed small wind turbines, representing more than 90,000 total units in the 90-Watt to 25,000-Watt size range. The U.S. small wind market is growing at about 15% to 20% per year, and it roughly doubles every 5 years.

There is a growing interest in small wind systems in the United States, especially for rural households. The implementation of net metering in most states is allowing the small wind industry to grow. Also, since the U.S. rural electric grids were never set up with the intent of meeting all of the electrical services for today's modern households with their many electrical appliances (big-screen TVs, satellite dishes, microwave ovens, computers, etc.), small wind systems could play a role in strengthening the rural electric grids.

There are several U.S. wind niche markets. For instance, some rural U.S. villages are not electrified (most notably in Alaska). Approximately 75,000 people live in 175 rural communities throughout Alaska [3]. Of these, 42,000-plus people in 91 communities have a high potential for wind/diesel systems. Most of these are Native American communities.

The largest Indian reservation in the United States is the Navajo Nation, and approximately one-third of the 250,000 people on the reservation lack electricity. The households are typically scattered and will never be electrified by the grid or a village system. The Navajo Tribal Utility Authority has already installed hundreds of individual PV systems for some of these rural households (typically about 300 Wp each). Small wind generators can help augment battery charging for these existing and new systems.

Another significant, often overlooked U.S. niche market is the sailboat market. Small wind turbines (e.g., Air Marine) are very popular with boaters. This market was one of the first to help launch Southwest Windpower to success.

Expected International Market

Predicting the future overseas market for the small-scale, remote power distributed wind applications market is not a simple process. Many political, technical, and fuel price variables will have a direct impact on future market growth. Energy demand for overseas markets will continue to rapidly grow in the near term (decade), but most will be supplied by conventional generation. Likewise, as oil prices continue to increase over the next decade, the economics of small wind systems improve. There will also be greater interest in using wind energy technologies as a clean energy technology to help offset CO_2 and other global warming emissions. The use of wind energy will become more desirable to operate remote diesel mini-grid systems as diesel fuel costs continue to increase. Small wind turbines (1 kW to 50 kW) can be shipped in containers and assembled and installed in areas with little or moderate infrastructure. The operation will be modular in that two to ten units can be added as needed. The prognosis is excellent for increased growth for small wind in the international markets for years to come.

China. China has been a leader in adopting small wind technologies. More than 70 million people in rural areas are still not connected to the national electricity grid. China has nearly 125,000 villages with 8.89 million households without electrical power. About one-third could be powered by renewable energy [4], as grid expansion is too slow and expensive. The province of Inner Mongolia has implemented a U.S.$30 million fund per year for 5 years for rural electrification. The United Nations recently completed a survey of Chinese village power and found that there are about 45 wind/solar or hybrid village power systems, with an installed capacity of 1,363 kW.

More than 170,000 mini wind turbines (60 to 200 Watts) operate in China, of which more than 110,000 are located in Inner Mongolia. An additional 12,000 units are installed in Mongolia. The annual production of mini wind turbines exceeds 21,000 units in the region. The Chinese government estimates that the total installed capacity of mini wind turbines was about 30 MW in 2000 and will be about 140 MW in 2020, with total energy generation of 90 and 450 GW-hours, respectively.

India. As per projections by the Indian Ministry of Non-Conventional Energy Sources, 10% of the 24,000 megawatts of the anticipated installed capacity requirement by the year 2012 will come from renewables. Half of this capacity (12,000 MW) may come from wind power. India has gained a wealth of technical and operational experience for mid-size to large wind turbines. It is anticipated that as the larger wind turbines become more popular, this will also have a positive effect on smaller wind turbine usage in rural areas and with hybrid systems. There are more than 24,000 remote village sites across all 23 states of India, many of which are located in good wind regimes.

Latin America. Mexico, Brazil, and the Caribbean represent the largest potential small wind markets in the Americas. More than 5 million people in Mexico in more than 70,000 small communities are without power. In 2006, the United Nations Development Program studied the use of distributed small wind systems for productive use applications in rural Mexico. The UN intends to help finance 15 MW of rural wind projects before the end of the decade. Likewise, Brazil has more than 25 million people without power in hundreds of thousands of dispersed small communities. Other areas, such as Central America and the Southern Cone, also have significant potential for hybrid systems development, with more than 10 million people without electric service.

Europe. Europe has an extensive electric grid, so there is little need for off-grid wind energy systems. However, there is some potential for small on-grid wind energy systems, which many Europeans would find attractive. Likewise, the European Union members are examining ways to successfully develop and market hybrid wind systems for developing countries, as well as supply high-penetration systems for existing diesel-powered micro grids. A survey from monitoring programs in France states that there were 276 renewable projects in the European Union, with only 24 projects that could be classed as hybrid or autonomous wind systems [5].

Spain has an increased interest in hybrid systems because of the recent success of the utility-scale wind farms in Tenerife [Spain]. In the Canary Islands, two research groups (ITC and ITER) are active in testing these types of systems. Federal funds are funneled to the CIEMAT test facility in Soria, Spain, to develop components and whole systems for autonomous hybrid systems.

Africa. Africa has seen relatively little use and development of small wind technology to date. South Africa, the most developed country on the continent, is only now seriously examining hybrid systems for village electrification. There are a few small pilot wind hybrid projects, including a 1-kW PV, 6-kW genset, 1-kW wind system by Peninsula Teknicon in Port Elizabeth, which is used to power a local radio station. There is a 500-W PV, 4-kW genset powering a remote area school north of Durban in Kwa Zulu, Natal Province. Finally, there are three 150- to 250-kW PV/wind/diesel hybrid systems powering the Hluleka Nature Reserve on the Wild Coast in the Eastern Cape Province, as well as two other villages in the same area.

Global. A good indicator of potential market size for small- and village wind hybrid systems is the need for electrification around the globe. Approximately 1.7 billion people around the world are without electrical service. The largest unserved electrical markets are in Asia and Africa. Table 2-1 provides relative comparisons among unserved electrical markets around the globe.

Technology Adoption Timeframe

While further innovations are needed for supporting technologies such as energy storage, the timeframe for technology adoption is not dependent on these. Generally, any site with a Class 2 or better wind resource, such as much of the Midwest, is good enough to justify the investment for a small wind turbine. Economics for small wind systems are very good in Class 3 or better wind sites. There is already a robust small wind energy manufacturing industry in China, the United States, and the United Kingdom.

One of the key drivers will be energy prices, especially as compared to conventional energy and the likely continued escalation of diesel fuels and electricity costs. There will be an eventual tipping point at which diesel mini-grids, which can already cost U.S.$.50/kWh or more to operate, become so expensive to operate that wind hybrid systems could become the system of choice for many regions. As other energy prices increase over the next 10 to 20 years, the market for small wind systems will rapidly open (especially grid-connected, the way it has recently opened for PV).

As the rest of the world becomes electrified, wind will be selected as a better option over extending the grid for many places. If the grid can be easily extended to a location, chances are good that it’s already there. The remaining areas to electrify are often difficult to get to and located farthest from existing infrastructure.

Small wind technology and know-how exist already. We have experience with more than 150 pilot wind hybrid systems around the world. The small wind technology can be rather quickly adopted and implemented. Additional capacity building will be needed, especially overseas, to help hasten the pace of adoption.

Table 2-1. Electrical Access in Developing Countries by Region (Year 2000)

	Total Population Year 2000 (estimate)	Electrical Access With Access		Electrical Access Unserved	
	Millions	Millions	%	Millions	%
Total	5,060.0	3,391.7	67.0	1,668.3	29.2
Europe & Central Asia	477.1	472.4	99.0	4.7	1.0
Latin America & Caribbean	507.8	441.4	86.9	66.4	11.5
East Asia & Pacific	1,798.7	1,582.6	88.0	216.1	11.0
Middle East & North Africa	292.4	256.0	87.6	36.4	10.4
South Asia	1,343.5	529.5	39.4	813.9	52.2
Sub-Saharan Africa	640.5	109.7	17.1	530.8	66.7

Source: World Bank, 2001. Prepared from country-level estimates using best available data.

Non-Technical Barriers for Technology Adoption

Current small wind technology has not been as widely successful as small solar electric systems, even though solar is a more expensive technology. Issues regarding interconnection, cost, safety, and net metering for small wind systems impede market development. Some of the key non-technical barriers are as follows:

Cost. A key driver for all renewable energy technologies is the installed cost. The adage that "wind energy is free – but it's not cheap" is a problem, especially for the smaller wind turbines. The cost is particularly high for village systems. Many of these systems are initially subsidized by the government, but then there are no funds available for the long-term operation of the system.

Education. Education of people at all levels, including the general public, is a barrier to widespread wind technology adoption. Local maintenance personnel and installers need to be trained to reduce dependence on foreign knowledge and expertise. Utility and government planners should be trained so they can understand how wind can be a viable, economic, and reliable source of energy that can be employed without dependence on foreign assets. Information that is understandable to local users needs to be disseminated (workshops) during system planning. Information for the general public about wise energy use will go a long way in reducing the village power micro-grid loads during the initial operation.

Regional infrastructure. There is a critical mass of systems required in any region to develop and retain sufficient technical expertise to properly maintain systems. With enough systems installed in a region, regional utilities obtain economies of scale for administration, operation, and maintenance. Using a minimum of half local materials/construction methods would reduce overall system costs and involve the locals at the onset of a project. Keeping the size of projects manageable for the anticipated grid size is a method of keeping maintenance costs down. Systems can be worked on without significant outside involvement of tools and materials for unexpected repairs. Increasing in-country training of systems developers, installers, and operators would allow for quicker response to system errors, making more people available system-wide to notice discrepancies or poor system performance. Suppliers need to offer a minimum 2-year warranty on parts, labor, and travel. If conventional generation is included, the units should be supplied in country, which would reduce dependence of small countries on developed countries.

Developing industry in the host country can pay off in the long run for U.S. manufacturers. Reducing shipping costs and down time by having materials readily available will make local government more apt to choose them over a competitor. Showing that the technology can be turned over to properly trained in-country representatives and letting them "work the territory," instead of U.S. representatives coming in as outsiders, should pay handsome dividends, as well as taking advantage of favorable exchange rates in managing company payrolls.

Image. The small wind industry sometimes suffers from a poor image in some sectors. This is in part due to a number of installed substandard small wind turbines that were not very reliable. Overseas, the image is even worse, as almost any garage shop can make a perfunctory wind turbine out of a car alternator and fan blades. These homemade units do not have the same reliability as well-engineered production units.

Safety concerns also exist for installing and operating units, as well as for living in proximity to an operating unit. When a wind turbine that is designed to feather its blades is operated in high winds, it sounds like a Formula One racecar, and neighbors become concerned that the unit is about to self-destruct. Likewise, turbines have been known to throw blades, etc. So decisions to install a wind turbine next to highly populated areas, such as a school, may require extra thought and preparation. The industry should self-police itself and develop minimal safety requirements for turbines.

When prototypes of first system installations are made, manufacturers should make a concerted effort to support viable projects and not just make the sale. Ten village hybrid projects installed in Mexico in the 1990s left the industry with a poor image after most failed within a few years and essentially resulted in a national hold on this kind of development.

Developers and manufacturers need to take a long-view approach when working in a country for the first time. It may be more advantageous to design the correct system instead of selling the system requested that may not fit the bill. Even if a problem has nothing to do with the wind turbine (e.g., inverter failure), the wind industry image is still tarnished. One of the ingredients for SWWP’s success is good customer service (even though SWWP had its fair share of turbine problems as the technology developed). Pilot and demonstration projects, especially for village hybrids, require at least 2 years of manufacturer support to ensure that everything works beyond the project inauguration day.

Institutional. Especially for village hybrid projects, institutional issues are key to the long-term project success. Too often hybrid projects involve complex technology that the local villagers cannot possibly operate and maintain. The community has to be involved in the planning process to determine goals and expectations. The implementation process requires sufficient political will, duration, good administration, and follow-up to be successful. Unrestrained load growth on a wind-hybrid village system cannot be supported. The industry must overcome the obstacle of villagers thinking that energy is free and no one at the local level has ownership in the system. Minimal payment for energy has to be implemented at the local level. It is important for the small wind industry to work with local partners on maintenance, tariff design, development coordination, planning tools, and delivery. The ultimate goal of such pilot projects is a standardized design for commercial replication. Project planning parameters that should be taken into account include performance, proven technology, loads, diesel retrofits, monitoring, buy-down, and bundling multiple projects.

Time-Critical Issues

Time critical issues are most often a factor of the project scale: the larger and more complicated a project, the more that time is an issue. A small individual wind generator of a few hundred Watts does not face significant time-critical issues for technology selection. The availability of small wind turbines is generally good in the United States, although such availability may vary regionally.

Larger village hybrid systems with perhaps hundreds of kilowatts of wind turbines face more time-critical issues, from possible new technology development (e.g., controllers) to the time and cost for transport and packaging of units (especially to remote villages). Also, often there are significant timelines for obtaining project financing for larger projects such as village hybrids.

Incentive Markets

In the domestic market, some states (and federal programs) provide wind energy subsidies and incentives. These include grant programs such as those offered by the USDA, net metering, and the production tax credit. Net metering is the only incentive that is really helpful for small on-grid systems. However, there are no relevant domestic incentives for small-scale, off-grid wind energy systems.

International markets have a variety of subsidies that are country dependent. Europe has feed-in tariffs that are beneficial for on-grid wind systems. Unfortunately, like the United States, European countries do not offer many incentives for off-grid wind systems.

Developing countries have even fewer incentives for small-scale, distributed wind energy development. In less-developed countries, rural users typically have limited financial means and usually do not even pay taxes. So the only possible subsidy of interest would be a direct subsidy for technology buy-down, and some international development programs will do this (e.g., the USAID/Winrock Dominican Republic small wind project in the late 1990s). The United Nations Development Program (UNDP) is already supporting small-scale wind development projects in China and Mexico.

Utility Industry Perspectives

For the most part, the utility industry (which includes rural cooperatives, investor-owned utilities, and municipal utilities) is not significantly impacted by the use of small wind turbines, either on or off the grid. Utilities can take advantage of small wind systems to limit their infrastructure investments. The utility did not build the hardware, so it does not have to maintain the wind energy systems. Individual small wind energy systems that are connected to the electric grid have essentially no impact on the grid and make the utility essentially indifferent to their application.

In developing countries, small wind systems can be an attractive option for utilities in lieu of extending the conventional grid to remote communities over difficult geographical hurdles. Some utilities operate independent diesel mini-grids that can use small wind turbines (given the appropriate resource) as a complementary fuel source that can help reduce diesel fuel expenditures and transportation.

V. Technical Barriers Issues and Assessment

Barriers for Small-Scale Turbines

There are many reliable and rugged wind turbines on the market for small wind systems. Small wind turbine technology has been around for some time, particularly for off-grid applications. The growth of small wind turbines providing grid-connected electricity is a relatively new market application, but it represents significant growth opportunities, some of which have already been realized. DC systems have an advantage of being more readily understood in remote areas due to exposure to automotive battery systems; however, AC power is more readily transported, and AC appliances are more available. Some of the key technology barriers for the further development and expanded implementation of small turbine technology are as follows:

Energy storage. One of the largest barriers to widespread small wind technology acceptance is energy storage, which is expensive. Most wind turbines use lead-acid battery storage, which is an old battery storage technology. Batteries currently offer the best method of energy storage for wind systems and help to reduce the on/off cycles of gensets when used at low wind/limited sunlight times of the day. The greatest fuel savings occur when the gensets are shut down; even a small amount of storage would aid in those periods when renewable energy flow is just meeting or slightly under the load needs.

Operation and maintenance (O&M). Wind turbines are rotating machinery, and thus they require maintenance. Long-term O&M is a problem, especially for installations in remote areas where there is little maintenance infrastructure. Lack of observation, diagnosis, and repair can take months or longer if there are no locally trained operators. O&M issues are of greatest concern in severe environments, such as corrosive coastal or severe arctic environments. Initial village installations need to be kept relatively small so that maintenance requirements are manageable. Inverters are expensive and generally not repairable at the local level.

Electrical grounding. Damaging lightning strikes are always an issue for the wind energy industry, big or small. Wind turbines in the West and Southeast often face significant problems from and can be shut down due to lightning events. Structural performance, sensitivity to electromagnetic effects, and grounding techniques make a difference as to wind system survivability.

Long-term reliability of blade coatings. Little research has been conducted on blade surface technology development and long-term life of coatings. Surface performance, soiling degradation, and aging are factors that are not currently monitored.

Controls. Power electronic and controls offer enhanced function. The most improvement in terms of system reliability and ruggedness can be made to the microprocessor or computer controller. Power monitoring of the grid is also an expensive item, yet a necessary component of any grid-tied system to keep the voltage/frequency levels suitable for good power transmission and to maintain suitable power quality. High-speed power switches can be made more rugged and able to energize on zero crossing of AC-voltage levels to minimize surges and unwanted harmonics in the microgrid.

Hybrid systems. There is a lack of high-quality, well-documented information of the true performance and costs of hybrid systems. Through detailed monitoring and evaluation of pilot systems, a large discrepancy was found between the power produced by small wind turbines and energy production estimates based on the wind resource and the turbine power curve. The reasons for this discrepancy vary but can result in as much as a 75% reduction in turbine output. Partial solutions include the wider use of discretionary loads and improved system control. System design impact should be considered, and computer models need to be evaluated to accurately assess this problem [6].

To avoid failure, village hybrid systems must include realistic system sizing and proper institutional controls from the onset. Planners must allow for anticipated load growth, a realistic tariff structure, and a means to meet future maintenance requirements. Allowable ranges of frequency fluctuation can be higher in microgrid applications than in conventional utility grid systems; a 3% variation is probably acceptable. This allows for simpler controllers and less stringent efforts on the part of the system controller to maintain frequency levels. Village power microgrids will often be the first exposure to utility power for many of the users, and they will not be disappointed with this level of variation over a day when compared with no power availability.

For wind hybrid systems to be a viable and sustainable energy solution for remote village applications, an adequate and manageable institutional structure must accompany the technology intervention. The need for accurate meters installed at each point of service is required to empower local leaders to establish a use-based tariff that is equitable and manageable. Villagers need to be trained on how to operate an equitable tariff system. Key lessons learned from village wind hybrid system experience around the world are as follows [6]:

- Maintenance is critical for long-term system survival.
- System ownership and responsibilities need to be established early.
- Metering is key for successful operation of village hybrid systems.
- Local village support and training are crucial for a successful hybrid system.
- Long-term planning is needed for all village hybrids.
- Corrosion-proof hardware for coastal locations is required.
- Battery charging from the generator is needed to enhance system efficiency and battery life.

Complexity of technical barriers. Maintaining a database of systems to determine what has worked and failed in other locales would help developers and designers pick components and controllers with a proven field record and avoid those that need more design or manufacturing improvements.

Diesel grids need to be retrofitted with hydrogen storage/peak shaving systems, a storable fuel cell, or heat engines to completely displace non-renewable fuels.

Design tools are helpful to plan or project the savings from hybrid operation; they must be readily available, user-friendly, and reliable. Simulating the mix of renewables with existing or planned conventional energy will help developers see the benefits of renewables when they are, in fact, economically viable. There are several good models to model complex systems, including the Hybrid Power System Simulation Model (Hybrid 2), the Hybrid Optimization Model for Electric Renewables (HOMER), ViPOR, and RETScreen International.

Optimal turbine size. For small household systems, optimal turbine sizes vary from about 0.3 kW to 3 kW. For hybrid systems, optimal turbine size is from 5 kW to 50 kW. This size range is considered the optimal village size, easiest to match with existing components and not too large to install in remote, undeveloped areas. Turbines are not readily available in size ranges for modular hybrid systems because there is not enough production volume to keep costs low, and the sizes currently in production make load matching difficult.

Cost of energy. System costs have been a stumbling block to the sales of small wind systems, especially for wind-hybrid systems. The key competitors for the small wind industry are diesel gensets, followed by the PV industry.

A small 1-kW wind system will cost approximately $3,200 to install. In a good wind regime, assuming a 20% capacity factor, such a unit might produce about 880 kWh/year. The most inexpensive wind turbines will cost about U.S.$1,000 to $1,200 to install, including all balance-of-system costs. This translates to a cost of energy of about $0.15 to 0.18/kWh for small wind turbines in a good wind regime and with little follow-up maintenance. The cost of energy of the wind turbine itself is about half of this amount; however, the final energy cost is due to the entire balance of system (inverters, cables, towers, etc.).

Thus, the small wind systems are already cost-competitive in off-grid applications, where diesel gensets can cost $.40/kWh or more to operate, and off-grid PV systems are almost as much. For on-grid applications, the small wind systems are not yet economically competitive with retail grid costs of $0.06 to .10/kWh. Some industry members believe that small turbine costs can be halved in the next 5 to 10 years, especially as production volumes increase [2]. Thus, in another decade or two, interconnected small wind turbines should prove competitive with an increasingly expensive grid power. However, for the meantime, subsidies and incentives will be required for small wind to compete against grid power.

For wind hybrids, the lack of a manufacturer with modular systems of the same design is a major problem. If standard-configuration, modular systems were available (instead of a newly engineered prototype or demonstration project), real costs would be reduced. Manufacturers would be able to buy components in bulk, and a single standard design, tweaked to fit the locale, would ultimately lead to commercial success.

Seasonal and intermittency wind resource impacts. For off-grid systems, seasonality is a larger issue. For instance, in the case of the Mexico Xcalak hybrid project, the villagers always suffered through about 2 to 4 weeks of little power during September, the lowest wind month [6]. This was unacceptable to them, and the issue would have been removed if the diesel generator were able to charge the battery bank. For other applications, the seasonality also can play a role, such as for water pumping (i.e., does the wind blow in the summer when the water is most needed?).

Some utilities (e.g., Xcel Energy, Idaho Power, Kansas co-ops) have installed off-grid solar energy systems to pump water so that extensive rural lines do not have to be maintained for small loads. It is conceivable that utilities could also be sold on the same concept for small wind systems (although in the Midwest there is a tendency for less wind in the summer when water pumping is of highest priority).

Interface. For small wind hybrid systems, 120- to 240-volt AC single-phase and 240- to 480-volt 3-phase microgrids are the two most common system voltage/configurations. Single-phase systems are most commonly selected for lighting and residential use, while the 3-phase is selected to handle industrial loads and to take advantage of the cheaper 3-phase gensets available. There are also many small off-grid wind systems used for battery charging, normally at 12 or 24 V.

Some components are incompatible when a wind turbine is combined with controllers, batteries, and PV or diesel gensets. While the individual components can be obtained from current manufacturers, it is often the designer's problem to size and integrate components to provide the best overall system. The integration of mismatched components will yield a working system, but not one that gives the best energy value over the life of the system. For off-grid systems, component mismatch is larger since there are more components than for grid-tied AC systems.

VI. Recommended Areas of Technical Concentration

Technical Challenges

Technical challenges focus on systems integration but also include innovative designs of controller/inverter integration or simply modifying current wind turbines to allow battery charging or autonomous operation. Some of the key areas for future technical research are as follows:

Energy storage. Small wind can be used in combination with other generation or with energy storage capability alone to meet small to medium loads. Adding some storage can improve fuel savings by reducing diesel start/stops and by reducing idling. Idling units consume 30% of full-load fuel rates. This also requires a reliable starting mechanism for each independent genset. But the battery bank comes at a high initial cost, and battery maintenance is an additional system operating expense. There may be other, newer energy storage technologies, such as NiMH batteries or fuel cells that can be used to replace more traditional lead-acid battery technology. Additional research should be performed on short-term battery storage to reduce diesel cycles during low/medium wind conditions when lightly loaded gensets are least efficient.

Controllers. Controls and metering need to be assessed for differing applications. Controllers and the control strategy that will simplify the coordination and connection of many manufacturers' units into a seamless system are a top research priority. The highest priority should be given to controllers, which determine the operational stages and integration with the conventional diesel gensets. Testing of the controllers near system limits of stability for extended periods of time is imperative. However, efforts also need to be placed on a standard methodology and a robust and reliable control plan. While some fluctuations are allowed, overall power quality will not be compromised. The operating stages are diesel, hybrid, and renewable power. Adding variable-sized diesels with complex controllers is a second method to better match loads to resource; starting a 30-kW diesel instead of a 100-kW diesel for a 20-kW load is preferable over the long term. There are limited developers and suppliers of controllers that are compact and rugged enough to last in field conditions for the life of the system. This limited availability results in high initial costs and a lack of opportunity to develop a standard controller for general applications rather than a specific high-cost controller for each system as it is specified.

Technology improvement. Optimizing rotor/controls for small wind turbines, along with optimizing the overall system layouts/controls should be completed. Among the prime targets are:

- New blade designs for light wind regimes
- Low Reynolds Number airfoils
- Axial permanent magnet generators
- Switched reluctance generators
- Passive yaw/passive power regulation
- Energy storage.

Hybrid village systems. Research has to be directed at reducing cost and improving performance and reliability. Many of these problems are intertwined with institutional issues at the local and regional level. Even though standardization and modular components would help reduce costs, the main problem is to have the standard, modular components in an integrated working hybrid system that is robust and has high availability. Economies of scale are needed to reduce costs for remote villages.

A standard design with modular components must be developed for village hybrid systems. This would allow resources to be added as the load grows within the original design. A new design for each village power system is a waste of engineering effort and cannot reduce costs. Low-maintenance and easy-to-maintain and easy-to-operate systems must be developed.

Computer models need to be validated against village hybrid systems at three stages: planning/design, installation, and after at least 2 years of operation. A simplified spreadsheet tool of expected performance and costs, with graphics output, for planners who are not technical experts must be readily available.

A database on problems of village systems at the following three stages must be developed: planning/design, installation (first 3 months of operation), and after at least 2 years of operation. Unless a database of component failures is available, it is difficult to determine where research emphasis should be placed. The current NREL village power database should be extended to include this information.

Targets to improve the amount of operating time in hybrid mode are:

- Reduce wind speed cut-in of turbines by increased rotor area
- Use as high a penetration of turbines as can be economically afforded to increase the wind band percentage time
- Increase the reliability of system controller to supply synchronous capacitance to maintain grid frequency with no diesel operation
- Rugged dump loads to shed unneeded power into useful storage at times of high wind/low village load.

Water desalination (salt or brackish water). Many areas with fresh water limitations have brackish or saline water availability in differing aquifers. This is especially true of coastal regions where there is also a good wind resource, as well as many desert regions. Wind energy could be applied to desalination techniques that could prove to be a huge industry. Likewise, fresh water can be stored fairly inexpensively. Technical challenges include assessing direct (high-efficiency) desalination opportunities and integration with wind turbines. This could be a particularly interesting market sector for off-grid small wind.

Table 2-2. Summary Information Table: Small-Scale Remote Power (Residential or Village)

Domestic Market Off-Grid Only		Regions of Specific Interest
(Specify units – MW potential, # of units)		*(not year-dependent)*
2010	16,000 turbines/yr, 11 MW	1. Western states (ranches, etc.)
2015	40,000 turbines/yr, 28 MW	2. Tribal lands (Alaska, Navajo)
2020	85,000 turbines/yr, 60 MW	3. Islands, sailboats (New England, Washington)
International Market Off-Grid Only		**Countries of Specific International Interest**
(Specify units – MW, # of units)		*Off-Grid*
2010	24,000 turbines/yr, 17 MW	1. China
2015	60,000 turbines/yr, 42 MW	2. India
2020	150,000 turbines/yr, 105 MW	3. Caribbean

Key Technical Barriers

1. Energy storage
2. Reliability/BOS lifetime
3. Undersized/underdesigned
4. Maintenance availability

Key Market Barriers

1. Cost
2. Lack of market investment incentives
3. Training/education
4. Image (noise, safety, reliability concerns)

Expected Turbine Size Range

0.3 kW to 60 kW United States

0.1 kW to 10 kW International

Expected Turbine Coupling

Mechanical (High speed:__; Low speed:__; proposed nominal speed:_____)

Electrical (Voltage: 12 to 48 DC, a few hybrids at 240/480 V AC; 1- or 3-phase)

Thermal (Temperature: _____)

Other: ____________

VII. Conclusions

The known problems have not changed much over the past few years. The major problems involve cost, low performance and reliability, and institutional problems. Also the maintenance should be allocated so that the villagers do not feel that the new power source is simply a right or gift from a benevolent government but is their responsibility to operate and upkeep. Charging even a pittance to ensure that the benefactors of the power are also the ones supporting its operation would make each one responsive to the real costs and value of this energy. This could also curb the unlimited growth in power use as more and more villagers become used to the advantages and benefits of reliable electricity. Village systems that were designed for 10% load growth over 5 years and experienced increases of 20% to 30% in a single year can quickly be overtaxed and fail prematurely.

Some key barriers facing the small wind industry for widespread adoption of small wind systems (both off-grid) include the following:

- Deployment challenges
- Untrained dealer network and high dealer pricing
- Questionable (unverified) wind resources
- Lack of available towers
- Lack of market investment incentives.

Planners should develop regional utility systems or cooperatives for village power systems for administration and maintenance. The hybrid system is still operated at the local village. There must be enough systems in a region or a state for a viable infrastructure. The main recommendations for further development of the use of distributed wind power in isolated power systems are as follows:

- Develop the use of wind power in isolated systems as concerted actions in national and international programs rather than as individual projects.
- Join forces in development of international standards for decentralized power systems with renewable energies.
- Develop best practice guidelines as dynamic documents with common references and based on updated experience from recent projects.
- Promote wind power in small- to medium-size systems following simple and proven approaches; e.g., by repeating and/or downscaling pilot and demonstration systems with positive track records.
- Filter down from the large-scale systems any technological achievements adaptable to smaller systems.
- Invest research and development in small systems to support development of rugged technology applicable for remote communities.
- Use modeling assumptions from the hardware reality for the types of systems that will be applied.
- Install experimental systems only at test benches prepared to serve as experimental facilities.

- Encourage the industry to offer medium-scale wind turbines (10 kW to 300 kW) for hybrid system applications; large wind turbine manufacturers need to give priority to allocation of production line capacity for smaller machines.

In summary, the technical capacity to design, build, and operate isolated power systems with high penetration of wind power exists, but the mature product and the market have not met. Interesting markets, such as water desalination, have not been significantly explored. The above recommendations are seen as moves that would lead to development of the use of wind power in distributed power systems, but as in any technological development process, financing is needed.

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Chapter 3. Residential Power

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I. Executive Summary

The distributed wind industry is poised for rapid market growth in response to continuing energy price hikes and increased demand for on-site power generation. However, in order for distributed wind to reach its mainstream market potential, the industry must overcome several hurdles, primarily in system costs, interconnection, and installation restrictions.

This study provides a preliminary assessment of the grid-connected residential wind market, with an emphasis on potential market size and critical technical and market barriers. It recommends high-priority research, policy, and outreach efforts to address these obstacles. This study is designed to assist the U.S. Department of Energy (DOE) Wind and Hydropower Technologies Program and NREL in their consideration of future technical and other programmatic investments.

The study confirms substantial and growing market potential in this sector; the dominant role of the United States distributed wind turbine (DWT) industry in domestic and international markets; and compelling reasons to continue research, development, and dissemination efforts to foster continued market expansion. Findings are based on surveys and interviews with key industry participants, a review of published and unpublished articles and studies, and the industry familiarity and expertise of the team members who conducted this study.

The small wind turbine and distributed generation markets are emergent in nature, with approximately 2,900 residential grid-connected turbines totaling 14.5 MW installed worldwide as of 2005. United States turbine manufacturers provide an aggressive outlook for the DWT market, forecasting approximately 32% annual growth in grid-connected residential sales. Historically, the residential grid-connected sector has comprised less than 5% of total small turbine sales (up to 100 kW). However, manufacturers expect that portion to grow to more than 20% by 2020. As a mid-point forecast between lower and upper bound estimates, this study projects that this sector of the DWT market will grow to about 78,000 units totaling 830 MW worldwide by 2020.

Currently, United States manufacturers dominate the world market, but new turbines from China, India, and Europe will provide stiff competition for U.S. products in overseas markets and potentially in the U.S. market as well. China and United Kingdom provide examples of strong government support for DWT product development and market incentives.

Historically the most significant barrier to residential market growth has been high total installed costs, which essentially reflects the cost of energy generated. The economics of residential DWT are highly variable, with an average cost of energy in the range of \$0.08-0.12/kWh required to be competitive with conventional generation sources. The most common alternative to residential DWT, solar photovoltaics (PV), currently has total installed costs of about \$7-10/W or around \$0.20-0.35/kWh without incentives, compared to \$4-7/W or \$0.12-0.15/kW for grid-connected DWT. In order to achieve significant market expansion in the U.S. grid-connected market, reductions in DWT total installed costs to \$2-3/W are needed. This can be achieved through technology improvements along with policy support. Drivers of market growth include financial incentives, favorable net metering, standardized interconnection policies, and high retail electricity rates. Key technical challenges include the lack of performance standards and ratings, product reliability, low-wind-regime technologies, and quiet operation.

Oversight of performance certification and compliance testing is urgently needed to address critical reliability and credibility issues in order to support major expected growth in the grid-connected residential wind market. A third party familiar with the issues of both inverter and turbine manufacturers is in the best position to bridge the gap and provide innovative system solutions. These are important roles for an independent national testing laboratory to fill.

With large wind turbine and PV manufacturers scrambling to keep up with demand, this study describes how the distributed wind industry can overcome long-standing stumbling blocks and play an important role both in the United States and internationally in supplying power at the point of end use. Efforts to enhance the viability of the DWT industry will have major global benefits in securing future energy supplies and meeting increased demand for decentralized, affordable clean power.

II. Application Background

Residential distributed wind generation, for the purpose of this study, is defined as small wind turbine systems, typically 1 to25 kW, connected to the utility grid on the customer side of the meter to supply electricity for residential applications, also referred to as grid-tied or grid-connected residential DWT.

Small wind energy systems provide clean, renewable power for on-site use and help relieve pressure on the nation’s power grid, while providing domestic jobs and contributing to energy reliability and security. The United States pioneered this technology in the 1920s, and it is the one renewable energy technology that the United States still dominates. American companies lead in both technology and world market share. In contrast to utility-scale wind turbines that no longer have a strong U.S. manufacturing base, more than 90% of small wind turbines installed in the United States are still manufactured in the United States.

Based on industry statistics, the 1- to 10-kW segment of the residential DWT market currently has the widest product coverage, with numerous market newcomers expected in various sizes [1]. Growing current and potential markets for these turbines are found in industrialized as well as developing countries.

Small wind turbine systems are typically procured by property owners. Manufacturers market their systems through distributors, dealers, and directly to customers. Local dealers or installers typically install grid-connected systems, although some customers install their own systems with inspections conducted by certified electricians. The wind resource, turbine size and model, micro-siting, and installation requirements such as tower height and foundation are site-specific. Many states, counties, and utilities are promoting distributed wind generation for its clean energy benefits and contribution to renewable portfolio standards, energy reliability, and energy independence.

Widespread deployment of small wind turbines can increase the public's familiarity with wind turbine visual impacts, attract mainstream media coverage, and pave the way for local community support for larger wind developments. Small turbines, in particular installations at schools and other high-visibility locations, can become an important asset in reducing fears about unfamiliar technology, which in turn can help reduce the expense and unpredictable nature of siting and permitting large wind developments. Small turbines can be installed in selected neighborhoods to increase public awareness of residential wind options and provide an additional benefit by educating students on how electricity is made and the benefits of wind power. Neighborhood DWT installations can also help utilities increase customer interest and participation in voluntary green power programs and provide local "advertisements" of utilities' involvement in renewable energy.

III. Current Status of Grid-Connected Residential Distributed Generation

The Future

Residential DWT installed capacity has historically comprised less than 5% of total sales of small wind turbines (up to 100 kW) [worldwide]. However, manufacturers expect that portion to grow to more than 20% by 2020 [2]. The U.S. Department of Energy Renewable Energy Plant Information System (REPiS) has documented nearly 1,200 small wind turbines (up to 100 kW) totaling 16 MW as of 2005 in 45 states. Approximately 70% of the DWT systems and 40% of the DWT capacity documented in the REPiS database are estimated to be grid-connected residential applications [3].

Based on a review of available market data, this study estimates that approximately 700 wind turbines totaling 3.5 MW were sold worldwide for residential grid-connected applications during 2005, with 500 of these totaling 2.5 MW sold in the United States. This study estimates that the cumulative grid-connected residential installed capacity was 2,900 units totaling 14.5 MW worldwide as of 2005, with 1,800 of these units totaling 9 MW installed in the United States.

Market challenges. Because economics are a significant barrier to market adoption and growth of grid-connected DWT, it is important to examine factors contributing to turbine system costs. Key determining factors include turbine size (rotor diameter, rated capacity), average wind speed at hub height, power output control/limitation technology, and applied grid control technology. External factors include infrastructure and transport logistics costs, permitting costs and time, and other location-specific conditions.

From the perspectives of power generation potential (kWh/kW), return on investment, and cost of energy (cents/kWh), current small turbine designs are at a disadvantage compared with much larger utility-scale wind turbines. Small turbines are relatively more expensive to manufacture (both materials and labor) and their limited hub heights (because of cost, setback requirements, aesthetics, etc.) result in comparatively less energy production. In addition, their low volume currently manufactured impede cost reductions with series-scale production [4]. The lack of performance standards, independent testing and consistent ratings for DWT contribute to product reliability concerns in the market. Complex interconnection standards and the reluctance of utilities to adopt net metering and DWT incentive programs further constrain the market and hinder market efficiencies. Dealers and installers increasingly report that the insurance industry is requiring additional insurance coverage for DWT owners. Finally, small wind turbines are not consistently addressed in state renewable portfolio standards (RPS), incentive policies, and consumer education campaigns.

In the United Kingdom, the most commonly perceived barriers to residential distributed generation are permitting, expensive metering, lack of installation targets and incentives, high cost, and low consumer awareness. As in the United States, the United Kingdom experiences a high correlation between incentives and installations [5].

Utility acceptance. The market for grid-connected residential wind is primarily rural homeowners and small businesses. Many domestic residential sites appropriate for wind power are served by rural electric co-ops (RECs), which typically view net metering and distributed generation as cross-subsidies and inconsistent with co-op principles that members share equally in the investment, risk, and benefits of the co-operative [6]. The official position of the National Rural Electric Co-operative Association (NRECA) is that net metering results in reduced co-op revenue while the fixed costs remain the same and that the co-op's other consumers ultimately subsidize the self-generating consumer [7]. While RECs do hold a large territory, many other utilities in more populated areas do not oppose net metering. However, most utilities still require significant education, softening of interconnection requirements, and generally an improved understanding of the benefits of capturing consumer investments in DWT.

Potential new market segments. While the rural residential market has been the primary target for United States grid-connected small wind systems, new initiatives are exploring the urban and suburban markets. Among others, a U.S. manufacturer is aggressively pursuing small wind for the suburban residential market with new turbine technology and shorter towers. It can be anticipated that at least 1 year of market experience will be required to determine if this is a viable market segment for DWT and to identify the key technical and market barriers for this market segment, as well as the best practices for suburban residential market penetration.

Several efforts are underway internationally to develop roof-top mounted [8] and building-integrated DWT designs [9], but so far none have proven commercially viable. It is premature to anticipate the feasibility of such designs, especially until extensive testing establishes that they pose no potential threat to the integrity of the structures on which they are mounted. The concepts are mentioned simply as examples of enabling technologies that may have the potential to significantly augment the distributed generation market in the future.

IV. Market Barriers Issues and Assessment

Expected United States Market

Market targets. Historically, rural properties have been the primary market for residential-scale wind distributed generation systems. The industry is increasingly focused on the rural residential market, with new attention on the large-lot suburban residential market. As shown below in

Figure 3-1, a 2004 survey of readers of Home Power Magazine (3,573 respondents) indicated that 38% intended to utilize renewable energy in a rural home, 27% in a suburban home, and 16% in an urban home, with more than 40% of respondents planning to install wind turbines [10].

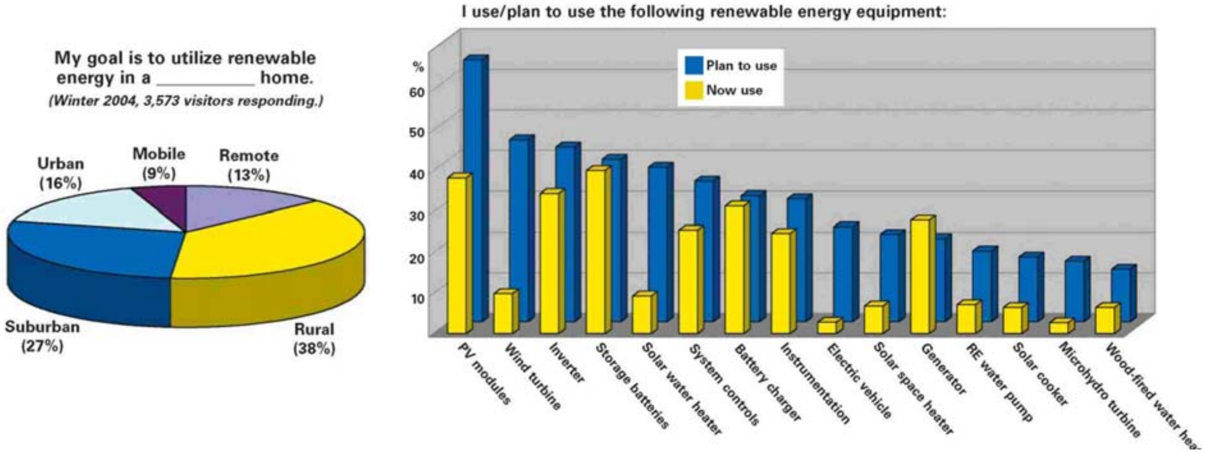

Figure 3-1. Renewable energy system end-use information from *Home Power* readers' survey

Market potential. The growth potential of the U.S. residential DWT market presents a unique, timely opportunity. Moreover, trends show that growth may occur at significantly increased rates if critical market barriers are overcome. A new market survey of the grid-connected residential wind market was conducted for this study in January 2006[1]. This most recent survey found that the leading U.S. DWT manufacturers are projecting an average annual growth rate of 32% for the U.S. grid-connected market through 2020, with their potential domestic market share as high as 9,500 units totaling 26 MW in 2010, 21,000 units totaling 70 MW in 2015, and 41,000 units totaling 130 MW in 2020. These projections provide an aggressive outlook for the DWT market and signify that manufacturers are confident that the market is poised for strong growth.

It is important to note that predictions about the percentage of future DWT market growth vary greatly and often depend heavily on the degree of expected state and federal support for DWT. The DWT market study conducted by the American Wind Energy Association (AWEA) in the spring of 2005 [11] found that in ideal market conditions (i.e., with sufficient policy support), annual U.S. sales of DWT could reach $55M by 2010. The same study forecasts a slow growth scenario based on scaled-back projections from only the established industry players, estimating annual U.S. sales at $27M in 2010 if the key barriers are not addressed. These estimates represent higher and lower bound average annual growth rates of 24% and 9%, respectively; however, some industry members believe that these projections are too conservative. With increased monitoring of these market trends, it is becoming increasingly evident that the DWT industry has the potential to become one of the leading renewable energy distributed system industries for residential homes in the United States.

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[1] See the Acknowledgements section for a list of survey participants.

In 2002, AWEA set a bold industry goal of installing 50,000 MW of total DWT capacity (3% of domestic electricity demand) by 2020 based on census data for appropriately sized lots and acreages, and put the total potential domestic market at 15.1 million homes[2]. The AWEA report estimated that more than 80% of the United States DWT market will be grid-connected residential systems with an average turbine size of 7.5 kW. Reaching 50,000 MW by 2020 would require average annual growth of around 60% over the next 15 years. Although this is an ambitious goal, given the recent annual market growth of 40% [12], it may be obtainable with adequate incentives, research and development (R&D) funding, and other policy support at state and federal levels.

In consideration of these studies and familiarity with current industry trends, this study conservatively estimates that cumulative U.S. on-grid residential wind turbine installations in 2010 will have a lower bound of 5,100 units totaling 29 MW and an upper bound of 7,400 units totaling 44 MW, with average annual growth rates of 9% and 28%, respectively. An increase in the average turbine size for this sector from 5 kW in 2005 to 9 kW in 2020 is projected as a result of the availability of new products. As shown in the Summary Information Table (Table 3-5), assuming the same growth rates in the number of units, this study's lower and upper bound United States estimates are 10,000-26,000 units totaling 72-211 MW in 2015 and 18,000-92,000 units totaling 170-1,000 MW in 2020, resulting in a midpoint forecast for the United States grid-connected residential market sector of 55,000 units totaling 590 MW in 2020.

One of the conclusions of this study is that the residential wind industry would benefit from a new, detailed potential market analysis. An in-depth market study focused on consumer motivations would provide valuable information to inform research, product development, marketing, and policy decisions.

Regions of interest. The criteria for states in the United States with strong residential DWT markets include high residential electricity rates and/or loads, adequate wind resources, financial incentives, clear and reasonable permitting requirements, positive public perception of small turbines, state or utility public education and awareness campaigns, and simplified interconnection processes.

Taking into consideration relevant economic variables, a 2004 study by Lawrence Berkeley National Laboratory calculated simple payback for DWT break-even turnkey costs in the United States [13]. The top ten states for DWT simple payback at $2.50/W were reported to be California, New York, New Jersey, Rhode Island, Vermont, Hawaii, Montana, Maine, Alaska, and Illinois.[3] Since then, California and Illinois rebate funding levels have declined, and Massachusetts and Washington have introduced significant DWT incentive programs. Fifteen states have renewable energy funds with $3.5 billion in aggregate for renewable energy from 1998 to 2010: California, Connecticut, Delaware, Illinois, Maine, Massachusetts, Minnesota, Missouri, New Jersey, New York, Ohio, Oregon, Pennsylvania, Rhode Island, and Wisconsin [14]. However, so far only a few of these have established funding mechanisms for DWT.

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[2] The 2002 AWEA Roadmap estimated that by 2020 there will be 43.2 million homes with more than 0.50 acre of land and that 35% of these homes will have a sufficient wind resource to generate electricity from DWT.

[3] The model assumed a 10-kW system, 25-year system lifetime, 8% IRR on investment, operating and maintenance at 1.5¢/kWh, cash payment, and wind production valued at full average residential electricity rate.

Responses to the survey conducted for this study confirm that the states of specific interest for the grid-connected residential market fall into three primary regions:

- West Coast (California and Washington State)
- Northeast and Mid-Atlantic (New York, Massachusetts, Pennsylvania, Vermont)
- Midwest/Central (Texas, Ohio, Minnesota, Iowa, Wisconsin, Colorado).

Correlations to residential PV. Considerable market information is available for the residential PV industry that could be useful to the DWT industry. Examples include trends in grid-connected PV installations and forecasts,[4] cost of energy, consumer demographics, purchase criteria, effectiveness of incentives and market drivers, and potential applications and market size for hybrid wind/PV systems. This insight can help inform marketing and technology decisions for the potentially large suburban residential market that some small wind turbine manufacturers are beginning to target.

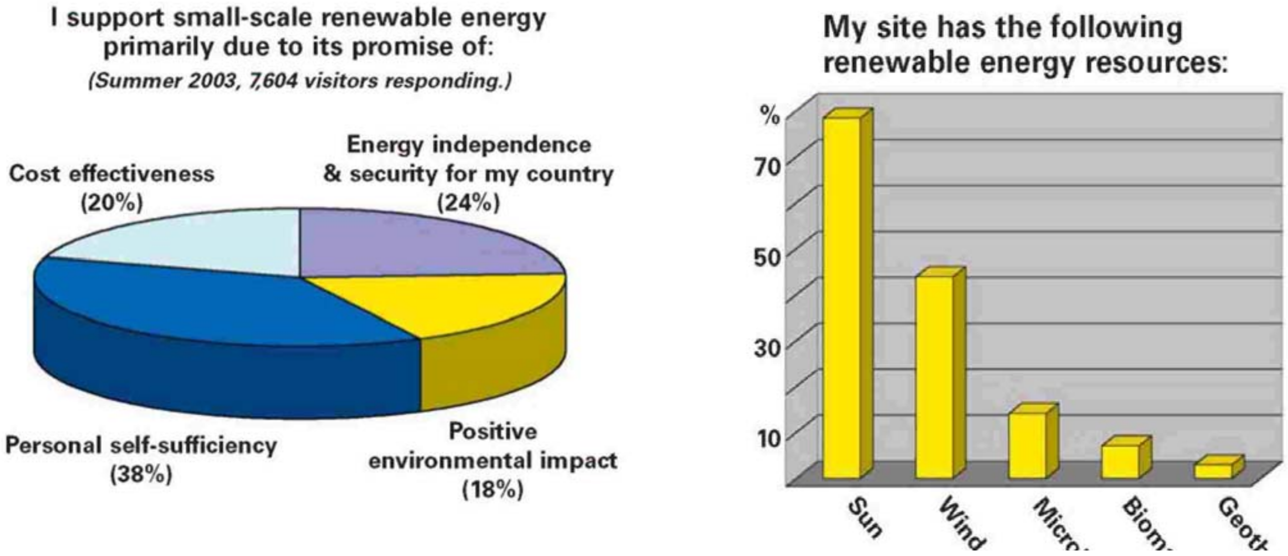

Figure 3-2. Renewable energy end-user information from *Home Power* readers survey

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[4] The U.S. Department of Energy's Energy Information Administration (EIA) forecasts residential grid-connected PV to be 127 MW of installed capacity in 2010, 141 MW in 2015, and 157 MW in 2020. The calculations are based on 2-kW residential systems.

It is also important to note that the PV industry has significant public support and resources to advance policy incentives, obtain research funding, and conduct public education and awareness campaigns. Coordination between the DWT and PV industries based on similar interconnection technologies and overlapping target markets could prove effective for developing recommendations beneficial to both industries. Customer motivations and resource information, such as that collected by Home Power Magazine in a 2003 reader's survey (Figure 3-2) can provide important insights for marketing both PV and DWT.

Expected International Market

U.S. DWT manufacturers are in an excellent position to take advantage of the international DWT market. AWEA estimates that more than 40% of U.S.-manufactured DWT are exported [15]. Currently, two U.S. manufacturers, Bergey Windpower and Southwest Windpower, are both recognized as the world's dominant market leaders in terms of sales volume [16]. A recent study conducted by Marbek for the Canadian Wind Energy Association indicated that 96% of reported sales in Canada are attributed to three U.S. manufacturers: Bergey Windpower, Southwest Windpower, and Aeromax [17]. The international export market, therefore, presents a considerable economic opportunity for U.S. manufacturers, both for grid-connected residential DWT as well as off-grid, remote applications.

The 2006 market survey conducted for this study confirms a robust international export growth outlook. The leading U.S. DWT manufacturers are projecting an average annual growth rate of 34% for the non-U.S. grid-connected market through 2020, indicating a potential U.S. export market of 3,200 units totaling 11 MW in 2010, 10,000 units totaling 31 MW in 2015, and 22,000 units totaling 66 MW in 2020.

Other estimates of the international DWT market come from AWEA's 2005 DWT market study and a 2002 study by Garrad Hassan Consulting. The AWEA study estimates that the international small wind market is roughly the size of the total domestic market and that 40% of DWT manufactured in the United States are exported. A 2002 article in REFOCUS magazine by United Kingdom-based Garrad Hassan Consulting projects a five-fold increase from 2002 for global small wind sales. This estimate equates to 150 MW/year, or 150,000 turbines/year assuming $5/W total installed costs and an average turbine size of 1 kW [18].

A number of countries have shown considerable interest in DWT technologies. In 2005, Canada and the United Kingdom published studies about their potential markets for small wind. A 2005 United Kingdom study on "microgeneration" anticipates up to 5 GWh of energy from residential wind by 2030 (1.5-kW systems), with a doubling by 2050 and with small wind supplying 4% of United Kingdom's electricity requirement [19]. The study, commissioned by the UK Department of Trade and Industry, estimates an upper bound of nearly 120 MW and a lower bound of 20 MW of installed DWT capacity by 2020, depending on the amount of government support.

The Canadian study reports a total potential of 120,000 units for grid-connected residential, 3-kW average capacity, and total capacity of 360,000 kW. The study references U.S. programs and market adoption rates and concludes that the Canadian DWT market requires incentives in four areas: market development (federal rebate and provincial incentives), policy development (net metering and streamlined environmental processes), technology development (standardized testing and demonstration programs), and education and awareness-raising (model interconnection agreements and installation guidelines for siting, zoning, permitting, and interconnection) [20].

Lawrence Berkeley National Lab reports that China manufactured 12,000 small wind turbines in 2000 and that the Chinese market has been strongly supported by government policies and incentives [21]. In February 2005, China passed a groundbreaking law to promote renewable energy. However, while China has a great potential for wind, as in much of the world, its primary market is off-grid rural electrification [22].

In consideration of these studies, the large DWT market share held by U.S. manufacturers, and familiarity with current industry trends, this study conservatively estimates lower and upper bound international annual growth rates of 11% and 28%, respectively. These rates are slightly higher than those estimated for the domestic residential DWT market as a result of the likelihood that new international residential markets will continue to emerge and expand. As with the U.S. market, the average international turbine size for this sector is expected to increase from 5 kW in 2005 to about 9 kW in 2020 as a result of the availability of new products.

As shown in the Summary Information Table (Table 3-5), using these estimated growth rates for the number of units, cumulative international on-grid residential wind turbine installations in 2010 are estimated to have a lower bound of 2,500 units totaling 14 MW and an upper bound of 3,300 units totaling 19 MW. Lower and upper bound international grid-connected residential wind installation estimates are 4,800-11,000 units totaling 34-86 MW in 2015 and 8,700-37,000 units totaling 82-410 MW in 2020, resulting in an international mid-point forecast for this sector of 23,000 units totaling 250 MW in 2020.

Regions of interest. Responses to the survey conducted for this study indicate that the major international markets for grid-connected residential wind fall in these three regions:

- Asia (Japan, China, India)
- Europe (United Kingdom, Spain, Italy, Germany, Netherlands, Greece)
- Central and South America.

Technology Adoption Time Frame

There are some technologies on the horizon that could stymie the implementation of worldwide residential DWT. Fuel cells are often cited as a potential future example. However, commercially available fuel cells that do not rely on ever-tighter supplies of natural gas will not be available for several decades. By contrast, the recent United Kingdom "microgeneration" study forecasts mass-commercialization of DWT in 2015, with electricity prices the most important market change for small wind [23].

A much more immediately available technology, and one that "competes" with small wind in various applications today, is PV. Given the current public benefits programs, PV is more competitive than wind in the 1- to 3-kW category. In addition, currently PV systems can be ordered, permitted, and installed in a fraction of the time that is required to install a comparably sized residential wind turbine. However, in areas that do not have incentives for PV, residential wind is cost-competitive and easily installed for those facing reasonable zoning, permitting, and interconnection requirements. While PV is often viewed as a competitor, market growth can be anticipated in hybrid wind/PV systems.

That said, there are still pressing hurdles that the DWT industry needs to overcome to reduce consumer hesitation with the technology, specifically in regard to reliability and timeframe for installation. In addition, the limited availability of cost-effective, state-of-the-art, synchronous inverters is a constraint to 3-kW (and larger) grid-connected variable-speed turbine types. While the manufacturers of these inverters also manufacture products for the grid-tied PV market, the inverter itself controls DWT generators differently than PV systems. When a small wind turbine manufacturer develops a new turbine model, inverter manufacturers may find it risky to invest in a new product line without the prospect of selling substantial numbers. Inverters and system electronics continue to be the least reliable component of small wind technology, which in turn has stalled innovation [24]. Some companies, such as SMA of Germany and Magnetek of the United States, have designed inverters for a number of residential wind turbines.

Development of new small wind turbines that do not require an inverter for grid-intertie applications is another direction being pursued by a few designers. This would bypass the above-mentioned dilemma. However, current development on these concepts has been greatly slowed by lack of R&D funding. Multiple paths for inverterless small wind turbines should be employed to seek the best solution to connecting DWT to the grid in a timely manner, including direct-drive induction generators and gear-driven systems.

Another significant time-sensitive barrier to current small wind turbine designers is the lack of effective computer modeling covering all components of a small wind turbine, in a variety of wind conditions including furling wind speeds. Quickly addressing this need could expedite crucial design improvements to help meet required cost targets during this critical window of opportunity to maintain U.S. dominance in this sector.

Towers are one of the greatest challenges for DWT. Towers for large wind turbines are generally less than 20% of the hardware cost. For small wind turbines, towers often comprise 40%-80% of the hardware cost. A concerted effort to develop more cost-effective designs with composites or other materials should be explored.

Non-Technical Barriers for Technology Adoption

The January 2006 survey (Table 3-1) conducted for this study indicates that economics, lack of incentives, zoning, public perception challenges, and interconnection issues are the most significant barriers to residential DWT market adoption. Up-front costs also are rated as the key decision-making factor in a recent Canadian DWT market study [25].

Economics

Most consumers carefully weigh the economics of DWT systems, taking into consideration total installed costs, out-of-pocket costs, perception of value and return on investment. Factors contributing to DWT system costs are listed above in the market challenges section. Reductions in total residential DWT installed costs from the current range of $4-7/W to $2-3/W after incentives will be necessary for significant market expansion in the U.S. grid-connected market [26]. This estimate is based on an analysis of PV module shipments vs. price (Figure 3-3) and an assumption that since PV and small wind are competitors in the grid-connected market, small wind must be priced competitively with PV.

Lengthy and costly permitting processes, requirements to access state incentive funds (environmental analyses, site assessments, installation inspections, lengthy applications), and other site-related processes also drive up total installed costs because dealers and installers typically assist consumers with these steps. Inconsistent “rated output” turbine model designations may be an additional factor in reducing consumer confidence and perceived value.

Table 3-1. 2006 Survey Responses on Grid-Connected Residential Wind Market Barriers

Residential Wind Market Barriers	Not an Issue	Moderately Low	Medium	Moderately High	Biggest Barrier	Response Average
Economics / out-of-pocket costs (total installed cost)	0% (0)	2% (1)	26% (11)	**55% (23)**	17% (7)	**3.86**
Economics/perception of value (cost of energy, return on investment)	0% (0)	10% (4)	26% (11)	**43% (18)**	21% (9)	**3.76**
Lack of incentives (rebates, buy-downs, loans)	2% (1)	22% (9)	17% (7)	**49% (20)**	10% (4)	**3.41**
Restrictive zoning	10% (4)	18% (7)	**28% (11)**	**28% (11)**	18% (7)	**3.25**
Connecting to the grid (rural electric co-op)	5% (2)	22% (9)	29% (12)	**34% (14)**	10% (4)	**3.22**
Visual impacts/neighbor concerns	0% (0)	**34% (14)**	24% (10)	27% (11)	15% (6)	**3.22**
Inadequate net metering/net billing	10% (4)	20% (8)	**34% (14)**	24% (10)	12% (5)	**3.10**
End User convenience/complexity (siting, installation, maintenance)	7% (3)	22% (9)	**39% (16)**	24% (10)	7% (3)	**3.02**
Wind myths (reliability, sound, aesthetics, safety, avian impact)	7% (3)	27% (11)	24% (10)	**41% (17)**	0% (0)	**3.00**
Lack of utility-sponsored programs and marketing for wind	7% (3)	24% (10)	**34% (14)**	29% (12)	5% (2)	**3.00**
Permitting costs and time	7% (3)	27% (11)	**37% (15)**	20% (8)	10% (4)	**2.98**
Low public awareness/support	10% (4)	22% (9)	32% (13)	**34% (14)**	2% (1)	**2.98**
Lack of tax incentives (sales, property)	10% (4)	24% (10)	**34% (14)**	27% (11)	5% (2)	**2.93**
Connecting to the grid (investor-owned utility)	10% (4)	30% (12)	**33% (13)**	25% (10)	3% (1)	**2.80**
Lack of consumer access to wind resource information/maps	22% (9)	32% (13)	**41% (17)**	5% (2)	0% (0)	**2.29**

Figure 3-3. Constructing a demand curve for DWT – experience from PV [27]

Lack of Incentives

Federal, state, and local governments have a role in establishing policies and incentives that affect market adoption of residential distributed generation. Both the small wind and PV markets have seen growth surges following the introduction of state financial and policy incentives and extensive public education campaigns. The most recent federal tax credit for small wind turbines was 1985; 2005 federal legislation did not include small wind in a residential tax credit for PV. At the local level, industry participants consistently report that the work required to remove or reduce DWT permitting barriers is time consuming and cost-intensive. However, actively engaging federal, state, and local governments in addressing the key economic, permitting, and public education barriers can ensure the realization of the energy security, self-sufficiency, and reliability that DWT promises.

Zoning, permitting, neighbor perception, and public awareness. Restrictive zoning (tower height, setbacks) and environmental requirements (state environmental assessments) contribute to the complexity, time, and costs required to install residential grid-connected systems. Model zoning ordinances and standardized data on sound, safety, reliability, rated output, setback requirements, and biological impact should be developed to streamline the zoning, permitting, and incentive application processes.

The industry would benefit from a national public education campaign to promote awareness among consumers and public policy makers and to create market demand. These campaigns would promote the benefits of DWT and address concerns about wind energy in general (reliability, acoustics, aesthetics, safety, avian impact). A separate campaign targeted at utilities could provide education on the topics listed above and promote economic and customer satisfaction benefits for utilities. DWT system cost and payback calculators, wind resource maps, and consumer guidebooks, such as those on the Wind Powering America Web site [28], need to be maintained and enhanced to aid consumers with residential DWT purchase decisions.

Connecting to the grid. Interconnection standards are important to streamline installations and reduce up-front costs for consumers. Increased awareness and support among investor-owned utilities (IOUs) and RECs will be necessary for small wind to be included in utility marketing efforts. As most preferred residential wind turbine sites are rural and fall in REC service territories, the unwillingness of many RECs to interconnect distributed generation is a significant market barrier for residential wind. New business models for both private and public utilities such as turbine leasing, sales, installation, maintenance, and turn-key "green energy" programs can be advanced as incentives for utilities to promote small wind. A marketing and public awareness campaign for RECs could assist in resolving grid balance and cross-subsidy issues.

Overcoming barriers. The majority of the barriers listed above are consistent with the 2002 U.S. Small Wind Turbine Industry Roadmap [29] that identified the following key market and policy barriers:

- Market: Lack of effective standards, low visibility of the industry and technology, misconceptions about the wind resources, insufficient capitalization, complicated financial impact, lack of multilateral bank funding for export markets.
- Policy: Lack of federal incentives, restrictive zoning, NIMBY (not in my backyard) and environmental concerns, excessive interconnection requirements and unequal billing policies, undervaluation of green energy, disincentives in the tax code, lack of state-based and national incentives, interconnection standards, and national models for net metering and zoning rules.

Since the publication of the 2002 Roadmap, the industry has made progress on addressing many of the challenges identified, in developing turbine standards, promoting small wind applications, contributing to state and national policy discussions, and developing zoning models. A leading industry member predicts that innovative turbine designs significantly reducing the cost of energy will lead to tremendous success for the small wind industry [30].

Time-critical nature of small wind technology. Residential-scale wind technology is driven by a range of customer needs and desires. These include customer requirements for reliable sources of electric power, the desire to reduce utility bills by self-generation, and customer interest in owning and running wind turbines. On-site electric power can be reliably provided by a number of other technologies, including fossil- and renewable-fueled generators, PV, fuel cells, batteries, and small hydro generators. These technologies can also serve to reduce utility bills. Other efficiency and conservation methods include solar hot water, solar and geothermal heat collectors and cooling, and building designs that include passive solar features, such as solar lighting strategies. Therefore, several alternatives are competitively available for nearly all customer motivations.

The main market drivers that impact customers' choices among technologies are the cost and perceived value of wind turbines available, effective incentive programs, the strength of provider firms' marketing and customer response capabilities, zoning and interconnection policies, and high fuel prices. Most of these issues lead to broad-scale patterns characterized by gradual shifts in market demand, rather than immediate or crisis-mode response. However, spikes in fuel prices can motivate customer decisions to investigate and invest in alternatives that reduce customer costs and risks, so it is important that advances in DWT technology are made in a timely manner to address the adoption timeframe issues discussed previously in this report.

Subsidy Market for Residential Wind Distributed Generation

Market drivers. The most significant drivers of residential DWT market growth in the United States are state incentives (buy-down programs, production incentives, tax credits or exemptions, favorable financing), favorable policies (net metering, standardized interconnection), and high retail electricity rates [31]. The DWT market has seen growth surges following the introduction of state financial incentives and extensive public education campaigns. Policy actions, such as state renewable portfolio standards, can increase interest and sale of renewable energy systems. Green marketing programs such as green tags, renewable energy credits, and utility green rates will have increasing impact on DWT market dynamics in the near future. These programs also serve as a metric for consumers' willingness to pay more for green energy products.

Several states and utilities have some form of incentives or enhanced buy-back rates for distributed generation, but in many cases these programs are not available for DWT or are not significant enough to move the market. One example of DWT's exclusion is the $0.15 premium paid to net-metered PV systems by WE Energies in southeastern Wisconsin. In 2005, the state of Washington introduced a feed-in law to pay up to $2,000/year for both solar and wind generation at $0.15/kWh; however, implementation of the program has been stalled. Massachusetts and New Mexico have enacted similar production-based incentives directed toward PV. Market experience in California and New York has shown that up-front financial incentives of approximately 50% are required to accelerate residential DWT market adoption. Annualized net metering can also be a market stimulus in areas with high retail rates.

Currently there are no federal incentives targeting small wind. However, Congressional and industry support is increasing for a federal investment tax credit following the passage of the 30% investment tax credit for PV in the 2005 Federal Energy Policy Act as an opportunity to "level the playing field." Although residential wind is eligible for the USDA Farm Bill Section 9006 grants, the grants are only available for agricultural producers and much of the scoring weight of applications is placed on the cost of energy, therefore limiting the applicability of this program to residential wind projects. [Editorial note: The USDA 9006 grants are available to rural homeowners and businesses, not just agricultural producers. Although the cost of energy alternatives is one of the many criteria, it is not a majority portion of the scoring weight.] Typically, Renewable Portfolio Standard rules do not effectively address small wind, although states and advocates are showing increased interest in including set-asides or extra credit for PV in RPS policies. Table 3-2 provides a summary of U.S. state small wind programs as of January 2006 [32].

Utility Industry Impact of Residential Distributed Generation

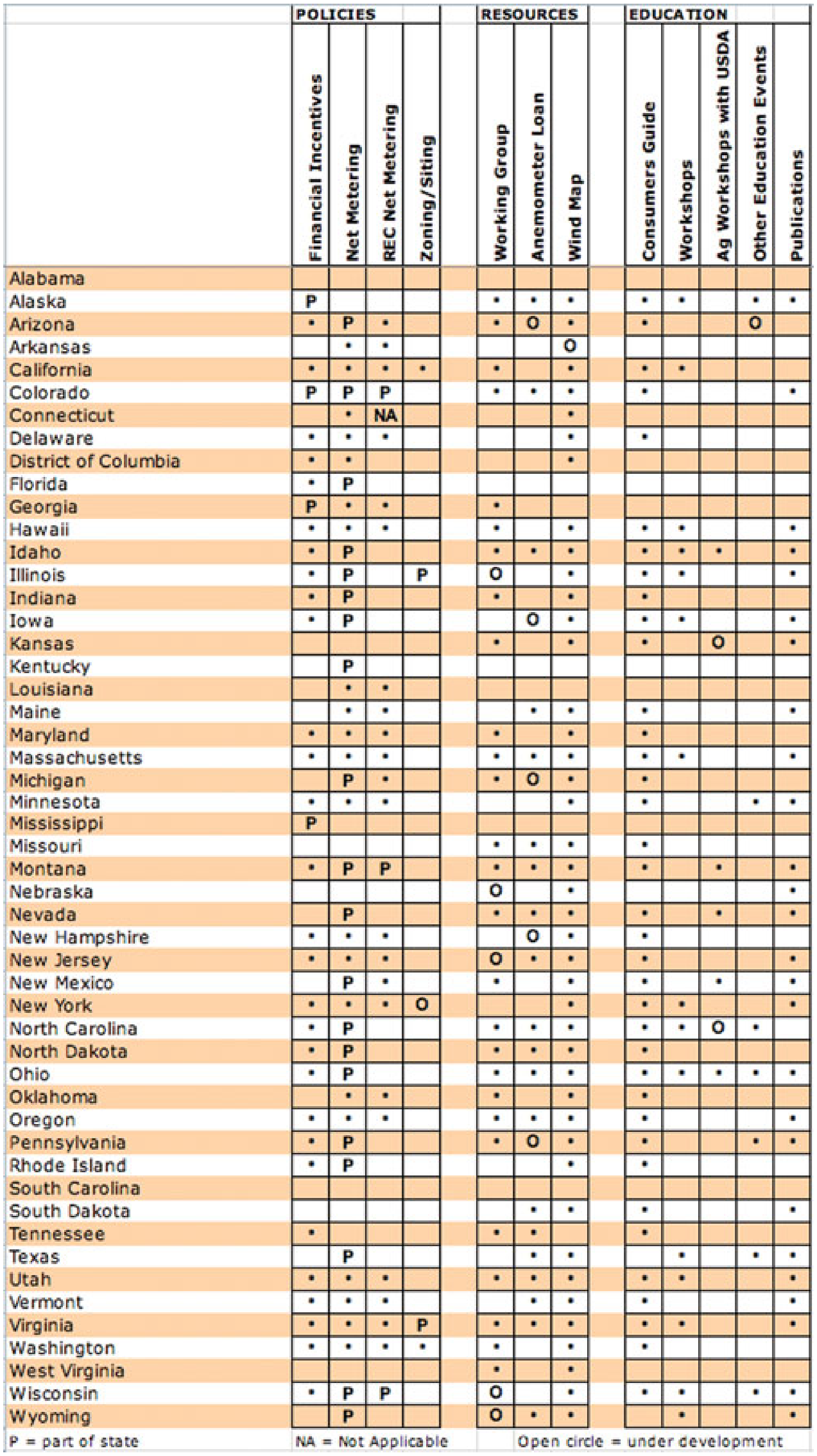
Investor-owned utilities. An increase in the number of residential wind turbines would likely have minimal impact on the IOU industry because the grid penetration on any particular feeder line is not likely to be very high. Therefore, the electrical impact and revenue loss for the local utility will be minimal from residential wind turbines. It should be noted that utilities are somewhat skeptical of DWT, in part a result of the common concerns about wind safety, interconnection, and reliability.

Rural electric co-ops. As stated earlier, although some RECs support residential-scale renewable energy systems, most view distributed generation as a cross-subsidy and inconsistent with co-op principles that members share equally in the investment, risk, and benefits of the co-op. Many RECs also perceive safety and reliability issues with distributed generation.

Co-ops in many areas of the country have grid capacity that could serve to aggregate and export distributed generation. Some minor technical modifications may be required at the utility substation to enable it to handle bi-directional power, but there are no technical reasons that the rural distribution system cannot act like a collector system for gathering distributed wind power and delivering it to the substation and higher voltage transmission system. Using the rural electric distribution system would provide economic diversification and fair-policy benefits for co-ops, economic returns for co-op members, and benefits to augment the national grid system.

Utilizing utilities to create market demand. There is a business opportunity for RECs and IOUs to provide DWT sales, lease, installation, and maintenance services as a new revenue source and customer service option. Offering turnkey systems to green-energy program customers, similar to programs in place for PV, would benefit both the small wind industry and consumers.

Table 3-2. Small Wind Programs by State



	POLICIES				RESOURCES			EDUCATION				
	Financial Incentives	Net Metering	REC Net Metering	Zoning/Siting	Working Group	Anemometer Loan	Wind Map	Consumers Guide	Workshops	Ag Workshops with USDA	Other Education Events	Publications
Alabama												
Alaska	P				•	•	•	•	•		•	•
Arizona	•	P	•		•	O	•	•			O	
Arkansas		•	•				O					
California	•	•	•	•	•		•	•	•			
Colorado	P	P	P		•	•	•	•				•
Connecticut		•	NA				•					
Delaware	•	•	•				•	•				
District of Columbia	•	•					•					
Florida	•	P										
Georgia	P	•	•		•							
Hawaii	•	•	•		•		•	•	•			•
Idaho	•	P			•	•	•	•	•	•		•
Illinois	•	P		P	O		•	•	•			•
Indiana	•	P			•		•	•				
Iowa	•	P				O	•	•	•			•
Kansas					•		•	•		O		•
Kentucky		P										
Louisiana		•	•									
Maine		•	•			•	•	•				•
Maryland	•	•	•		•		•	•				
Massachusetts	•	•	•		•	•	•	•	•			•
Michigan		P	•		•	O	•	•				
Minnesota	•	•	•				•	•			•	•
Mississippi	P											
Missouri					•	•	•	•				
Montana	•	P	P		•	•	•	•		•		•
Nebraska					O		•					•
Nevada		P			•	•	•	•		•		•
New Hampshire	•	•	•			O	•	•				
New Jersey	•	•	•		O	•	•	•				•
New Mexico		P	•		•		•	•		•		•
New York	•	•	•	O			•	•	•			•
North Carolina	•	P			•	•	•	•	•	O	•	
North Dakota	•	P			•	•	•	•				
Ohio	•	P			•	•	•	•	•	•	•	•
Oklahoma		•	•		•		•	•				
Oregon	•	•	•		•	•	•	•				•
Pennsylvania	•	P			•	O	•	•			•	•
Rhode Island	•	P					•	•				
South Carolina												
South Dakota						•	•	•				•
Tennessee	•				•	•		•				
Texas		P				•	•		•		•	•
Utah	•	•	•		•	•	•	•	•			•
Vermont	•	•	•			•	•	•				•
Virginia	•	•	•	P	•	•	•	•	•			•
Washington	•	•	•	•	•		•	•				
West Virginia					•		•					
Wisconsin	•	P	P		O		•	•	•		•	•
Wyoming		P			O	•	•		•			•

P = part of state

NA = Not Applicable

Open circle = under development

V. Technical Barriers Issues and Assessment

Technology Barriers for Distributed Wind Generation

The introduction of new grid-connected small wind generators in recent years along with major market growth demonstrate the public's desire to invest in residential-scale DWT. Economic factors including total installed cost, cost of energy produced, and payback, as noted throughout this study, drive the distributed generation market. While some industry participants are optimistic that DWT technology can reach cost targets to produce energy for approximately $0.05/kWh within the next few years, a more realistic near-term target may be the retail cost of energy. The average U.S. retail rate was $0.09/kWh in 2004 [33]. Technological advances, in addition to improved policy and financial incentives, can help the DWT industry to meet these targets and effectively compete in the residential distributed generation market.

As shown in Table 3-3, the January 2006 survey of key industry participants conducted for this study indicated that the most important technical challenges for the grid-connected residential wind market are consumer credibility and the lack of effective performance standards, testing, and ratings; product reliability, performance, and manufacturer support; the lack of equipment choices for low wind regimes; and quiet operation.

Performance standards, testing, and ratings. Establishing hardware certification, conducting certified field tests, and releasing consumer-friendly standardized ratings for small wind turbine performance and sound levels are urgent priorities for the residential DWT industry in order to assure consumers, zoning authorities, funding agencies, and lenders that small turbines are safe and will perform as expected. This activity is critically important to increase industry credibility and help prevent exaggerated claims and unethical marketing as new incentives become available. In several cases, including Oregon and California, the lack of effective standards and consistent ratings has delayed the implementation and funding of state rebate programs. Without credible, widely used performance and reporting standards for small wind turbines, there is a risk that some inexperienced manufacturers might sell unsafe or poorly performing systems that could damage the reputation of the entire wind-energy industry.

Product reliability, performance, and manufacturer support. Power electronics, the most unreliable element of DWT systems, would benefit from increased robustness, with more attention paid to efficiency and power quality. Integrated monitors could report on long-term system performance and track maintenance issues. Adding capabilities for PV inputs and alternate outputs (such as resistance heat or battery charging) could increase utility confidence. Small grid-tie inverters need to be more tolerant of ground faults and lightning, while also able to load the turbine in absence of the grid to reduce acoustics and rotor loading. Manufacturer support has been difficult because different companies usually build the inverter and the turbine. A fresh look at small direct-drive induction machines is warranted as they offer the promise of eliminating the inverter without introducing reliability problems of gearboxes. Most direct-drive DWT alternators would also benefit from more powerful super-magnets, reduced cogging, and a steeper or exponential output curve. Maximum power point tracker (MPPT) technology could also aid DWT performance.

Technologies for low-wind regimes. The highest percentage of people interested and willing to install small wind turbines do not live in high-wind regimes suitable for large commercial wind farms but in moderate Class 2 and 3 sites. There is a significant need for easily constructed DWT designs that function adequately and reliably in low wind regimes, work in turbulent environments, and produce enough energy to satisfy the needs of these homeowners with an anticipated long service-free life.

Survey respondents recommended R&D efforts for supervisory control systems that coordinate wind turbine operation with load management (discretionary electric loads, heating loads, refrigeration loads, etc.), energy storage to enhance the performance and economics of distributed wind, and improved electronics and integration systems. Several industry players believe that towers need to be much taller because in some cases the doubling of tower height from 20 m to 40 m adds as little as 10% to system cost while increasing energy capture by 35%.

It should be noted, however, that a major industry player believes that a high-performance turbine on a short tower is needed to address zoning restrictions and aesthetic considerations in order to penetrate the potentially large suburban residential market. Regardless, new lighter-weight tower materials and self-erecting capability, when coupled with simpler footing and anchor systems, could reduce costs and enhance aesthetics for all turbine designs.

Reduction of acoustic emissions. As rotors are optimized for Class 2 and 3 wind resources, higher tip speeds during gusts will create greater acoustic challenges as the optimal tip-speed ratio will occur at lower wind speeds. Lower tip-speed ratios and higher blade solidity are worth investigating. Computer models are needed to predict the complex behavior of passive rotor control strategies along with quantifying blade, wind shaft, and tower reactions to help manage rotor speed during governing and in unloaded conditions. Small changes to a blade design (such as the tip or leading edge shape) can greatly aid in reducing acoustic emissions without the need for redesigning the entire system. NREL's initial R&D in this area has made promising advances; however, more research and product development are needed to achieve consistently quiet operation.

Complexity of Technology Barriers

The technology barriers discussed previously are not unique to any single small grid-tie wind turbine manufacturer but are common to all. Addressing these challenges will require considerable time and monetary resources beyond the capabilities of most manufacturers.

Performance certification along with examining reliability issues is the natural role of a single independent national testing laboratory. Standards can be proposed by the industry, but compliance testing must be overseen by an outside source. A third party familiar with the issues of both inverter and turbine manufacturers is in the best position to bridge the gap and provide innovative system solutions.

Many of the reliability improvements outlined in Section V can be applied incrementally in the form of minor detailed design changes or exchanging one component for a more reliable but otherwise equivalent component. Improved alternators, generators, and power electronics can be introduced to a design with relative ease if their basic specifications (such as the torque vs. RPM curve) are not significantly changed.

Table 3-3. 2006 Grid-Connected Survey Responses

Residential Wind Technical Barriers	Not an issue	Moderately Low	Medium	Moderately High	Biggest Immediate Challenge	Response Average
Credibility with consumers/lack of effective performance standards & ratings	6% (2)	17% (6)	28% (10)	**31% (11)**	19% (7)	3.42
Product Reliability	6% (2)	18% (6)	**35% (12)**	26% (9)	15% (5)	3.26
Sound levels/quiet operation	6% (2)	21% (7)	**44% (15)**	26% (9)	3% (1)	3.00
Manufacturer support	6% (2)	29% (10)	26% (9)	**35% (12)**	3% (1)	3.00
Installation	3% (1)	**38% (13)**	29% (10)	21% (7)	9% (3)	2.94
Hardware & shipping costs	9% (3)	**40% (14)**	26% (9)	14% (5)	11% (4)	2.80
Power electronics & software	9% (3)	30% (10)	**42% (14)**	15% (5)	3% (1)	2.73
Maintenance costs	9% (3)	35% (12)	**44% (15)**	12% (4)	0% (0)	2.59
Engineering or reengineering of specific turbine components	16% (4)	**36% (9)**	**36% (9)**	12% (3)	0% (0)	2.44
High cut-in speed/complete turbine redesign	13% (4)	**47% (15)**	28% (9)	9% (3)	3% (1)	2.44
Designing self-erecting capabilities	21% (7)	30% (10)	**33% (11)**	15% (5)	0% (0)	2.42

Some of the improvements may require major system redesigns. Certification may lead to substantial redesign of a system if that system is found to be unsafe. A new airfoil may change the rotor loads and performance so much that the supporting structure and controls would also need to be adjusted. In most cases, the use of a new tower would not require redesign of the turbine, but there may be situations, particularly for larger and/or constant-speed systems, where system changes would be necessary.

While excessive sound levels from wind systems remain a large consumer issue, especially for residential DWT to access the suburban market, for some manufacturers acoustics are farther down the priority list. One possible reason is the complexity of the issue and the necessity of hiring outside expertise largely beyond the manufacturers' resources. In addition, because of its complexity, variable geometry rotors have yet to be modeled satisfactorily. Such modeling would surely benefit all passive controlled machine manufacturers, as well as manufacturers of blade-pitch-governed machines that furl in high winds beyond their rated capacity and during unloaded operation.

A dynamic look at a furling rotor under the influence of wildly varying angles of attack with specific attention paid to acoustic emissions would greatly aid the advancement of small wind technology. Development of such a model is likely beyond the scope of a single small turbine manufacturer, but it would benefit nearly all small turbine designs.

Expected Turbine Size for Residential Distributed Generation

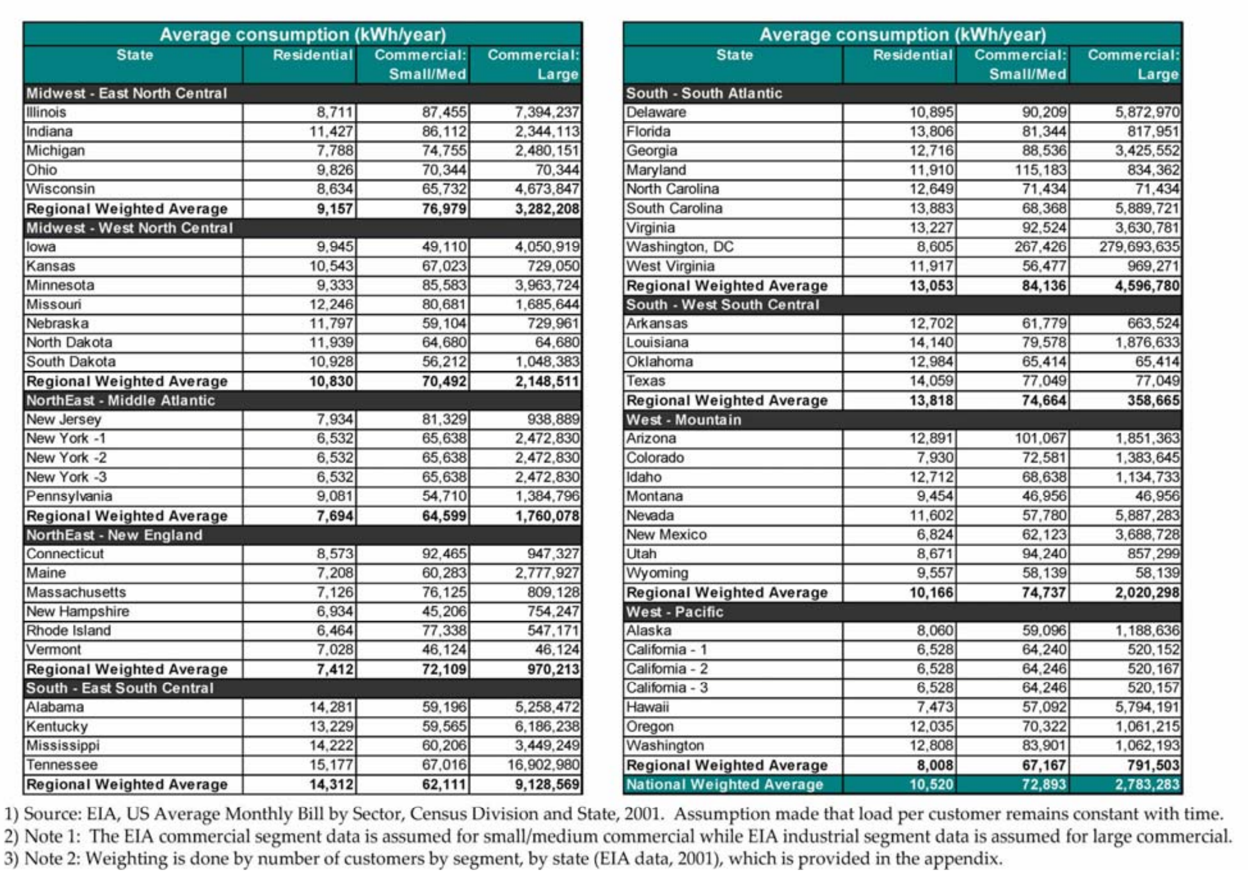
Small wind systems for grid-connected residential applications require turbines in the 1- to 25-kW range. The appropriate turbine size for residential applications is site specific and cannot be generalized. This wide range in turbine size takes into account variations in residential consumptions for different types of homes and energy conservation measures, the wind resource available, seasonal load variations, and economic incentives, such as net metering. This turbine range is also consistent with the wide variation in residential lot sizes and related zoning provisions (e.g., smaller turbines for more densely populated areas).

The January 2006 survey of key industry participants conducted for this study revealed that the most common size for the residential market falls in the 1-kW to 25-kW range (96% of the responses falling within this range) based on the average U.S. residential consumption of 10,900 kWh per year [34]. Currently, turbine models rated at 1, 2.5, 3, 10, and 20 kW are commercially available. Within this range of available turbines, there are notable gaps for 5- and 15-kW systems where development and substantial market growth could be seen if products become available. Turbines at the larger end of this range are expected to see only limited residential use because they have less attractive economics related to high upfront costs, limitations on three-phase service in residential areas, height and setback restrictions on many residential lot sizes, and reduced production where there are height restrictions. Smaller turbines must be highly efficient to offer significant power output and competitive cost per installed kW of capacity.

The DOE's consumer guide for small wind electric systems states that for a typical home with an annual electricity consumption of 10,000 kWh, depending on the wind resource, a 5- to 15-kW wind turbine is required to make a significant contribution to this demand [35]. In the United States, load varies substantially by region and season as well as household size. Table 3-4 provides a breakout of average residential load by state and region [36]. This information further supports the need for various turbine sizes for the residential distributed generation market.

Feedback from dealers and installers reveals that many residential consumers install distributed generation systems to offset electricity costs and benefit the environment; few expect to export significant amounts of electricity to the grid [37]. Small wind residential systems, in the absence of annualized net metering, are generally sized to generate approximately 80% of the residential load to maximize the offset of retail energy.

Table 3-4. Average Customer Load in kWh/year, by State and Segment



Average consumption (kWh/year)			
State	Residential	Commercial: Small/Med	Commercial: Large
Midwest - East North Central			
Illinois	8,711	87,455	7,394,237
Indiana	11,427	86,112	2,344,113
Michigan	7,788	74,755	2,480,151
Ohio	9,826	70,344	70,344
Wisconsin	8,634	65,732	4,673,847
Regional Weighted Average	**9,157**	**76,979**	**3,282,208**
Midwest - West North Central			
Iowa	9,945	49,110	4,050,919
Kansas	10,543	67,023	729,050
Minnesota	9,333	85,583	3,963,724
Missouri	12,246	80,681	1,685,644
Nebraska	11,797	59,104	729,961
North Dakota	11,939	64,680	64,680
South Dakota	10,928	56,212	1,048,383
Regional Weighted Average	**10,830**	**70,492**	**2,148,511**
NorthEast - Middle Atlantic			
New Jersey	7,934	81,329	938,889
New York -1	6,532	65,638	2,472,830
New York -2	6,532	65,638	2,472,830
New York -3	6,532	65,638	2,472,830
Pennsylvania	9,081	54,710	1,384,796
Regional Weighted Average	**7,694**	**64,599**	**1,760,078**
NorthEast - New England			
Connecticut	8,573	92,465	947,327
Maine	7,208	60,283	2,777,927
Massachusetts	7,126	76,125	809,128
New Hampshire	6,934	45,206	754,247
Rhode Island	6,464	77,338	547,171
Vermont	7,028	46,124	46,124
Regional Weighted Average	**7,412**	**72,109**	**970,213**
South - East South Central			
Alabama	14,281	59,196	5,258,472
Kentucky	13,229	59,565	6,186,238
Mississippi	14,222	60,206	3,449,249
Tennessee	15,177	67,016	16,902,980
Regional Weighted Average	**14,312**	**62,111**	**9,128,569**
South - South Atlantic			
Delaware	10,895	90,209	5,872,970
Florida	13,806	81,344	817,951
Georgia	12,716	88,536	3,425,552
Maryland	11,910	115,183	834,362
North Carolina	12,649	71,434	71,434
South Carolina	13,883	68,368	5,889,721
Virginia	13,227	92,524	3,630,781
Washington, DC	8,605	267,426	279,693,635
West Virginia	11,917	56,477	969,271
Regional Weighted Average	**13,053**	**84,136**	**4,596,780**
South - West South Central			
Arkansas	12,702	61,779	663,524
Louisiana	14,140	79,578	1,876,633
Oklahoma	12,984	65,414	65,414
Texas	14,059	77,049	77,049
Regional Weighted Average	**13,818**	**74,664**	**358,665**
West - Mountain			
Arizona	12,891	101,067	1,851,363
Colorado	7,930	72,581	1,383,645
Idaho	12,712	68,638	1,134,733
Montana	9,454	46,956	46,956
Nevada	11,602	57,780	5,887,283
New Mexico	6,824	62,123	3,688,728
Utah	8,671	94,240	857,299
Wyoming	9,557	58,139	58,139
Regional Weighted Average	**10,166**	**74,737**	**2,020,298**
West - Pacific			
Alaska	8,060	59,096	1,188,636
California - 1	6,528	64,240	520,152
California - 2	6,528	64,246	520,167
California - 3	6,528	64,246	520,157
Hawaii	7,473	57,092	5,794,191
Oregon	12,035	70,322	1,061,215
Washington	12,808	83,901	1,062,193
Regional Weighted Average	**8,008**	**67,167**	**791,503**
National Weighted Average	**10,520**	**72,893**	**2,783,283**

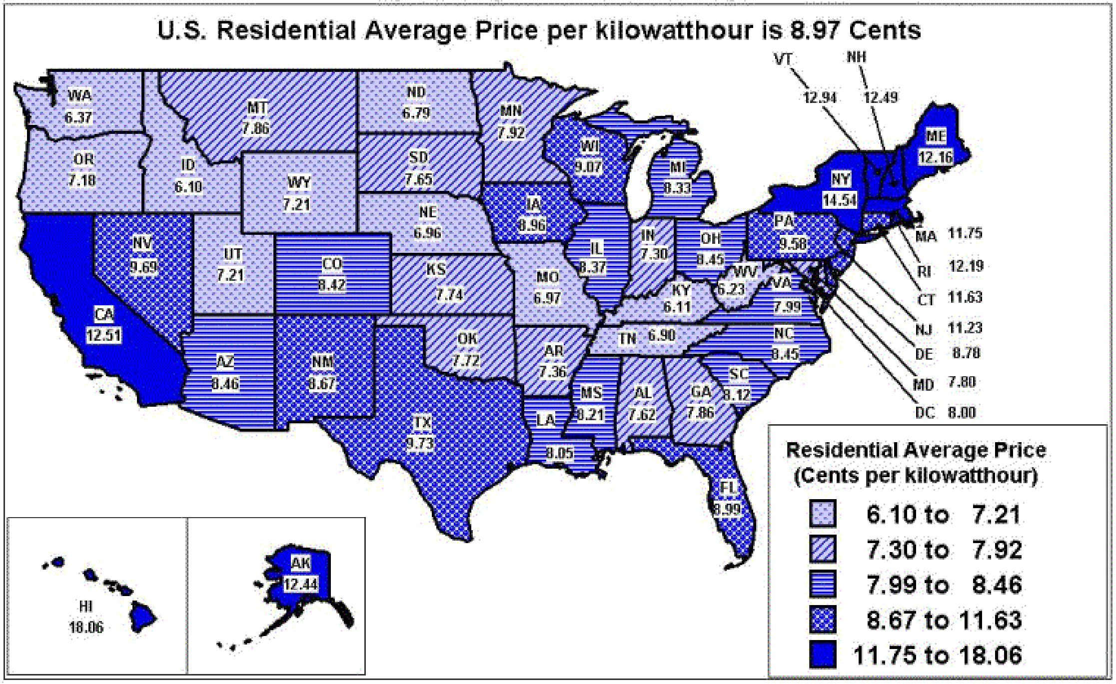
1) Source: EIA, US Average Monthly Bill by Sector, Census Division and State, 2001. Assumption made that load per customer remains constant with time.
2) Note 1: The EIA commercial segment data is assumed for small/medium commercial while EIA industrial segment data is assumed for large commercial.
3) Note 2: Weighting is done by number of customers by segment, by state (EIA data, 2001), which is provided in the appendix.

Required Cost of Energy

The survey conducted for this study indicated a range of $0.05-0.19/kWh in the retail cost of energy required for wind systems to compete in the grid-connected residential market without incentives, with most responses between $0.08 and $0.12/kWh. Consumers generally desire a payback period of 8 to 12 years, assuming nominal rate increases. In addition to electric rates, standby demand charges can impact the economics of small residential projects.

Because residential DWT is usually an alternative to grid-connected electricity, its cost must be close to the cost of commercial energy to the end user for the project to be economically competitive. The residential retail electricity rates vary widely across the U.S. (Figure 3-4), with state averages ranging from about $0.06 to $0.18/kWh as of 2004 [38]. This data is useful to calculate the required cost of energy for DWT economic returns and to identify the key states for expected DWT market growth. The most common alternative to residential DWT, PV, currently costs about $7-10/W or around $0.20-0.35/kWh without incentives, compared to $4-7/W or $0.12-0.15/kW for grid-connected DWT sited in adequate wind resources [39].

Figure 7.5 U.S. Electric Industry Residential Average Retail Price of Electricity by State, 2004 (Cents per kilowatthour)



Note: Figure information is shown by 5 groupings of 10 States and The District of Columbia. The presented range moves from the values for the lowest 10 States to the top 10 States.
Source: Energy Information Administration, Form EIA-861, "Annual Electric Power Industry Report."

Figure 3-4. United States residential average retail price of electricity by state, 2004 (cents/kWh)

Seasonality and Geographic Nature of Wind Resource

In general, most grid-connected rural residential areas with adequate wind resources are suitable for small wind turbines. However, turbulence resulting from the presence of trees, obstructions, and uneven terrain remains a significant problem for residential wind systems, particularly for the large suburban market and with towers that have less than 10 m clearance above nearby obstacles.

Coastal marine environments can also cause problems for turbine operation over time. Power electronics in unheated spaces suffer from corrosion of connections, relays, and contactors. In warmer climates, serious tower erosion, slip ring corrosion, and shorting of windings can greatly reduce system life.

The structure of net metering laws can have a significant affect on the economics of residential systems. Seasonal wind variations are strong in many regions with the result that a residential turbine may produce more energy than the consumer demands in some months and much less in others. Banking of excess generation on a yearly basis allows customers to accumulate electricity credits in the winter and spring when winds are typically strongest and use them in months when less wind is available. Annual net metering enhances the value of wind energy and reduces the cost and complexity of evaluating a site by eliminating questions regarding seasonal matching of load and wind.

NREL's research conducted to date has greatly aided performance in cold climates and with roughness-tolerant blades and is an example of how federal research and development programs can assist the industry.

Impact of Intermittency on Residential Wind Energy

The intermittency and variable nature of wind generation reduces the value of the electricity generated to some utilities. However, for residential applications, net metering essentially mitigates the intermittency issue because it lets wind turbine owners bank their excess generation with the utility for later use when the wind turbines are not generating enough power to meet site loads. If net metering is not available, intermittency of the wind resource reduces the amount of wind-generated electricity that can be used because any excess cannot be banked and must be granted or sold to the utility at "avoided cost." Therefore, the owner has an incentive to undersize the wind turbine so as to minimize the excess sold back to the utility; because smaller wind turbines typically cost more per kWh, systems become less attractive without net metering.

Wind resources typically are not well correlated with utility load profiles. Therefore, utilities still need to size their systems for peak load. While the cumulative amount of residential distributed generation may be significant, peak load correlation may be promoted as added value with utilities at the local level when there is a peak-coincident wind regime. Improved wind resource maps will be necessary to improve turbine siting and resource matching.

A research and demonstration project for supervisory control systems that coordinate wind turbine operation with load management (discretionary electric loads, heating loads, refrigeration loads, etc.) and/or energy storage to enhance the performance and economics of distributed wind may be helpful to the grid-connected DWT industry.

Interface between Turbine and Wind-Distributed Generation

Typically, the interface of residential wind turbines is 120/240V AC at 60 Hz as this is the standard voltage and frequency of most residential loads. Smaller wind turbines in the range of 1 to 10 kW use permanent magnet alternators that generate AC of variable frequency and voltage level, which must be converted using a power electronic inverter to DC and back to AC at 120/240V at 60 Hz. Most residential loads have single-phase service, limiting the size options available for turbines without significant upgrades to the typical home's electrical service. Larger wind turbines are three-phase because of the simpler, more robust design of induction machines.

Any applications that smaller turbines might power in a residential setting will already have the ability to interface with 120/240 V and 60 Hz AC. The development of more versatile, efficient, reliable, and robust controllers/inverters with higher power quality is needed to improve the interface of small wind systems with residential service.

VI. Recommended Areas of Technical Concentration

The Future

The United States dominates the international small-wind turbine industry, and the major industry participants are small, privately owned companies. Other governments (e.g., United Kingdom, China) are providing technical and market support for their fledgling small turbine manufacturing industries. Federal assistance in the form of R&D, performance standards, testing, and ratings will be required for U.S. manufacturers to continue to dominate and compete in the DWT market.

Recommended areas of technical concentration for the grid-connected residential wind sector fall into four primary areas.

Performance standards, testing, and ratings. In several cases, the lack of effective standards and consistent ratings has delayed the implementation of state rebate programs for small wind systems. The industry must establish hardware certification, conduct certified field tests, and release consumer-friendly standardized ratings for small wind turbine performance and sound levels. If these standards can be established, consumers will have reliable data upon which to base purchase decisions, and industry credibility will be enhanced. The existence of industry standards will also deter exaggerated product claims and unethical marketing. The industry requires federal assistance to develop performance standards, testing, and ratings.

Reliability and performance. Power electronics are the most unreliable element in any wind system. Numerous technical enhancements are needed for increased robustness, reliability, and efficiency: integrated monitors, capabilities for PV inputs and alternate outputs, lightning-tolerant components, acoustic and rotor loading enhancements, and maximum power point tracker technology. Direct-drive turbine alternators would benefit from more powerful super-magnets, reduced cogging, and a steeper or exponential output curve. Addressing reliability problems with gearboxes for direct-drive induction machines without inverters is also warranted.

Low-wind regime technologies. New turbine technologies are required for cost-competitive energy in low-wind regimes, often characteristic of the suburban residential areas, which offer huge potential for distributed generation. Turbines must function reliably in low wind regimes (Class 2 and 3) and turbulent environments resulting from topography, vegetation, or ground structures. R&D investments include supervisory control systems that coordinate turbine operation with load management, improved electronics and integration systems, and lighter-weight towers with self-erecting capability.

Acoustics. Lower tip-speed ratios, higher solidity, and blade design will help reduce acoustic emissions. Computer models to predict the complex behavior of variables to help manage rotor speed are also needed.

Table 3-5. Summary Information Table: Residential Power

Domestic Grid-Connected Residential Wind Market Potential*

Potential Market Size (cumulative installations)

2005	9 MW	1,800 Units
2010	29-44 MW	5,100-7,400 Units
2015	72-211 MW	10,000-18,000 Units
2020	170-1,000 MW	18,000-55,000 Units

Regions of Specific Interest

1. West Coast (California and Washington State)
2. Northeast and Mid-Atlantic (New York, Massachusetts, Pennsylvania, Vermont)
3. Midwest/Central (Texas, Ohio, Minnesota, Iowa, Wisconsin, Colorado)

International Grid-Connected Residential Wind Market Potential*

Potential Market Size (cumulative installations)

2005	5.5 MW	1,100 Units
2010	14-19 MW	2,500-3,300 Units
2015	34-86 MW	4,800-11,000 Units
2020	82-410 MW	8,700-37,000 Units

Countries of Specific Interest

1. Asia (Japan, China, India)
2. Europe (United Kingdom, Spain, Italy, Germany, Netherlands, Greece)
3. Central and South America

* Grid-connected residential capacity has historically been less than 5% of the total DWT market (up to 100 kW); however, that portion is expected to grow to more than 20% by 2020.

Key Market Barriers

1. Economics (total installed cost, cost of energy generated, payback period)
2. Lack of incentives (financial and policy, state and federal)
3. Zoning, permitting, neighbor perception, and public awareness
4. Connecting to the grid (interconnection standards, IOU, and REC issues)

Key Technical Barriers

1. Lack of performance standards, testing, and ratings
2. Product reliability
3. Technologies for low-wind regimes
4. Sound levels / quiet operation

Expected Turbine Size Range:

1 kW to 25 kW, market void for 5-kW and 15-kW turbines

Expected Turbine Coupling

Voltage: 120V to 240V, 60-Hz AC, the standard electrical service of most residential homes

VII. Conclusions

Small wind energy systems provide clean, renewable power for on-site use and help relieve pressure on the nation's power grid while providing domestic jobs and contributing to energy security. America pioneered this technology in the 1920s, and it is the one renewable energy technology that the United States still dominates. American companies lead in both technology and world market share. In contrast to utility-scale wind turbines that no longer have a strong U.S. manufacturing base, more than 90% of small wind turbines installed in the United States are still manufactured in the United States.

Actively engaging federal, state, and local governments in addressing key economic, policy, permitting, and public education barriers can ensure the realization of the energy security, self-sufficiency, and reliability that DWT promises. The DWT market will be vitally enhanced by cost-competitive and easily obtainable equipment, with production rates keeping up with growing market demand. Technology advances with rotors, towers, and controllers can substantially improve DWT performance, as well as ease installation complexity and maintenance. Industry standards, consistent policy and financial incentives, and public education campaigns will all help enable residential wind turbines to compete vigorously in the distributed generation market. On the other hand, if there are not credible, widely used performance and reporting standards for small wind turbines, there is a risk that some inexperienced manufacturers might sell unsafe or poorly performing systems that could damage the reputation of the entire wind energy industry.

Federal assistance in the form of R&D, support for performance and rating standards development, and testing facilities and expertise will be required for U.S. manufacturers to continue to dominate and compete in the DWT market. A third party familiar with the issues of inverter and turbine manufacturers is in the best position to bridge the gap and provide innovative system solutions. Performance certification along with examining reliability issues is the natural role of a single independent national testing laboratory. Standards can be proposed by the industry, but compliance testing must be overseen by an outside source. Residential distributed wind generation would benefit from technology enhancements and public awareness programs to shift the business paradigm of rural electric co-ops to include support services for members generating wind power as a "cash crop." Co-ops could aggregate wind power from members for sale to outside parties, upgrading their extensive distribution and transmission infrastructure for bi-directional power. Both IOUs and co-ops could offer sales, leasing, installation, and/or maintenance of wind turbines for rural residential members.

The residential wind industry would benefit from a new detailed potential market analysis. With the emergence of more accurate wind resource maps, new low-wind turbine technologies, updated census data, and analysis of economic and social market drivers, a new in-depth market study focused on consumer motivations would provide valuable information to inform research, product development, marketing, and policy decisions.

Widespread deployment of small wind turbines can increase the public's familiarity with wind-energy generation, attract mainstream media coverage, help mitigate concerns about visual and avian impacts, and pave the way for local community support for large wind developments. Small turbines, in particular installations at schools and other high-visibility locations, can become an important asset in reducing fears about unfamiliar technology, which in turn can help reduce the expense and unpredictable nature of siting and permitting large wind developments.

For example, small turbines can be installed in selected neighborhoods to increase public awareness of residential wind options and provide an additional benefit by educating students on how electricity is made and the benefits of wind power. Neighborhood DWT installations can also help utilities increase customer interest and participation in voluntary green power programs and provide local "advertisements" of utilities' involvement in renewable energy.

The international market, and more importantly the international impact on the growth of the residential DWT market, is much larger than the capacity estimates indicate. The added megawatts of distributed grid-connected electricity can make a huge difference to people around the world. Energy security and grid stability can be greatly improved by spreading distributed generation over a broad area. Efforts to enhance the viability of the DWT industry will have major global benefits in securing future energy supplies and meeting increased demand for decentralized, affordable clean power. Mainstream adoption of DWT can enhance awareness and support for the entire wind-energy industry.

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Chapter 4. Farm, Industry, and Small Business

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I. Executive Summary

Wind energy has proven to be one of the most economical, modular, and readily connected renewable technologies. Its use in agricultural, production plants, and small business/home applications will continue to grow for the next 20 years and beyond.

This report is a summary of the expected growth areas, the growth rates, the necessary turbine style/sizes, and the barriers to sustainable market growth for the farm, industry, and small business wind market sector.

The prime barrier is cost. Too few turbines are currently produced to obtain the economies of scale through volume production. Thus, favorable life-cycle costs will not be realized to sell these mid-size turbines alone. The economic payback has to be on the order of 4 to 7 years to be attractive compared to other similarly sized investments for agribusiness. The cost of energy (COE) is in direct competition to that of utility-provided energy at $10–$15/MWh.

The second barrier is lack of installed infrastructure for the ongoing sales and maintenance of a distributed array of many types of turbines. Enough income must exist within 150 miles of a central service site to support $1 million/year in sales (20-25 turbines/year of 50-kW units). An installed base of 300 turbines is needed for an area to support a maintenance facility fulltime. However, a model of similar scale exists for the large farm implement market, covering the same size area, expected sales per year, and installed repair/re-supply base.

The lack of enough matching turbines to the loads is the third most important barrier to the implementation of wind for the farm and small-business market. A 10-kW unit will meet all small loads. These units are available and easily connected through net billing laws in most states already allowing this size unit. Likewise, 50-kW turbines are in production and can help meet the farm-ranch-small irrigation market. Unfortunately, 100- to 250-kW units for center-pivot irrigation and agri-processing industry are very limited. And the 250- to 500-kW units for large industrial loads are no longer made in any significant quantities.

One way to improve the potential sales is not to focus on turbine sales alone, but to develop the market in combination with demand-side energy management and full service of the turbines after installation. This would reduce owners' worries regarding long-term O&M and also ensure that energy produced was used at the best value to the turbine owner (displacing energy that would have been purchased at retail rates from the utility).

II. Application Background

Wind energy use in the agricultural sector has a history of more than 1,000 years. Transportation of goods from source to market by sailing vessels and the use of wind for food processing and land reclamation in Europe demonstrate that wind power has enjoyed a long, broad-based acceptance as an energy source.

During the past century, the wind has provided water for ranching and transportation requirements of American railways, providing a ready corridor for products to go from the Midwest producers to the populated consumer locations on the coasts. Before rural electrification, electric power was often supplied by small wind chargers with an on-site storage system of batteries. Wind power allowed rural residences to be entertained and informed and provided electric light and the powering of small appliances.

Urban communities were also able to use renewables with the passage of the Public Utility Regulatory Policy Act (PURPA), allowing the interconnection of qualified renewable energy products. The generator size limits have only recently been raised to 20 MW by the Federal government. This should help promote the use of small wind for the farm, industry, and small business market sector.

III. Current Status of Activities for this Application

A 1990 report on the wind market in the Great Plains [1] described an annual market of 10,000, 6,000, and 4,000 units for turbine sizes of 10 kW, 50 kW, and 250 kW, respectively. But this was true only if all production could be valued at retail rates. Using this \$10/MWH value resulted in \$660 million/year of expected value to the wind turbine owners. That report also stated that wind turbines would start to be fully economic in small business, agribusiness, and industrial-sized applications in 2000 to 2005.

The development of wind turbines for the farm, industry, and small business market has been overshadowed by the development of wind turbines for the utility-scale market. Manufacturers have not emphasized production of the smaller turbines in more than 20 years, allowing the greater profits and market share to be driven by the megawatt-class turbines. Articles like those in *North American Windpower* reveal that small projects scattered in a wide geographic area can offer substantial system benefits [2]. Even though there is a penalty for single or small projects (5%-15% increased cost/turbine), they can be matched by better distribution of income/value than direct sales of electricity to utilities from a centralized wind plant. Small- and medium-sized wind turbine manufacturers exist all over the world [3], but the volume of machines needed to meet the expected market is not currently available.

The value of displacing conventional energy versus direct sale of energy can be substantial (retail rate of \$6-8/MWh versus wholesale rate of \$2-3/MWh). The loss of Production Tax Credit (PTC) assistance from the independent sales of electricity is a burden for on-site users of wind energy, but not one that is too onerous to bear in these smaller configurations. The advantage of the increased value of displaced energy produced on site compared to direct sale of energy to a utility means that turbines can return value to the owner faster if interconnect can be allowed at higher power levels.

IV. Market Barriers Issues and Assessment

Expected Market in the United States

The American Wind Energy Association (AWEA) conducted a complete market survey of more than 250 wind industry members. The results were included in a report on other barriers [4]. The questionnaire revealed the following areas of concern in the small wind (<100 kW) industry: economics, lack of consistent incentives, zoning-permitting, and interconnection issues. Additional views were collected from the U.S. Department of Agriculture and consultations with manufacturers of mid-size and small-size turbines.

The market can take advantage of changing regulations to create sustainable growth for wind for small businesses and farms, given the Federal support in the United States of interconnection rules and individual states net-billing agreements. The turbine sizes that are most useful need to generate about 750 – 1,000 MWh per year in a decent (upper Class 3) wind regime. This is equivalent to a 250- to 300-kW unit. These sized units, returning $40,000 – $60,000/yr, would have simple paybacks in approximately 10 years. But this approach can only work if net billing is allowed and all the energy is used on-site (no wholesale sale of excess energy to the utility). This would help address the respondents’ concern that economics is the driving factor in the turbines’ perceived value.

Currently, the readily available turbine sizes are smaller than the long-term market sizes (10 to 50 kW, not 250 to 400kW), resulting in higher installed cost/kW. Economics are such that, even with net billing, it is difficult to recoup the initial cost of the system within a 15-year time frame. This has to be reduced to 10 years or less payback to obtain a rate of return that is acceptable for the high capital investment.

These smaller wind systems have worked in the United States, and when properly sized along with utility cooperation, the systems performed with few start-up problems or long-term difficulties [5]. But even the more successful projects have increased in size toward the utility-scale turbines because those are most readily available for projects. Also, siting projects in states with significant incentives (Illinois, Minnesota, Iowa, Colorado) shows that where local value is placed on renewables, it is readily implemented.

There is no specific problem with the turbine technology; the former sizes and designs are simply no longer in the production stream. The units that are available are at a premium because of low production volumes. Good turbines that are technically sophisticated are commercially available, but only for the smaller-size loads/energy use projects, delivering 100 to 150 MWh per year. But this energy level is not enough to offset the energy needed in most agricultural or food processing industries that are considered potential wind energy users.

Non-technical barriers are mostly political in nature. The lack of consistent interconnection standards across states hurts the utilization of wind in some markets. The wide range of net billing techniques used in different states means that there are widely varying returns for units even in areas of similar wind power potential. There is no simple solution for these policy differences, but focusing on the states with the better wind resources and agricultural/industrial base (Midwest, Rockies, Southeast coast) to improve the existing net billing rules would provide the most fertile ground for future wind energy growth for this market sector.

The existing mid-size turbine designs are from the 1980s and have historically been rugged, reliable, and readily reproduced. However, they are no longer the desired turbine sizes of choice for the utility-scale market and have fallen off the production horizon. This shows that large, megawatt-scale turbines have begun to displace conventional energy sources and that conventional energy costs have increased sufficiently so that wind is a viable economic consideration. But at present, the utility market is driving megawatt-size wind turbine production.

Current manufacturers are using the turbines that are still in production and trying to match these smaller-scale energy loads (120 – 175 MWh/year) to the performance of available turbines. A recent meeting in Amarillo, Texas, hosted by Entegrity Wind Systems [6] (formerly Atlantic Orient Corporation) introduced several agricultural businesses to the idea of wind turbines displacing conventional energy use on the farm and the expected economics for such systems.

The best incentives for the wind systems are currently the Federal funds available through Section 9006 of the U.S. Farm Bill and the guaranteed loan program of the U.S. Department of Agriculture. State programs have inconsistent support for renewables for the mid-size turbine market sector, with New Jersey the only state allowing the interconnection of up to 2-MW turbines and allowing net energy billing over a 12-month time frame.

The expected wind energy markets for farm, industry, and small businesses are for any business that has energy use and sufficient resource to justify the use of wind energy. This includes the following:

- Agriculture industry
  - Meat packing (large use of hot water/cooling facilities year round)
  - Food processing (industrial-scale plants that operate annually)
  - Peanuts, cheese, confined feedlots, etc.
  - Irrigation (center pivot units of 1/8 to 1/2 mile radius)
- Machining
  - Foundries (metal heating and industrial-sized movements of metal)
  - Metal smelting
- Small business – similar to home-size markets, similar-sized turbines.

These industries and businesses have traditionally been found in rural areas of the United States and as such have fewer impediments to zoning and use of wind energy because they have more suitable land space for turbine installation.

The expected COE has to be within 10% of the conventional sources of energy with expected annual growth in conventional energy to be 3% to 5% per year. Most agribusinesses will begin to lock in or hedge costs that they see as rising with other resources or long-term purchase agreements if they see the real costs as being equal to the projected costs in a 3- to 4-year time frame. Long-term planning for many businesses often includes an analysis of these types of operational expenses.

A case in point is the Owens-Corning fiberglass plant in Amarillo, Texas, which has considered installing wind turbines on the property to offset long-term energy costs every 2 to 3 years over the past 8 years. Conventional power purchase has been deemed the least-cost option. But the next period of review may change because the projected energy cost growth has doubled compared to estimates from 2004.

Studies of the seasonal wind resource variation show that the change in crop type and the watering schedule can be adjusted to meet the wind resource, allowing for maximum energy use during the production season. The variation with wind on power output is well understood, but with good cooperation between the user and the local utility/cooperative, the electrical problems are minimal and the only concern is the length of time the billing can be carried on the books. The New Jersey model allows wind energy from strong months to be used in the lower-production months. This is a good model that other states should consider; it would work well in any of the target areas: Midwest, Rocky Mountains, and Southeast coast.

By using the standard utility inter-tie connection, the mid-size wind systems can be standardized for the U.S. grid. Making the flow of energy seamless from the utility to the user and back is the goal. This retains the benefit of the production on-site and having the conventional energy source as the backup to supply all the energy needed for the plant/business operation at any time, whether or not the wind is blowing.

Expected International Market

Internationally, the market will be driven by the need for energy and the desire for clean energy, with economics also as a consideration but with the other two factors playing a more deciding role for or against wind. Again the desire is for the larger-scale turbines placed in very good wind regions for a better economic return on investment. But in many cases overseas, there is subsidized support for conventional energy prices at the federal level, and so the cost paid by the consumer is lower than the true value of energy. This places wind energy at a disadvantage unless strong federal policies offset the value for the energy from renewables. The feed-in tariff rules in Germany have aided the industry there for years, setting a very good value for the electricity sent to the utility grid. The Peoples Republic of China has a state goal for the use of renewables at local and industry levels. The current 5-year plan demands the use of a set amount of renewables. This type of support will continue to push the wind markets in those countries in the future.

V. Technical Barriers Issues and Assessment

Studies have consistently shown that most potential users of small- to mid-size wind turbines for the farm, industry, and small business sector request ruggedness and reliability (low long-term maintenance). Users do not want to be burdened with a system that takes too much time from their other ongoing operations. Unfortunately, without a vast installed dealer network, some service and oversight has to come from the local users of wind systems. So if potential users are more familiar with required procedures, expected performance, and the typical operational characteristics of the turbine they plan to use, they will be better able to monitor non-optimal conditions, controlling the turbine or shutting it down until a trained repair crew can make sure the turbine can be returned to full-time operational use.

The second most important concern is that because wind turbines are tall, they can attract direct lightning strikes. In the past, the conventional wisdom was that full lightning protection was impossible and that steps to minimize or offer alternate paths for the bolt/surge to dissipate without damage to components of the turbine were available, but not foolproof. Improved blade production methods have allowed for lightning pathways to be incorporated into the fabric of the blades and thus allow for the discharge of high-static conditions before they can build up to lightning-bolt levels. Improved electronics protection on the utility interconnection and the systems-controller sensors and electrical connections has improved turbine life and reduced downtimes.

For those units that are considered small scale but still require utility inter-tie inverters, the reliability and longevity of these electronics units is of concern. Experience shows that even with recommended grounding and protection devices, the possibility for inverter damage from direct or nearby lightning strikes is never fully mitigated. The loss for the user is lost energy while a unit is repaired, as well as the replacement costs for electrically and mechanically removing the unit to return it for repair and then properly re-installing the unit once it is returned.

None of these perceived barriers alone will stop the use of the technology. The wind turbine should still be considered like any other piece of industrial equipment; it is used to produce energy when the conditions are right and requires some small degree of supervision and attunement so that proper operation is readily noticed. When it's not "quite right," it is removed from service until it is repaired.

The turbine sizes are in two stages. The smaller systems of 10 to 60 kW would be used for the home and small businesses/farm. The mid-size turbines of 250 to 400 kW would be used for the larger industrial operations that can utilize the energy from a system this size, while maintaining the utility interconnection on this scale and installing the electrical connections on the owner's side of the utility meter. This distributed energy method of using what is needed on site would reduce stress on the utility lines, rather than becoming a large negative load outside the utility control. It would avoid many of the megawatt-scale system problems associated with utility system stability and interaction but still be of sufficient scale that a good economic return can be realized over time, thus making the mid-size wind turbines attractive to individual business operations.

VI. Recommended Areas of Technical Concentration

Technical problems are not as great a concern as the perceptual and economic issues. Large wind is getting a large boost from Federal and state incentives for large wind farm facilities (accelerated depreciation, Production Tax Credits, etc.). Unfortunately, this same level of support for farm/industry-sized turbines has been much less substantial.

California offers a generous state buyback policy of $2,500 for the first 7.5 kW, then $1,500/kW up to 30 kW. Ohio is another state with aggressive support for wind energy of similar scale. New Jersey has the fewest limits for a wind turbine system (2 MW installed capacity and 12-month billing for net metering). Other states offer programs (for a comprehensive overview of available incentive programs, refer to the Database of State Incentives for Renewable Energy at www.dsireusa.org [7].

A future incentive program might be based on the non-emission/creation of NOx or SOx. Distributed wind systems should be allowed to have their fair share of any tradable credits or value once carbon-based trading for greenhouse gases becomes widespread (probably in the next decade).

A ready market for distributed wind energy systems would be to allow rural electric cooperatives to install and operate their own wind facilities to offset energy costs from their wholesale supplier. This would match the rural connection, make the co-ops a maker of renewables rather than a skeptic of renewables, and match the expected windy areas of the nation to the key electrical providers in these areas.

A new possible boost to development will be the 25 x ’25 program that is endorsed by several key agribusiness firms and farm cooperatives. While the main focus of these programs is the use of agriculture products in non-conventional energy sources (biofuels/biomass), the adoption of the targets of 25% of the U.S. energy sources coming from our rich agricultural lands by the year 2025 will boost the use of dedicated wind energy sources. While most of the rhetoric included in the proposal that concerns wind energy is directed to large-scale wind farms, the benefit of distributed energy will have to be included in meeting this ambitious goal in the desired time frame. The expected impact to the numbers of units that can be installed is considered to be an increase on the order of 10% to 15% of the projections made in the summary table. Since there is no specific target or plan yet in place for this initiative, no impact is predicted from it. It is shown in our figures in the summary table.

Finally, educational development for small businesses, industry, and farms on how to use mid-size wind turbines to help meet their energy needs could be very helpful. Most potential users are simply not aware of how wind energy can help offset their energy costs, nor do they understand the technology or net metering. A few well-placed, successful, and publicized industry pilot installations could help lead the way toward larger-scale adoption across the industry sectors.

VII. Conclusions

The key concern for the wind industry will always be maximizing profit. When there is a market for a product or turbine type/size, such as the farm, industry, and small business market, a manufacturer will step up to meet that market potential. This will only happen when a long-term profit can be made for the company. When turbine sizes are available to meet a particular need, end users will compare costs to install/operate/maintain the turbine versus purchasing energy and will choose the option that makes economic sense. Unfortunately, the manufactured wind turbine sizes are, for the most part, below or above the required turbine sizes that can readily serve the farm, industry, and small business market.

However, things may change as larger-capacity net metering policies gain in popularity. One turbine manufacturer is in production right now for a 50-kW unit and is willing to ramp up production; indeed, they are trying to generate market interest to make this a sustained turbine size/style. They are placing turbines in areas of increased public view to gain valuable public acceptance, as well as providing the performance information online to demonstrate how the unit is operating over time.

The wind industry turbine manufacturers have drifted into producing higher-return, larger megawatt-scale turbines. Currently, one manufacturer [8] has a prototype 250-kW turbine undergoing testing, but this prototype has yet to be produced in volume. The designs are there, but production volumes of these turbines are currently very low and, thus, costs are high. Mid-size turbines are no longer in the production plans of major manufacturers.

The main issues for the farm, industry, and small business wind energy sector are more political than technical. The growth of this market sector will largely hinge on increasing fuel prices, net metering, and potential government incentives for clean energy technologies. The market will grow, but the rate of growth will depend on the convergence of these factors.

Table 4-1. Summary Information Table: Farm, Industry, and Small Business

Domestic Market		**Regions of Specific Interest**
(with net billing)		*(not year dependent)*
2010	200-300 turbines/yr	1. MidWest (Great Plains)
2015	500-700 turbines/yr	2. Inter-Mountain (Rockies)
2020	1,000 – 1,500 turbines/yr	3. Southeast Coastal Areas
International Market		**Countries of Specific International Interest**
(dependent on incentives)		*(not year-dependent)*
2010	100-200 turbines/yr	1. Western Europe
2015	200-300 turbines/yr	2. China/India
2020	400-600 turbines/yr	3. Russia
Key Technical Barriers		
Underdeveloped turbine sizes for irrigation market		
Maintenance availability		
Grounding/lightning susceptibility		
Inverter Reliability and Availability		
Key Market Barriers		
Net annual energy billing		
System costs, initial and long-term operation		
PTC/PPA unavailable to farmers/small businesses if energy not sold to third party		
Rural electric co-ops' permission to inter-tie		
Expected Turbine Size Range		
250 kW to 500 kW irrigation, industrial-sized loads		
10 kW to 60 kW net-billing applications, on-site use of energy		
Expected Turbine Coupling		
Mechanical (High Speed:__; Low Speed:__; Nominal speed:_____)		
Electrical (Voltage: 240 to 480; AC X , DC__; Variable__ Constant X)		
Thermal (Temperature: ______) Other: ___________		

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Chapter 5. “Small-Scale” Community Wind Power

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I. Executive Summary

This study estimates potential market growth and evaluates the major market and technical barriers that currently impede the development of “small-scale” community wind, a subset of the larger community-owned wind market utilizing turbines of 1 MW or less, to assist NREL, DOE, and the Wind and Hydropower Technologies Program in assessing potential technical research areas with large market opportunities. Market and technical questions are explored to identify high-priority areas for the Program to consider for future investment.

A clear and available market for “small-scale” community wind is established. The current size of this market segment is estimated at 11,000 turbines currently installed internationally, totaling 8.2 GW, which is approximately 20% of the 2005 EU wind market. As a mid-point forecast between lower- and upper-bound estimates, we expect this sector of the distributed wind turbine (DWT) market to grow to about 130,000 units, totaling 99 GW, by 2020. The U.S. “small-scale” community wind market and U.S. participation in the international market are currently facing major market and technical constraints that may be reduced or eliminated with focused Program support.

This study concludes that the “small-scale” community market would be enhanced by research and development efforts, with the following high-priority research areas identified and recommended to be considered in further, more detailed studies:

- Conducting grid-integration studies to identify the potential for “small-scale” wind development that would decrease or eliminate the need for transmission system upgrades
- Advancing innovative designs for mid-size turbines, rotors, and towers optimized for Class 3 winds, addressing productivity, installation, and maintenance issues
- Designing, testing, and certifying advanced remote-monitored controllers to simplify the grid interconnection process and to support weak rural distribution systems
- Developing technical training programs for mid-size turbine technicians (windsmiths)
- Developing easy-to-use computer tools for analyzing project economics and modeling wind resources to assist with siting, seeking project financing, negotiating power purchase agreements, and taking advantage of incentives

- Developing a set of regional model zoning ordinances and educating local planning officials to aid in the adoption of responsible siting requirements, while streamlining approval processes for “small-scale” community wind.

II. Application Background

The scope of this study addresses “small-scale” community wind, a subset of the larger community-owned wind market. “Small-scale” community wind is defined as projects utilizing mid-size turbines of 1 MW or less in nameplate capacity, where an entity from the local area has a significant financial stake in the project outcome. “Small-scale” community wind projects typically connect to 13.8-kV or lower distribution lines, either behind the meter—thus offsetting a portion or all of the electricity used on-site by a load in the community—or using a dedicated transformer with all energy sold to the interconnecting utility.

“Small-scale” community wind projects currently represent a decreasing segment of the larger community wind market because projects with larger turbines are becoming more economical, and turbines below 1 MW are increasingly less available for such projects. The trend can be seen in Figure 5.1, which shows large community wind projects in the advanced planning stages and projected to be commissioned by 2010. This study primarily examines the smaller segment shown in Figure 5.1.

In recent years, with advances in turbine production and technology, wind energy has become competitive with traditional forms of electrical generation, and community stakeholders have latched onto wind-derived energy as a way to diversify and revitalize rural economies and become more energy independent. Numerous schools, universities, farmers, Native American Tribes, small businesses, rural electric cooperatives, municipal utilities, and even abbeys have installed their own mid-size and large wind turbines to promote environmental responsibility and keep energy dollars local.

According to Windustry’s community wind project database, about 270 MW of community-owned wind projects are currently installed in the United States, representing $250 million in investment in rural communities. Of these, about 110 MW meet our definition of “small-scale” community wind, utilizing wind turbines under 1 MW. (See Appendix A for a table of “small-scale” community wind projects.)

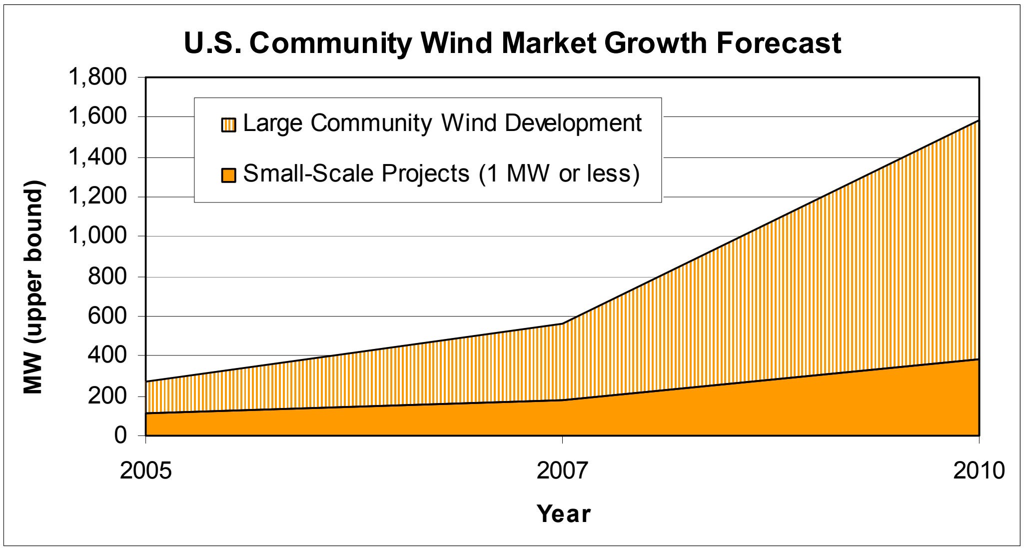

Figure 5-1. United States large- and small-scale community wind energy market upper-bound growth forecast

Unique business structures have been developed to aid community wind projects in taking advantage of federal and state incentives, such as the "flip" structure that involves an equity investor with a large passive tax appetite to allow community-owned projects to utilize the federal Production Tax Credit (PTC). Typically the equity investor is majority owner of the project for the first 10 years, when the tax credit is available to the project. The equity investor then flips its stake in the project to the community owners, usually accompanied by a payment from the community owners to the investor. This flip typically occurs in Year 11 or when the tax investor reaches the target return on investment, which is allowed to occur later.

Because of the wind industry's increasing focus on multi-megawatt turbines, the "small-scale" community wind sector is facing a major challenge of product availability. New cost-competitive mid-size turbine designs will be needed to ensure the future of the "small-scale" community wind market.

III. Current Status of Community Wind

The PTC has fostered rapid growth in large-scale wind development with periods of stagnation resulting from the advance planning requirements of large wind projects, typically 2 to 3 years, and the timing of extensions of the incentive, which have expired three times since it was created by Congress in 1992. This boom-and-bust cycle has caused apprehension for wind turbine manufacturing firms interested in opening facilities in the United States and led to major shortages of equipment, personnel, and business and legal expertise for smaller wind project developments while the incentive is available. Large wind turbines above about 900 kW are essentially unavailable for purchase for community wind projects until 2008, after the current PTC expires. In addition, very few suppliers are currently producing turbines in the 100- to 1000-kW range.

Elected officials across the United States and internationally are showing increased support for small and community wind. The 2005 Federal Energy Policy Act included a provision initiating

Clean Renewable Energy Bonds (CREBs) [1] that allow electric cooperatives, government agencies, tribal governments, non-profit organizations, and other entities that cannot utilize the PTC to apply for low-interest bonds to help finance wind and other renewable energy resources for local economic development. CREBs are an important new financing instrument for project ownership structures without a tax appetite and that don't quality for the PTC.

The state of Minnesota recently passed into law Community-Based Energy Development (C-BED), a special rate structure requiring utilities in the state to enter negotiations with qualifying, locally owned wind energy projects for payments in the first 10 years of the power purchase agreement at a higher rate than the past 10 years. The front-loaded payments are calculated based on a maximum of 2.7 cents/kWh net present value and the purchasing utility's discount rate that is used for daily business operations. This rate structure does not impact the utility's bottom line but greatly aids the wind project with debt service over the first 10 years of the project, helping to acquire financing, one of the major barriers for "small-scale" community wind project developments.

The state of Iowa recently passed a tradable production tax credit that can be sold to a third party. This incentive was passed to help level the playing field between large corporate-owned wind projects that can easily take advantage of the federal PTC and locally owned community projects for farmers, schools, and other non-profit organizations that are either tax-exempt or cannot take advantage of the federal PTC. The program provided incentives for up to 90 MW of wind projects and was fully subscribed within 3 weeks of its first availability.

Currently, there are at least 440 MW of new community-owned wind projects in the advanced planning stages, located mostly in the Midwest. The Governor of Minnesota has pledged that 800 MW of new C-BED projects be developed within the state. However, community wind project developers are expecting to utilize turbines larger than 1 MW for nearly all of this new capacity because of their better economics. Nebraska, Texas, and Colorado are also emerging as leaders in the community wind market. Other states, including Oregon and Washington, have taken an interest in community wind, commissioning several studies to examine the barriers, economic impacts, and best models for community wind energy development [2].

John Deere recently provided equity investments in several wind energy projects in Minnesota, Texas, and other rural areas in the United States and abroad, creating a business unit to provide project development, debt financing, and other services to farmers interested in harvesting the wind. Deere's new wind-energy initiative, supporting the company's goal of "helping its customers improve their profitability and productivity," signifies major growth potential in the market segment in attracting such a leading financial service provider.

More than 500 participants attended Windustry's third national Community Wind Energy Conference in Des Moines, Iowa, in March 2006 to learn about new models, best practices, and new state and federal programs that will promote community wind energy in the future.

IV. Market Barriers Issues & Assessment

Expected U.S. Market for "Small-Scale" Community Wind Applications

To date, about 110 MW of "small-scale" community wind capacity is installed in the United States, primarily in the Midwest [3][5]. Minnesota's experience with community wind may be viewed as an indicator of the potential market for community wind in the United States given sufficient incentives, adequate wind resources, and an ample supply of cost-effective mid-size wind turbines. In 1997, Minnesota enacted a production incentive available for the first 100 MW of "small-scale" wind projects (less than 2 MW each) that applied. After 5 years, the limit was reached, and in 2003 the state legislature extended the incentive to cover an additional 100 MW. This time, the incentive was fully subscribed within 6 months [4].[6] Even more indicative of potential growth is the fact that community wind projects in Minnesota are becoming cost competitive with larger commercial projects [5].

To estimate the future domestic market of "small-scale" community wind, this study examined both the DOE Energy Information Administration (EIA) U.S. wind capacity growth estimates and historical U.S. wind capacity growth. Because community wind has recently emerged in the U.S. market, these numbers do not specifically account for community wind growth but can be used in conjunction with recent "small-scale" community wind trends to create a reasonable estimate for future growth. Because "small-scale" community wind often competes with commercial wind in the market, using total wind capacity projections to estimate growth for this sector is not an unreasonable assumption.

Some areas have developed markets specifically for community wind energy. In November 2005, the Governor of Minnesota announced his administration's objective to have 800 MW of Community-Based Energy Development (C-BED) projects commissioned by 2010. With growing interest in several states including Colorado, Oregon, and Massachusetts, similar markets could be created for "small-scale" community wind projects, creating substantial market growth even greater than the wind industry in general.

EIA estimates that total U.S. capacity will grow at an average annual rate of 11% from 2005 to 2010 and then 3% from 2010 to 2020 [6]. However, from 1998 to 2003, installed wind capacity grew an average of 28% per year [7], and growth from 2004 to 2005 was a record 35% [8]. This study estimates a conservative annual growth rate for "small-scale" community wind to be 8%. With favorable policies, economic conditions, and sufficient supply of competitively priced mid-size wind turbines, the estimated average annual growth rate for this sector could be as high as 28%.

As shown in the Summary Information Table (Table 5-3), this study estimates that the cumulative installed U.S. capacity of "small-scale" community wind in 2010 has a lower bound of 220 units, totaling 160 MW, and an upper bound of 500 units, totaling 380 MW[7]. These estimates are based on the 110 MW of installed "small-scale" community wind capacity as of

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[5] See Appendix A for a listing of community wind projects utilizing 100-kW to 1-MW wind turbines.

[6] Some of the projects listed in this cited report are turbines over 1 MW and therefore do not fit the definition of "small-scale" community wind for this study.

[7] Estimates assume an average turbine size of 750 kW, which is the current average for U.S. "small-scale" community wind projects utilizing turbines 1 MW or less, documented in the Windustry database.

2005, the current average “small-scale” community wind turbine size of 750 kW, and the estimated lower- and upper-bound growth rates discussed above. Assuming the same growth rates, the lower- and upper-bound estimates for the cumulative installed U.S. capacity for this sector are 320 to 1,700 units totaling 240 to 1,300 MW in 2015 and 470 to 6,000 units totaling 350 to 4,500 MW in 2020.

Regions of interest. Based on projects installed and planned as documented in Windustry’s community wind database, as well as responses to the January 2006 survey of 46 key industry participants conducted for this study, ten of the states of specific interest for the “small-scale” community wind market fall into three primary regions:

- Midwest (Minnesota, Iowa, Nebraska, Texas, North Dakota, South Dakota, Illinois)
- Northeast and Mid-Atlantic (including Massachusetts, New York, Vermont)
- West (Colorado, Montana, California, Oregon, Washington, Alaska).

Expected International Market for “Small-Scale” Community Wind Applications

The European Union (EU) has been the historic leader in community wind. In 2000, about 80% of installed wind turbines in Europe could be considered community wind [9]. By the end of 2005, Europe had 40.5 GW of installed capacity and therefore close to 32 GW of community wind [10]. Since Europe is by far the largest market for community wind, assuming that 25% of these turbines are 1 MW or less with an average turbine size of 750 kW, a fair estimate of the current international market in this sector is 11,000 turbines totaling 8.1 GW.

From 1995 to 2005, Europe realized an average annual growth in wind capacity and number of installations of 32% and 22%, respectively [11]. Using this historical information and recent trends, this study estimates the future international market for “small-scale” community wind to have a lower-bound annual growth rate of 10% and an upper bound of 22%. The slightly higher lower-bound estimate, compared to the U.S. estimate, reflects the fact that the “small-scale” community wind market is already firmly established in the EU. The upper-bound estimate is lower than the U.S. estimate for this sector, reflecting the maturity of the European market and the overall direction of the EU wind market toward large offshore wind development.

Starting with the estimated total installed capacity of 8.1 GW in 2005 and assuming an average turbine size of 750 kW, this study estimates that the international cumulative installed capacity in 2010 will have a lower bound of 17,000 units totaling 13 GW and an upper bound of 29,000 units totaling 22 GW (Table 5-3). Assuming the same growth rates, our lower- and upper-bound estimates for cumulative international installed capacity are 28,000 to 79,000 units totaling 21 to 59 GW in 2015 and 45,000 to 210,000 units totaling 34 to 160 GW in 2020.

Regions of interest. Responses to the survey conducted for this study indicate that the major international markets for “small-scale” community wind, offering substantial export opportunities for U.S. manufacturers of mid-size turbines, fall in the following regions:

- Europe (Germany, Spain, Denmark, Norway, Netherlands)
- Asia (China, India, Russia)
- South America/Central America

- Africa
- Canada.

Germany and Spain are of particular interest and currently are leading the EU in growth and installed capacity. These two countries accounted for 58% of the total wind capacity growth in the EU in 2005 and 70% of the total installed capacity in the EU [12]. Canada shows signs that it will follow the lead of many European nations by enacting feed-in tariff laws to encourage wind energy growth. To date, only Ontario has enacted a feed-in tariff, but there has been growing support by other Canadian provinces to enact similar tariffs.

"Small-Scale" Community Wind Technology Adoption Time Frame

The entire wind industry would benefit from a concerted media campaign with increased news coverage of positive reports on the successes of wind power, similar to current press conferences on "clean coal" and nuclear energy, and highly visible recommendations to elected officials to maximize the use of abundant wind resources for clean electricity generation within the next two decades. Global energy supplies are at a point where as much wind as possible needs to be installed on a short time frame to prove it can be successfully integrated into the grid and other existing infrastructure. Because distributed wind generation can be installed in a shorter turn-around time than large-scale wind farms, identifying and addressing the barriers for "small-scale" community wind should be considered a high-priority activity. Field studies on the distribution grid need to be conducted before and after distributed wind generation is installed so the costs and benefits can be clearly documented and highlighted for administrative and policy proceedings. Results and recommendations are critical in building arguments such as in Illinois, where Commonwealth Edison (ComEd) has proposed energy fees for community wind projects. ComEd plans to track the penalties for imbalance that FERC allows without giving credit for benefits such as reinforcing the grid.

Utilities often highlight the negative impacts of distributed generation in interconnection policy proceedings; however, the benefits to the grid are rarely recognized. For example, distributed wind turbines installed in strategic locations can provide reactive power support with substantial benefits to weak feeders that experience voltage-regulation problems. Technical guidance and strategies are critically needed for using the grid more efficiently.

Given the boom-or-bust cycles in the utility-scale wind turbine industry, small community wind project developers are often squeezed out of the market when manufacturers deal almost exclusively in large volume orders rather than the one or two turbines that many community wind projects seek. This is leading some community wind developers to consider smaller turbines in the 50-kW to 500-kW range as a viable alternative to the more cost-effective multi-megawatt turbines. Only a few turbine suppliers, including Energy Maintenance Services, Fuhrlander, and Entegrity have products available to fill this growing niche.

The lack of available mid-size wind turbines has led to other problems with the development of "small-scale" community wind projects. Because the PTC is difficult for most community wind project owners to utilize on their own because of the requirement for large passive tax appetites[8],

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[8] Passive tax refers typically to tax paid on rent, interest, and dividends, as opposed to earned income. A 1-MW wind project with a capacity factor of 33% has the potential to utilize about $55,000 per year based on the PTC's current level of 1.9 cents per kWh, which is above the level of many community members or groups wishing to *(footnote continued)*

equity partner investors must be found before financing can be secured. Power purchase agreements must be negotiated with the host utility, and insurance must be secured based on specific equipment orders. All of this means that the developers of community wind projects must juggle many balls, and the falling of one means the unraveling of an entire project. Once the project developer identifies an interested equity partner and secures financing, the availability of the PTC narrows the potential construction window. Inside that window, the developer must secure firm delivery on the turbine, tower, transmission/interconnection requirements, critical construction equipment including an adequate crane, permitting (including conditional use permit or zoning approval), project financing, and a power purchase agreement before the expiration of the PTC. While larger projects face these same obstacles, they are in a much better position to gain the attention of equipment manufacturers, contractors, investors, and financers.

Some "small-scale" community wind project developers have turned to the used wind turbine market for hardware to install in lieu of new equipment. There are several challenges with this. First of all, this equipment is typically not optimized for Class 3 sites where there is much interest in small wind projects. More important, these older designs are not able to take advantage of the technology advances that have occurred in the past two decades and often have not completed a comprehensive "remanufacturing" process.

Finally, some investors are beginning to look at biodiesel, landfill gas, biomass, cogeneration, and ethanol as investment opportunities. Unfortunately, if mid-size wind turbines cannot meet the needs of investors and owners in a reasonable time frame and supplement these technologies, the distributed generation market will move forward without the significant participation of "small-scale" community wind.

Based on analysis of critical path technologies, the following measures are expected to enhance the viability of the "small-scale" community wind market:

- Conducting more in-depth analysis of the steps needed to transition the utility grid from the one-way distribution of energy that it was originally designed for into an efficient multi-direction system that not only distributes electrons but also acts as an aggregator for electricity produced in rural areas.
- Incorporating voltage support capability into turbine designs to increase benefits from distributed wind generation in areas with weak grids. The technology already exists and needs to be made available to the U.S. market. One mechanism would be the development of a national standard or grid code for voltage support from distributed wind, similar to the Irish, Danish, and German grid codes, incorporating standard interconnection technical requirements for wind energy conversion systems.
- Designing reliable, easily installed, and easily maintained advanced mid-size wind turbines that are optimized for Class 3 wind regimes based on existing designs. This could be accomplished in a year with sufficient funding. Bringing that design to the prototype stage would take another year, followed by at least 2 years of beta testing. It would take another

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invest in wind energy. Tax-free institutions such as public schools, government agencies, and non-profit organizations suffer from the inability to utilize this incentive.

year to prepare the new product for the market, bringing the total timeframe for adoption to 5 years.

- Developing advanced controllers that meet a certified national standard. These could be designed in a year, with field testing and certification by a certifying agency like Underwriters Laboratories (UL) consuming another 2 years.
- Developing user-friendly computer tools for analyzing "small-scale" community wind project economics to assist with seeking project financing, negotiating power purchase agreements, and taking advantage of incentives.

Non-Technical Barriers for "Small-Scale" Community Wind Technology Adoption

As shown in Table 5-1, responses to the January 2006 survey of key DWT industry participants conducted for this study indicate that the most significant market barriers for "small-scale" community wind are turbine availability, economics, interconnection, and permitting[9]. New legislation supporting locally owned wind projects could include incentives for rural electric co-ops to develop their own projects and/or partner with their members, financial vehicles allowing capital for distributed wind projects to aggregate, and interconnection standards.

Turbine availability. As described above, large-scale wind turbine production continues to be driven by the PTC, which results in turbine shortages for the "small-scale" community wind market, inflated costs, and an industry emphasis on the largest turbines commercially available.

Economics. Coordinated public policy and consumer awareness programs are needed to aid "small-scale" community wind development in meeting market demand. Economic factors, in order of importance, include the following:

- Total installed cost
- Return on investment (perception of value)
- Inadequate net metering/net billing
- Lack of project financing
- Permitting costs and time
- Lack of utility-sponsored programs and marketing for wind
- Lack of financial incentives (rebates, buy-downs, loans)
- Lack of tax incentives (sales, property).

Interconnection. Connecting to the grid with rural electric co-ops and investor-owned utilities is ranked as an important market barrier for "small-scale" community wind. Increased awareness and support among public and private utility personnel will be necessary for wind to be included in utility-marketing distributed generation programs. A marketing and public awareness program targeted at utilities would benefit "small-scale" community wind, with particular emphasis on

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[9] Online survey of key industry participants conducted in January 2006 for this study.

outreach to rural utility representatives highlighting customer satisfaction and community stakeholder benefits of generating electricity with locally owned mid-size wind turbines.

Permitting and siting. The development of a set of regional model zoning ordinances for mid-size wind turbines with consideration given to proper setbacks for sound levels and safety, attention to avian issues and wildlife areas, and visual impacts on the landscape, with different conditions based on land use and the size of projects, could help to streamline permitting processes for “small-scale” community wind projects. Dissemination of best-practice recommendations and education of local planning agencies can aid in the adoption of responsible and appropriate siting requirements for community wind projects.

Table 5-1. 2006 Survey Responses on “Small-Scale” Community Wind Market Barriers

Community Wind Market Barriers	**Not an issue**	**Moderately Low**	**Medium**	**Moderately High**	**Biggest Barrier**	**Response Average**
Turbine availability	3% (1)	15% (5)	**29% (10)**	**29% (10)**	24% (8)	3.56
Economics/out-of-pocket costs (total installed cost)	0% (0)	12% (4)	30% (10)	**48% (16)**	9% (3)	3.55
Economics/perception of value (cost of energy, return on investment)	3% (1)	11% (4)	34% (12)	**37% (13)**	14% (5)	3.49
Connecting to the grid (rural electric co-op)	9% (3)	12% (4)	26% (9)	**32% (11)**	21% (7)	3.44
Connecting to the grid (investor-owned utility)	9% (3)	16% (5)	28% (9)	**38% (12)**	9% (3)	3.22
Inadequate net metering/net billing	9% (3)	24% (8)	24% (8)	**33% (11)**	9% (3)	3.09
Lack of financing	3% (1)	26% (8)	**35% (11)**	32% (10)	3% (1)	3.06
Permitting costs and time	6% (2)	23% (7)	**45% (14)**	16% (5)	10% (3)	3.00
Visual impacts/neighbor concerns	7% (2)	30% (9)	23% (7)	**37% (11)**	3% (1)	3.00
Lack of utility-sponsored programs and marketing for wind	6% (2)	25% (8)	**38% (12)**	25% (8)	6% (2)	3.00
Lack of incentives (rebates, buy-downs, loans)	9% (3)	27% (9)	27% (9)	**30% (10)**	6% (2)	2.97
Restrictive zoning	6% (2)	28% (9)	**44% (14)**	6% (2)	16% (5)	2.97
Lack of tax incentives (sales, property)	12% (4)	21% (7)	**36% (12)**	27% (9)	3% (1)	2.88
Low public awareness/support	10% (3)	**29% (9)**	**29% (9)**	**29% (9)**	3% (1)	2.87
Owner/Operator Convenience/Complexity (siting, installation, maintenance)	13% (4)	23% (7)	**37% (11)**	27% (8)	0% (0)	2.77
Wind myths (reliability, sound, aesthetics, safety, avian impact)	10% (3)	**32% (10)**	**32% (10)**	26% (8)	0% (0)	2.74
Lack of consumer access to wind resource information/maps	26% (8)	32% (10)	**42% (13)**	0% (0)	0% (0)	2.16

Time-Critical Nature of “Small-Scale” Community Wind Technology

Community wind projects are characterized by desires to own productive wind assets for the benefit of investor groups, public, educational, tribal, special district, or cooperative corporate entities. Often the motivation is to invest for the benefit of a local (usually rural) area by keeping money in the local economy, rather than paying for imported fuel resources or returning investment profits to remote owners. The projects aim to create, and keep, an economic surplus by using local wind resources, owning the means of production locally, and supplying power on an export basis to bring money into the local economy. These projects are normally of a scale that requires power purchase agreements with utilities or access to real-time markets that can absorb power in addition to the requirements of the local owning entity. At the same time, the scale of these projects does not generally offer access to markets for the lowest cost power because they are generally too small to achieve the economies of scale of larger commercial projects.

Critical timing issues impact numerous characteristics of "small-scale" community wind projects, including the following:

- The availability of the federal PTC or a comparable incentive and whether "small-scale" community projects can find business and tax structures to benefit from it
- For turbine prices and availability, mechanisms for encouraging the aggregation of "small-scale" community wind turbine purchases and the cooperation between community wind and large commercial projects can be created to help address these issues
- For access to low-cost financing, Clean Renewable Energy Bonds (CREBs), for example, are limited in amount and have short application deadlines[10], and USDA grant programs are not guaranteed to be fully funded
- The staying power of community wind power proponents is a factor. The leadership required to mount and sustain a community wind project proposal can be exhausted by the need for a long campaign to structure an entity, identify land, access wind data, complete required studies, obtain a conditional use permit or zoning approval, and secure easements, turbines, transmission access and terms, and negotiate a power purchase agreement
- Policy and program support is needed. There is tremendous potential for the renewable energy initiatives in the Farm Bill to grow to be a significant aspect of the rural economy, but technical guidance is needed to prepare the rural infrastructure in anticipation of more distributed wind generation. Once the grid integration issues are addressed, policies can be developed to give priority to local generation. Because the economics of the power from smaller wind projects do not readily win contracts in bulk-power markets focused on lowest costs, sources of additional support, either in policy or financially, must be located, engaged, and brought to bear on projects. The timing and effectiveness of programs and policies that support "small-scale" community wind projects have an important impact.
- The output of community projects can usually only be sold to a single buyer: an electric utility. Because most projects are in rural areas and many rural areas do not have access to effective competitive wholesale electric energy markets, the cooperation of an electric utility will be required to purchase the power produced by the community-owned project. Utility cooperation varies widely, depending on the market and policy conditions that impact utility generation acquisitions. Policy can create markets for community wind, as evidenced by initiatives in Iowa and Minnesota that are leading the way.

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[10] Made available on 1/1/2006, applications are due 4/26/2006 for all CREBs to be issued before 1/1/2008.

Subsidy Market for "Small-Scale" Community Wind

The U.S. government offers a variety of incentives for wind projects, including USDA Farm Bill Section 9006 grants, the Production Tax Credit[11], an accelerated depreciation system, and the Renewable Energy Production Incentive (REPI)[12]; however, few are optimal or available for mid-size turbines. Community wind projects are beginning to receive some subsidies from states, although the current state subsidy market is still limited. In Minnesota, noteworthy exceptions are Xcel Energy's standardized purchase tariffs; Renewable Energy Production Incentive (Minnesota REPI); tiered tax rates[13]; Xcel Energy Renewable Development Fund; and standardized interconnection policies are noteworthy exceptions. Low-interest loans, grants, tax deductions, and technical assistance are also available in some states [13].

In the international community, particularly in EU countries, feed-in tariffs[14] have led to substantial community wind markets [14]. Germany has had a renewable tariff policy since 1991 and currently has more total wind capacity (more than 18,000 MW) than any other country in the world [15]. Ten countries[15] currently have some variation of a feed-in tariff for wind generation [16].

Utility Industry Impact of "Small-Scale" Community Wind

Community wind projects utilizing turbines less than 250 kW in size have negligible electrical impact on the distribution grid, whereas a 2-MW wind project can have a potentially significant electrical impact on a 12.47-kV rural distribution grid and limit locations for connection to the distribution grid. Excess generation from most community wind projects is sold directly to the local distribution utility or its wholesale provider at the established "avoided cost" or a relatively low wholesale rate in the 3¢ to 4¢ per-kWh range. Under this arrangement, the wind generation does not reduce the retail revenue of the local utility and thus should not affect the local utility's finances. Instead, the wind turbine becomes just another bulk power resource used by the wholesale power supplier in the area. Therefore, even though there are some exceptions, the local distribution utility should be indifferent to community wind generation.

Mid-size wind turbines used to provide power to schools or businesses under net metering policies can cause noticeable reductions in small utilities' retail revenue. In these instances, the local utility may discourage a large number of these installations. However, in general, "small-scale" community wind should have minimal impact, if any, on the utility industry's electrical system or finances.

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[11] The Renewable Electricity Production Tax Credit (PTC) has expired three times since it was first enacted in 1992. The PTC provides $0.019/kWh and is currently effective until the end of 2007.

[12] REPI provides $0.015/kWh and was effective until the end of 2006.

[13] For more than 12 MW, the tax is 0.12 cents/kWh, between 2 MW and 12 MW the tax is 0.036 cents/kWh, and for projects between 0.25 MW and 2 MW the tax is 0.012 cents/kWh.

[14] Feed-in tariffs create a standard permitting process and a fixed price for electricity purchased from specified renewable electricity generators.

[15] This number does not include the United States, although Minnesota has initiated a limited renewable tariff and California currently has a renewable feed-in tariff for PV. Countries that currently have renewable tariffs for wind generation include Austria, Brazil, China, France, Germany, Greece, PEI (Canada), Portugal, Spain, and The Netherlands. For a complete listing of international renewable energy policies, see the International Energy Agency Global Renewable Energy Policies and Measures Database at www.iea.org/textbase/pamsdb/grresult.aspx?mode=gr

V. Technical Barriers Issues and Assessment

Technology Barriers for “Small-Scale” Community Wind

Four primary technical barriers have been identified that are slowing the widespread application of “small-scale” community wind projects. These barriers are listed in order of importance and share some commonality over a wide range of turbine sizes. Table 5-2 shows responses to the January 2006 survey of key DWT industry stakeholders conducted for this study on technical barriers for “small-scale” community wind.

Grid interconnection and integration. Interconnection processes could be greatly simplified by more sophisticated remote-monitored controllers, which are certified to meet a national standard. Such controllers can allow the turbine to support weak rural distribution systems while taming voltage excursions, flicker, and supplying reactive power support to the system, as well as monitoring system health and logging important system events.

Distributed generation grid-integration studies completed to date are just a starting point. More in-depth analysis is needed on what is required to transition the utility grid system from the one-way distribution of energy that it was designed to do into an efficient multi-direction system that not only distributes electrons but also acts as an aggregator for electricity produced in the rural areas of the countryside. The national grid is woefully inadequate to function this way today. The discussion must progress to understand what technologies are required to move forward.

Turbine and tower options. Technology is needed to optimize the next generation of mid-size wind turbines for Class 3 wind regimes. Advanced rotors with lower rotational speeds could yield longer fatigue life and lower acoustic emissions. Innovative tall towers, especially for refurbished machines, would boost energy capture while diminishing turbulence.

Installation and maintenance. Reliability and maintainability are becoming more of an issue for community wind projects as challenges with heavy crane access, a lack of trained technicians, and parts shortages are leading to delays in installation and increased turbine downtime. Easing the installation complexity while increasing the reliability and service intervals of future mid-size wind turbines, along with simplifying the troubleshooting and maintenance regimen, could make the community wind machine just another agricultural implement. The development of “wind smith” technical programs to provide for a larger set of skilled turbine technicians to aid in operations and maintenance of community-owned projects will be key.

Performance projections. Although current resource assessment techniques have yielded satisfactory results, a more timely means of quantifying a wind regime must be found. Wind resource modeling coupled with short-term on-site measurement and correlation to a base station has been helpful for numerous sites in Iowa. Wind resource assessment programs specifically targeting “small-scale” community wind projects coordinated with rural economic development agencies could greatly aid the market. Wind forecasting, which is becoming fairly common in the larger wind farms, could be applied to distributed systems and add value to their energy product.

Community wind can make it possible for small rural groups to take an active role in their energy future while providing all the benefits of placing clean generation close to the point of use. By spreading distributed generation over a broad area, energy security and grid stability can be greatly improved.

Table 5-2. 2006 Survey Responses on "Small-Scale" Community Wind Technical Barriers

Community Wind Technical Barriers	**Not an issue**	**Moderately Low**	**Medium**	**Moderately High**	**Biggest Immediate Challenge**	**Response Average**
Grid interconnection	7% (2)	7% (2)	28% (8)	**38% (11)**	21% (6)	**3.59**
User-friendly peformance ratings for mid-sized and refurbished turbines	4% (1)	29% (7)	**38% (9)**	29% (7)	0% (0)	**2.92**
Hardware & shipping costs	11% (3)	30% (8)	**37% (10)**	7% (2)	15% (4)	**2.85**
Manufacturer support	4% (1)	28% (7)	**48% (12)**	20% (5)	0% (0)	**2.84**
Installation	8% (2)	**35% (9)**	**35% (9)**	19% (5)	4% (1)	**2.77**
Product Reliability	12% (3)	**38% (10)**	23% (6)	23% (6)	4% (1)	**2.69**
Maintenance costs	12% (3)	31% (8)	**42% (11)**	15% (4)	0% (0)	**2.62**
Power electronics & software	4% (1)	**48% (12)**	36% (9)	12% (3)	0% (0)	**2.56**
Sound levels/quiet operation	8% (2)	**48% (12)**	28% (7)	16% (4)	0% (0)	**2.52**
Engineering or reengineering of specific turbine components	15% (3)	**50% (10)**	10% (2)	20% (4)	5% (1)	**2.50**
Designing self-erecting capabilities	24% (6)	**40% (10)**	8% (2)	24% (6)	4% (1)	**2.44**
High cut-in speed/complete turbine redesign	13% (3)	**58% (14)**	17% (4)	13% (3)	0% (0)	**2.29**

Complexity of "Small-Scale" Community Wind Technology Barriers

Each of the barriers discussed in the previous section presents substantial technical challenges that can be reduced or eliminated by focused R&D efforts.

The electricity grid is regarded as the most complicated system that humankind has ever constructed. Understanding its limitations and how to utilize it more efficiently should be a national priority. Building on and expanding the scope of distributed wind generation grid integration studies, such as those performed by Tom Wind and Mike Michaud, focusing on key states, can help to show that the traditional approach of extensive upgrades to the transmission system is not always the most economic and efficient way to expand the market for renewable energy. Conducting these studies will take the cooperation of utility companies; researchers; politicians at the local, state, and national level; and community groups examining the actual and potential impact of distributed wind generation on existing transmission and distribution infrastructure. More detailed studies must be carried out on the local distribution level to define where added generation can be connected with minimal system upgrade costs, which typically are assigned to interconnecting project owners.

A new generation of mid-size turbines designed for low-wind regimes will obviously require the application of many technologies and require a substantial investment. This process could begin immediately and take advantage of new technologies or design methods that become available during the design. Use of innovative tower concepts for new or refurbished systems is likely to require substantial design analysis to ensure that dynamic interaction problems will not be induced by the new towers. The basic technology required for this process is available now.

VAR (volt-amperes reactive) support will be very valuable for mid-size turbines located on weak distribution systems. Power electronics systems should be developed and made available as soon as possible.

Federal support in the form of technical assistance, information dissemination, and university research programs will be very important to establishing a trained workforce to operate, maintain, and design "small-scale" community wind projects. The wind industry is unlikely to create "wind smith" training programs at community colleges or wind-engineering programs at universities tailored toward mid-size wind turbines without federal or state support.

The economics of community wind projects rely on credible wind data, turbine-performance data, and energy projections. It is essential that tools be available for establishing and confirming mid-size turbine performance projections in a timely manner.

Expected Turbine Size to Meet "Small-Scale" Community Wind Market

The optimal turbine size for the "small-scale" community wind market ranges significantly depending on ownership, availability of land, ability to contribute significant amounts of renewable energy to the grid, ability to acquire financing, ease of operations and maintenance, state incentives, and ease of interconnection. The range most frequently cited in the January 2006 survey conducted for this study was 100 kW-1 MW because of the intersection of many of the previously mentioned factors. If cost-competitive turbines in this range are made available, many "small-scale" community wind projects may opt to install one or multiple machines of a smaller size than the multi-megawatt-class machines advanced by the major turbine manufacturers. They would do this because of the simpler design and lower capital requirements of the smaller machines, making maintenance and financing easier. High thresholds on net-metering rules in several states[16] allow for matching turbine size to the load at the site for medium-size loads, such as schools, businesses, and many manufacturing facilities. Respondents also indicated that machines in this range are of appropriate sizes to match loads of hospitals, public schools, and small industry and have a similar return on investment as the multi-megawatt machines with a smaller investment threshold.

Currently, only a few commercial models are available in this size range, including the Suzlon 950 kW; the Fuhrlander FL 100, FL 250, FL 600, and FL 1000; the EMS 65 kW; and the Entegrity 50 kW. However, production numbers are limited, and manufacturers are challenged to keep up with the market growth rate for this size range, making it difficult for “small-scale” community wind developers to obtain equipment.

Required Cost of Energy to Compete in “Small-Scale” Community Wind Market

The primary alternatives to “small-scale” community wind are large-scale community wind and commercial wind projects. Based on current incentives that are driving community wind development in Minnesota (currently $0.01/kWh REPI) and Iowa ($0.015/kWh Personal Renewable Energy PTC), the necessary cost of energy for most community wind projects to be competitive is, therefore, roughly within $0.015 of commercial wind farms [17], which is currently around $0.05/kWh.

The survey of industry participants conducted for this study indicated a range of $0.03-0.15/kWh in the retail cost of energy for wind systems to compete in the community-scale distributed generation market, with most responses between $0.05 and $0.08/kWh.

Seasonality and Geographic Nature of Wind Resource

Community wind projects are generally connected to the grid and, therefore, typically have no need for storage; however, wind regime characteristics are both seasonal and geographic in nature. Many locations suitable for “small-scale” community wind experience more wind in winter months but have higher electricity loads in summer months. The more closely the wind resource matches local load (peak coincidence), the more valuable the wind resource and economic benefit of the project. Annualized net metering can also aid “small-scale” community wind market.

Interconnection processes and access to the grid vary considerably on a geographic basis. Windy rural areas have low population densities and weaker girds than more populated regions, making costs high and availability low for interconnection points. More in-depth analysis of these issues will allow for greater understanding of how best to utilize existing resources and more efficiently design upgrades and additions to distribution systems to facilitate more distributed wind generation in rural areas.

Impact of Intermittency

Intermittency is a significant issue for “small-scale” community wind applications. Schools and large businesses purchase electric power under utility tariffs that typically have both demand and

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[16] In Iowa and Virginia, the size limit for net-metered wind energy facilities is 500 kW, and in California net metering is allowed up to 1000 kW in name plate capacity (DSIRE).

energy charges. If the community wind turbine is used to offset power purchases for a school or large business, then the intermittent power output may not be able to reduce the demand charge significantly in the electric power bill. Because up to two-thirds of the electric bill can be for the demand charge, the power bill savings from the wind turbine would be much less because of the intermittency. If the school or business could switch tariffs to one that only has energy charges, then the power bill savings would be at a rate about equal to the retail rate.

One way to mitigate the loss of value caused by intermittency is to install equipment that stores either electrical or thermal energy. The added cost of electrical storage equipment, such as a battery and inverter, is typically only justified for smaller off-grid applications where the price of utility power is high. However, using wind generation to reduce natural gas or fuel oil usage for heating is potentially cost effective in some cases, especially if heat can be stored in the form of hot water. The cost effectiveness derives from the fact that a larger wind turbine can be justified as a result of the increased need for electricity for heating. This type of project also requires a control system to determine when and how much of the wind generation output is converted into heat for storage rather than simply used to offset electric usage. Using a wind turbine with a thermal heat storage unit has the potential to greatly reduce natural gas or fuel oil usage for heating. One barrier to this concept is the restriction that the Federal PTC only applies to power sold to a third party, rather than to power used locally for offsetting electrical usage or saving natural gas.

If the entire output of a community wind turbine is simply sold on a wholesale basis to the local utility, electricity storage is not likely to be cost-effective because the added cost of the electrical storage equipment is usually much higher than the cost of incorporating the variable output with the utility's other generation resources. Even if the local wind generation penetration is very high, such as in Denmark, electrical storage would probably only be cost effective on a large scale at a central facility, such as with pumped hydro or compressed-air energy storage.

Interface for "Small-Scale" Community Wind

Typical interfaces for "small-scale" community wind installations are dedicated three-phase transformers connecting to distribution feeders (typically 13.8 kV or lower) for projects consisting of one or a few mid-size turbines, in comparison to dedicated three-phase substations connected to the transmission system (69 kV and higher) for multiple large-turbine projects. Appropriate fuses, breakers, relays, and other switch gear are needed for large-scale applications to ensure power system safety under abnormal operating conditions. Standardization for appropriate integration studies and required interconnection equipment for single or small aggregations of large turbines (in the 0.5-20 MW installed capacity range) has happened in many states in response to increased levels of distributed generation resources on systems. Larger projects will still require an extensive engineering study to determine the appropriate equipment necessary to safely interconnect.

Most community wind applications sell power to the grid, although many "small-scale" installations offset at least a portion of the power coming in. Specific applications typically have power electronics available to condition the power generated because power from wind turbines above about 30 kW is three-phase, 60 Hz, and around 600V. The only interface technology needed is a transformer to step up or down the voltage. Further research in the area of reactive power compensation, voltage support, and flicker mitigation will add value to distributed wind generation for interconnecting utilities and can help minimize or eliminate the need for distribution feeder upgrades.

VI. Recommended Areas of Technical Concentration

The U.S. "small-scale" community wind market and U.S. participation in the international "small-scale" community wind market have major growth potential but are currently facing major market and technical constraints that could be addressed with focused support. In particular, turbine production numbers are limited, and manufacturers are not keeping up with the rate of market growth for this size range, making it difficult for "small-scale" community wind developers to obtain equipment. Reliability and maintainability are becoming more of an issue for community wind projects as challenges with heavy crane access, a lack of trained technicians, and parts shortages are leading to delays in installation and increased turbine downtime.

The Future

A new generation of mid-size turbines designed for low-wind regimes will obviously require application of many technologies and a substantial investment. This process could begin immediately and take advantage of new technologies or design methods that become available during the design. Use of innovative tower concepts for new or refurbished systems is likely to require substantial design analysis to ensure that dynamic interaction problems will not be induced by the new towers.

Based on market and technical issues discussed above, the following high-priority areas are recommended for future investment with more detailed studies.

Grid interconnection and integration. Interconnection processes could be greatly simplified by more sophisticated remote-monitored controllers that meet a certified national standard. Such controllers can allow the turbine to support weak rural distribution systems while taming voltage excursions and flicker and supplying reactive power support to the system, as well as monitoring system health and logging important system events.

Distributed-generation grid-integration studies completed to date are just a starting point. More in-depth analysis is needed on what it will take to transition the utility grid system from the one-way distribution of energy that it was originally designed for into an efficient multi-direction system that not only distributes electrons but also acts as an aggregator for electricity produced in rural areas. The national grid is woefully inadequate to function this way today. What is required to develop an infrastructure that would more easily integrate distributed wind technology?

Turbine and tower options. Innovative tall towers, especially for refurbished machines, would boost energy capture while diminishing turbulence. Easing the installation complexity while increasing the reliability and service intervals of future mid-size wind turbines, along with simplifying the troubleshooting and maintenance regimen, could make the community wind machine just another agricultural implement.

Installation and maintenance. NREL's expert assistance in the development of technical training programs for mid-size turbine "windsmiths" can help increase the availability of installation and maintenance crews for smaller community-owned projects.

Performance projections. Easy-to-use computer tools for analyzing "small-scale" community wind project economics would assist with seeking project financing, negotiating power purchase agreements, and taking advantage of incentives. User-friendly wind resource modeling with on-site measurement correlations could make annual power prediction much easier.

Zoning and permitting. Development of a set of regional model zoning ordinances for mid-size wind turbines with consideration given to proper setbacks for sound levels and tower fall zones, attention to avian migration patterns and wildlife areas, visual impacts on the landscape, with different conditions based on land use and the size of projects could help to streamline the permitting process for community wind projects. National participation combined with education of local zoning agencies can aid in the adoption of responsible and appropriate siting requirements of community wind projects.

Table 5-3. Summary Information Table: “Small-Scale” Community Wind Power

Domestic Market Potential for “Small-Scale” Community Wind

(cumulative installed capacity)

2005	110 MW	150 Units
2010	160 – 380 MW	220 – 500 Units
2015	240 – 1,300 MW	320 – 1,700 Units
2020	350 – 4,500 MW	470 – 6,000 Units

Regions (States) of Specific Interest

1. Midwest (Minnesota, Iowa, Nebraska, Texas, North Dakota, South Dakota, Illinois)
2. Northeast and Mid-Atlantic (including Massachusetts, New York, Vermont)
3. West (Colorado, Montana, California, Oregon, Washington, Alaska)

International “Small-Scale” Community Wind Market

(cumulative installed capacity)

2005	8.1 GW	11,000 Units
2010	13-22 GW	17,000-29,000 Units
2015	21-59 GW	28,000-79,000 Units
2020	34-160 GW	45,000-210,000 Units

Regions of Specific Interest

1. Europe (Germany, Spain, Denmark, Norway, Netherlands)
2. Asia (China, India, Russia)
3. South America/Central America
4. Africa
5. Canada

Key Market Barriers

1. Turbine availability
2. Economics
3. Interconnection
4. Permitting/Siting

Key Technical Barriers

1. Grid interconnection and integration
2. Turbine and tower options
3. Installation and maintenance
4. Performance projections

Expected Turbine Size Range

1 MW or less for “small-scale” community wind applications

Expected Turbine Coupling

Voltage: 540 V to 660 V AC

Typically connecting to distribution level voltages of 13.8 kV or less

VII. Conclusions

The market for “small-scale” community wind projects is substantial and growing, attracting increasing attention from policy makers, community groups, and economic development professionals. With an estimated 150 turbines currently installed nationally in “small-scale” community wind applications (utilizing turbines 1 MW or less) totaling 110 MW, and an estimated 11,000 turbines installed worldwide totaling 8.1 GW, forecasts based on recent growth rates of the entire wind industry indicate the potential for a substantial market in this sector. Based on lower- and upper-bound growth estimates, this sector is expected to grow to an estimated 470-6,000 “small-scale” community wind turbines totaling 350 to 4,500 MW in the United States and 45,000 to 210,000 turbines totaling 34 to 160 GW internationally.

However, major barriers still exist for community groups seeking to invest in wind energy. Notably, these issues include the boom/bust cycle created by the federal PTC, causing limited availability of field-tested, economical turbines; components; construction crews; operations and maintenance professionals; and experts in business, finance, and legal matters.

Significant attention must be paid to the design and delivery of new mid-size turbine models in the 100- to 1,000-kW range, sized for moderate loads such as schools, businesses, and government buildings and optimized for Class 3 wind regimes with the capability to provide reactive power and voltage support to weak distribution feeders. Addition of such capability will add value to distributed wind energy for utilities, giving it the ability to lessen or mitigate the need for feeder upgrades and reduce transmission congestion.

New tower technologies, such as self-erecting designs, have the potential to decrease the upfront costs of construction, as well as reduce or eliminate the scarcity of cranes.

The development of and support for education programs for technicians skilled in routine and special maintenance of mid-size wind turbines will aid greatly in providing support for current and future “small-scale” community wind projects, as well as help to create a new job sector.

Extension of the PTC for periods of 5 to 10 years, rather than the past 2- to 3-year extension periods, could develop a more stable market for wind energy. A more stable overall wind industry will allow many of the critical market barriers to be addressed by smaller businesses that can develop expertise in all areas of “small-scale” community wind energy development. Steady wind industry growth can also help increase equipment availability; business and financial planning; and crews for construction, operation, and maintenance.

The United States market for “small-scale” community wind and the major international markets for “small-scale” community wind, offer substantial growth and export opportunities for future mid-size turbine suppliers, and project developers. Favorable policies, economic conditions, and the sufficient availability of competitively priced mid-size turbines will help ensure that this sector continues to grow and enable the DWT industry to become one of the leading renewable energy distributed generation industries.

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XI. Appendix A

Table 5-4. Community-Owned Wind Projects Utilizing Turbines from 100 kW to 1,000 kW

Location	State	Name	Owner	Size	# of turbines	Manufacturer	Model	Date of commissioning	Ownership structure
Royal	IA	Clay-Everly Central School District	Clay-Everly Central School District	95	1	Windmatic	17s-95	1986	School
Belcourt	ND	Belcourt	Turtle Mt. Chippewa	100	1	NEG Micon	100 kW	1997	Tribal
Fort Totten	ND	Fort Totten	Spirit Lake Sioux	100	1	NEG Micon	100 kW	1997	Tribal
Boston	MA	IBEW Local 103	IBEW Local 103	100	1	Fuhrlaender	100 kW	2005	Locally owned
Marshalltown	IA	Consumers Energy	Consumers Energy	108	1	Micon	108	2004	Locally Owned
Miner County	SD	City of Canova	City of Canova	108	1	NEG Micon	108	3/1/2002	Municipal Utility
Miner County	SD	City of Carthage	City of Carthage	108	1	NEG Micon	108	5/1/2003	Municipal Utility
Richardton	ND	Richardton	Richardton Abbey	125	1	Silver Eagle	125 kW	1997	Locally Owned
Laker	MI	Laker Elementary School	Laker Elementary school	195	3	Nordtank	65 kW	2005	School
Richardton	ND	Sacred Heart Monastery	Sacred Heart Monastery	200	2				Locally Owned
Miner County	SD	City of Howard	City of Howard	216	2	NEG Micon	108	10/1/2001	Municipal Utility
Boise	ID	Bob Lewandowski	Bob Lewandowski	216	2	NEG Micon	108 kW	2003	Locally Owned
Adair	IA	Schafer Systems, Inc.		225	1	Vestas	225 kW	1994	Locally Owned
Lac qui Parle	MN	Lac qui Parle High School	Lac qui Parle High School	225	1	NEG Micon	225 kW	12/4/1997	School
Riverton	UT	Camp Williams, Utah National Guard	Camp Williams, Utah National Guard	225	1	NEG Micon	225 kW	2000	Government Agency
Near Rochester	NY	Lorax Energy	Harbeck Plastics	250	1	Fuhrlaender	250 kW	2002	Locally owned
Joice	IA	Windway Technologies	Northwood-Kensett School	250	1	Nordex	250	2005	School
Nevada	IA	Story County Medical Center	Story County Medical Center	250	1	Nordex	250 kW		Locally Owned
Princeton	MA	Princeton Muni Light	Princeton Muni Light	320	1	Enertech	320 kW	1984	Municipal Utility
Nevada	IA	Nevada High School	Nevada Highschool	450	2	WinWorld	200 & 250 kW	1998	School
Akron	IA	Akron-Westfield School District	Akron-Westfield School District	600	1	Vestas		1999	School
Forest City	IA	Forest City School District	Forest City School District	600	1	NEG Micon	600 kW	1999	School
Hull	MA	Town of Hull	Town of Hull	660	1	Vestas	V-47	2001	Municipal Utility
Near Valley	NE	Omaha Public Power District	Omaha Public Power District	660	1	Vestas	V-47	2001	Municipal Utility
Wall Lake	IA	City of Wall Lake	Wall Lake Municipal Utilities	660	1	Vestas	660 kW	2003	Municipal Utility
Stuart	IA	Stuart Municipal Utilities	Stuart Municipal Utilities	660	1	Vestas	660 kW	2005	Municipal Utility
American Windmill Museum	TX	American Wind Power Center	American Wind Power Center	660	1	Vestas	V-47	2005	Locally Owned
Riverton	UT	Camp Williams, Utah National Guard	Camp Williams, Utah National Guard	660	1	Vestas	660 kW	2005	Government Agency
Clay County	MN	Moorhead Public Service #1		750	1	NEG Micon	750 kW	1999	Municipal Utility
Clay County	MN	Moorhead Public Service #2		750	1	NEG Micon	750 kW	8/23/2001	Municipal Utility

Location	State	Name	Owner	Size	# of turbines	Manufacturer	Model	Date of commissioning	Ownership structure
Eldora	IA	Eldora-New Providence Community School District	Eldora-New Providence Community School District	750	1	NEG Micon		2002	School
Lenox	IA	Lenox Municipal Utilities	Lenox Municipal Utilties	750	1	NEG Micon	750 kW	2003	Municipal Utility
Rosebud Sioux Reservation	SD	Rosebud Sioux	Rosebud Sioux Tribe	750	1	NEG Micon	750	2003	Tribal
Pipestone	MN	Pipestone School	Pipestone School	750	1	NEG Micon	750 kW	2004	School
Waverly	IA	Waverly Light and Power	Waverly Light and Power	900	1	NEG Micon	NM 900/52	2001	Municipal Utility
East of Petersburg	ND	East of Petersburg	Minnkota Power Cooperative	900	1		900 kW	2002	Rural Electric Cooperative
Valley City, Oriska	ND	Valley City, Oriska Hills	Minnkota Power Cooperative	900	1	NEG Micon	900 kW	2002	Rural Electric Cooperative
Lincoln County	MN	Hendricks Wind I LLC	Thomas Daggett	900	1	NEG Micon	900 kW	5/15/2002	Farmer owned
Lincoln County	MN	Borderline Wind LLC	Jay Gislason	900	1	NEG Micon	900 kW	12/31/2003	Farmer owned
Nobles County	MN	Sieve Windfarm	Don & Janet Sieve	950	1	NEG Micon	950 kW	12/2002	Farmer owned
Spirit Lake	IA	Sprit Lake Community School District	Spirit Lake Community School District	1,000	2	NEG Micon	250 & 750 kW	1992 & 2001	School
Sibley	IA	George Braaksma, et al	George Braaksma, et al	1,200	2	NEG Micon	600 kW	1996	Locally Owned
Lincoln	NE	Lincoln Energy System	Lincoln Energy System	1,320	2	Vestas	V-47	1999	Investor owned utility
Lincoln	NE	Lincoln Electric System	Lincoln Electric System	1,320	2	Vestas	V-47	1999	Municipal Utility
F.E. Warren Air Force Base	WY	F.E. Warren Air Force Base	F.E. Warren Air Force Base	1,320	2	Vestas	660 kW	2005	Government Agency
Spring View	NE	Nebraska Public Power District	Nebraska Public Power District	1,500	2	Enron	Z-46	1998	Investor owned utilty
Springview	NE	Nebraska Public Power District	Nebraska Public Power District	1,500	2	Enron	Z-46	1998	Municipal Utility
Alta	IA	Waverly Light and Power	Waverly Light and Power	1,500	2	Zond	Z-50	1999	Municipal Utility
Murray County	MN	Ed Olsen Wind LLC	Olsen Farms	1,500	2	NEG Micon	750 kW	12/1/2001	Farmer owned
Pipestone County	MN	Kas Brothers Wind LLC	Richard and Robert Kas	1,500	2	NEG Micon	750 kW	12/2/2001	Farmer owned
Dodge County	MN	BT LLC 2002	Brandon McNeilus	1,800	2	NEG Micon	900 kW	2002	Locally Owned
Dodge County	MN	Burmese Children Support	Burmese Children Support	1,800	2	NEG Micon	900 kW	2002	Locally Owned
Dodge County	MN	GarMar Foundation 2002	GarMar Foundation	1,800	2	NEG Micon	900 kW	2002	Locally Owned
Dodge County	MN	GM LLC 2002	Garwin McNeilus	1,800	2	NEG Micon	900 kW	2002	Locally Owned
Dodge County	MN	McNeilus Windfarm (2002)	Grant McNeilus	1,800	2	NEG Micon	900 kW	2002	Locally Owned
Dodge County	MN	SG, LLC	Silvester Stoeckel	1,800	2	NEG Micon	900 kW	2002	Locally Owned
Nobles County	MN	Wisconsin Public Power	WMMPA and WPP	1,800	2	NEG Micon	900 kW	2002	Municipal Utility
Nobles County	MN	Western Minnesota Municipal Power	Local Goverment Joint Powers	1,800	2	NEG Micon	900 kW	1/11/2002	Municipal Utility
Rock County	MN	Minwind I	Cooperative of Farmers	1,900	2	NEG Micon	950 kW	10/2002	Farmer owned
Rock County	MN	Minwind II	Cooperative of Farmers	1,900	2	NEG Micon	950 kW	10/2002	Farmer owned

Location	State	Name	Owner	Size	# of turbines	Manufacturer	Model	Date of commissioning	Ownership structure
Dodge County	MN	Ashland Windfarm	Garwin McNeilus	1,900	2	NEG Micon	950 kW	2003	Locally Owned
Dodge County	MN	Asian Children Support	Asian Children Support, Inc.	1,900	2	NEG Micon	950 kW	2003	Locally Owned
Dodge County	MN	Bangladesh Children Support	Bangladesh Children Support, Inc.	1,900	2	NEG Micon	950 kW	2003	Locally Owned
Dodge County	MN	BT LLC 2003	Brandon McNeilus	1,900	2	NEG Micon	950 kW	2003	Locally Owned
Dodge County	MN	GarMar Foundation 2003	GarMar Foundation	1,900	2	NEG Micon	950 kW	2003	Locally Owned
Dodge County	MN	GM LLC 2003	Garwin McNeilus	1,900	2	NEG Micon	950 kW	2003	Locally Owned
Dodge County	MN	Grant Windfarm	Grant McNeilus	1,900	2	NEG Micon	950 kW	2003	Locally Owned
Dodge County	MN	Indian Children Support	Indian Children Support, Inc	1,900	2	NEG Micon	950 kW	2003	Locally Owned
Dodge County	MN	McNeilus Windfarm (2003)	Grant McNeilus	1,900	2	NEG Micon	950 kW	2003	Locally Owned
Dodge County	MN	Salvadoran Children Support	Salvadoran Children Support, Inc.	1,900	2	NEG Micon	950 kW	2003	Locally Owned
Dodge County	MN	Zumbro Windfarm	Brandon McNeilus	1,900	2	NEG Micon	950 kW	2003	Locally Owned
Martin County	MN	SMMPA	SMMPA	1,900	2	NEG Micon	950 kW	2003	Municipal Utility
Pipestone County	MN	Bisson Windfarm LLC	Peter & Maurine Bisson	1,900	2	NEG Micon	950 kW	10/1/2003	Farmer owned
Pipestone County	MN	Boeve Windfarm LLC	Gary & Gail Boeve	1,900	2	NEG Micon	950 kW	10/1/2003	Farmer owned
Pipestone County	MN	Windcurrent Farms	Steve & Jane Tiedeman	1,900	2	NEG Micon	950 kW	10/1/2003	Farmer Owned
Pipestone County	MN	CG Windfarm LLC	Corey Juhl	1,900	2	NEG Micon	950 kW	10/1/2003	Locally Owned
Pipestone County	MN	Fey Windfarm LLC	Douglas & Pamula Fey	1,900	2	NEG Micon	950 kW	10/1/2003	Locally Owned
Pipestone County	MN	K-Brink Wind Farm LLC	Aleanor Kruisselbrink	1,900	2	NEG Micon	950 kW	10/1/2003	Locally Owned
Pipestone County	MN	TG Windfarm LLC	Tyler Juhl	1,900	2	NEG Micon	950 kW	10/1/2003	Locally Owned
Pipestone County	MN	Tofteland Windfarm LLC	Dean & Jennifer Tofteland	1,900	2	NEG Micon	950 kW	10/1/2003	Locally Owned
Pipestone County	MN	Westridge Windfarm LLC	Dan & Mary Juhl	1,900	2	NEG Micon	950 kW	10/1/2003	Locally Owned
Nobles County	MN	Western Minnesota Muni Power Agency		1,900	2	NEG Micon	950 kW	12/15/2003	Municipal Utility
Chandler Hills	MN	Great River Energy	Great River Energy	1,980	3	Vestas	660 kW	1998	Rural Electric Cooperative
Lincoln County	MN	Autumn Hills LLC	Northern Alternative Energy	1,980	2		990 kW	2/1/2001	Farmer Owned
Algona	IA	Iowa District Wind Energy Project	Cedar Falls, Algona, Ellsworth, Estherville, Fonda, Montezuma, Westfield Municipal Utilities	2,250	3	Zond	750	1998	Municipal Utility
Dodge County	MN	McNeilous, Garwind	Garwin McNeilous	3,000	2	Vestas	1500 kW	2004	Locally Owned
Chandler	MN	Chandler Hills Phase II	Great River Energy	3,960	6	Vestas	V-47	2001	Rural Electric Cooperative

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Distributed wind energy systems provide clean, renewable power for on-site use and help relieve pressure on the power grid while providing jobs and contributing to energy security for homes, farms, schools, factories, private and public facilities, distribution utilities, and remote locations. America pioneered small wind technology in the 1920s, and it is the only renewable energy industry segment that the United States still dominates in technology, manufacturing, and world market share.

The series of analyses covered by this report were conducted to assess some of the most likely ways that advanced wind turbines could be utilized apart from large, central station power systems. Each chapter represents a final report on specific market segments written by leading experts in this field. As such, this document does not speak with one voice but rather a compendium of different perspectives, which are documented from a variety of people in the U.S. distributed wind field.

15. **SUBJECT TERMS**

wind energy; distributed wind; wind turbine; small wind; small wind turbine; wind market

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