ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY
Environmental Energy Technologies Division
1 Cyclotron Rd., MS 90-4000, Berkeley, CA 94720

MEMORANDUM

From: Mark Bolinger and Ryan Wiser, EETD
Subject: Analysis of Small Wind Turbines and Prospective Markets
Date: November 27, 2002

4. Small-Scale Wind Turbine Markets in the U.S. and Abroad

This memo primarily covers the small-scale wind turbine market in the U.S., with some information provided on overseas markets as well. For the purposes of this memo, we define "small-scale" to include turbines of 100 kW or less that are used primarily in customer-sited applications, including residential or commercial grid-connected, off-grid battery charging, and village power hybrid applications. While the size threshold is somewhat arbitrary, our understanding is that this size range (from <1kW to 100 kW) is consistent with the size range of potential turbines envisioned by WindSail. While most small-scale turbines are at the low end of this range, there is at least one U.S. manufacturer of a 100 kW turbine intended primarily for remote off-grid applications (Northern Power Systems),[1] and several manufacturers of 50 kW models (Atlantic Orient Corporation, Bergey Windpower).

When reading this document, WindSail should keep in mind that the quality and quantity of data pertaining to the small wind turbine market leaves much to be desired. We have attempted to piece together the various snippets of data that we have found in such a way so as to provide a broad picture that will be of value to WindSail as it contemplates entering this market. Our overview of the market, however, is limited by the quality and quantity of our data, and is by no means comprehensive. Furthermore, much of the data and market forecasts contained herein are self-reported from the small wind turbine industry, and so may be somewhat biased. Our main source of objective data comes from California – perhaps the largest market for small wind turbines in the U.S., yet also perhaps not a very representative market for the rest of the country or world.

Given these data limitations, we have not attempted to reach prescriptive findings or recommendations as to how WindSail should proceed. Instead, we offer the following as a reference document that compiles much (most?) of the relevant publicly available data on small

[1] Enercon (a German manufacturer of utility-scale wind turbines) is also rumored to be developing a 100 kW model.

wind turbines into one place. It is up to WindSail to interpret this data and draw its own conclusions.

4.1 Market Size and Potential

Current Market Size

A 1984-1989 market study of all known small wind turbine (SWT) manufacturers found that these companies had produced over 38,000 turbines totaling $3.8 million in annual sales (REFOCUS 2002). As of 1997, the global SWT market had grown to $24 million (REFOCUS 2002), and there were reportedly 55 small turbine manufacturers throughout the world (8 in the U.S. and 47 abroad), offering 146 different turbine models (23 U.S. and 123 international) (Forsyth 2000).[2] In the past 5 years, global SWT sales have reportedly grown at a rate of 40%/year (REFOCUS 2002, AWEA 2002a), which would place 2002 sales at around $130 million, while Whale (2001) reports that as of June 2001 the number of SWT manufacturers remains little changed, with more than 50 worldwide.[3] A recent private market study by the respected wind consulting firm Garrad Hassan projects that SWT sales have the potential to increase five-fold to well over $750 million by 2005 (REFOCUS 2002), implying that current sales are more on the order of $150 million/year, rather than the $130 million calculated above.

Taking the midpoint of $140 million/year and assuming (conservatively?) a per-watt cost of $5/W and an average SWT size of 1 kW implies that 28,000 SWT amounting to 28 MW of capacity will be sold in 2002.

Despite comprising only a small minority (~15%) of global SWT manufacturers and models, the U.S. SWT industry leads the market both at home and abroad in terms of the number and capacity of turbines produced (AWEA 2002a). For example, Southwest Windpower sold more than 10,000 turbines in 2001 (Southwest 2002) – i.e., approximately one-third of our 28,000 SWT estimate for 2002 – and Bergey Windpower claims to have achieved 80% market share in the 5-15 kW size range, with ~700 10 kW Excel-S turbines (i.e., 7 MW) installed as of 2001 (Bergey 2001a). Furthermore, while the U.S. is certainly not the world's largest market for SWT, Sagrillo (2002) points out that only two foreign SWT manufacturers – one European and one African – are represented by U.S. distributors, underscoring U.S. dominance of the market.

The leading market position of the U.S. SWT industry stands in contrast to other renewable energy technologies (e.g., large wind turbines and photovoltaics), which are dominated by foreign manufacturers. Furthermore, compared to the "homegrown" U.S. SWT industry, other renewable energy technologies are becoming increasingly controlled by large industrial interests with deep pockets and substantial political clout – e.g., BP Solar, Shell Solar, GE Wind, ABB (Reid 2001).[4] Ironically, despite its position as a global leader, the U.S. SWT industry has been

[2] Reportedly, 37% of the international turbine models were either Russian or Chinese.
[3] At the end of this memo, we present data and web links for many of these manufacturers.
[4] On the one hand, WindSail could interpret the fact that these big energy corporations are investing in PV and utility-scale wind but not small wind as a sign that the profitability of the SWT market is limited. On the other hand, the fact that the SWT market has survived in the face of deep-pocketed competition and relatively little political support may indicate underlying strength in the market.

unable to attract the same level of attention as other renewable technologies such as PV and large wind, and has in turn received less political and financial support than these other technologies, at least at the Federal level.

One outcome of political impotence is a relatively weak domestic market for SWT. While the market for SWT has recently been growing by 40% per year, and there are currently between 15-18 MW of SWT installed in the U.S., the largest markets remain overseas (AWEA 2002a). In 2001, the U.S. SWT industry sold 13,400 turbines, more than half of which were exported (AWEA 2002a). Southwest Windpower – the U.S. Export-Import Bank's 2002 Small Business Exporter of the Year – alone claims to have built 10,000 turbines in 2001 (again, half of which were exported, most of which are presumably under 1 kW in size), bringing its cumulative manufactured volume to more than 60,000 turbines since the company was formed in 1986 (Southwest 2002).[5]

Many of these turbines are going to the developing world, where millions of people still lack access to electricity. Bergey (2000) calls the rural electrification of China the "world's largest market for small wind," and reports that 150,000 SWT have been installed to date in China, with more to come. Many of these SWT are very small and portable units (< 500 W) used primarily by nomadic herdsmen in Inner Mongolia.

While the off-grid market, particularly in developing countries, would appear to be the largest potential market for SWT, by nature it is difficult to find data on the size of this market. Data on grid-connected systems are relatively easier to find, though still spotty. In the U.S., Forsyth (2002) looked at 10 states that offer favorable policies for SWT and found 1,363 kW of grid-connected, net-metered SWT in place. This number appears to be fairly conservative, based on Mike Bergey's claim that his company alone has sold many times more grid-connected SWT systems domestically.

Given the relatively poor quality of national or international data on SWT that is publicly available, we will now take an in-depth look at the SWT market in California, which is arguably the largest and most favorable market for SWT in the U.S., and also provides some of the most complete and reliable data.

<u>California's SWT Market</u>

Table 4.1 provides historical data, as well as future projections, on the number and size of SWT operating in California's grid-connected, off-grid residential, and off-grid telecom markets. Data come from EPRI (2001b), and future projections are necessarily speculative. The grid-connected market is logically segmented into before and after the inception of the CEC's buy-down program in 1998 (more on the buy-down program below), with the off-grid markets structured similarly for comparison purposes (despite not being eligible for the buy-down).

[5] Given Southwest's numbers, Whale's (2001) assertion that 60,000 small wind turbines have been manufactured in Western countries over the past 20 years seems conservative.

Table 4.1. California's SWT Market

Market	Period Covered	# Turbines	Notes	Operating Experience
Grid-Connected	1990-1998	~100 total, not including sales from Jacobs	Ranging from 1-10 kW	Most turbines installed prior to CEC buy-down program are no longer in operation.
	Current	~150 turbines installed, >1 MW of capacity either installed or planned**	Expanding through CEC buy-down program	
	Future	300-500/year	Ranging from 400 W to 10 kW	
Off-Grid Residential	1972-1998	~2000 total	Rapid expansion with introduction of 300-400W turbines in 1990s (i.e., Southwest Windpower)	~50% of turbines installed in the 1970s and 1980s no longer in operation. Most turbines installed in 1990s still in operation.
	1999	~800 systems sold <500W, plus 75 systems from 1-10 kW	Not eligible for buy-down funds.	
	Future	250-400/year, mostly 400W	Not eligible for buy-down funds.	
Off-Grid Telecom	1990-1998	~80 total	Most <1 kW	Most still in operation
	Current	~75, most <1 kW	Expanding slowly; not eligible for buy-down	
	Future	250-400/year, mostly 400W	Same projection as for off-grid residential (i.e., a guess)	

*Source: EPRI 2001b, except ** from Brasil 2002 and Orta 2002*

Table 4.1 shows that, as expected, the off-grid market is larger (in number of units sold) than the grid-connected market, although off-grid applications tend to use smaller turbines of less than 1 kW – the market segment dominated by Southwest Windpower. Also of interest is that half of all SWT installed in the 1970s and 1980s, and many of the grid-connected SWTs installed in the 1990s, are no longer operational. While some of this poor performance history can be attributed to inferior turbine design and quality among certain (likely now defunct) manufacturers,[6] much of this phenomena is also maintenance related: a person relying on a SWT as the only source of electricity is likely to take better care of a turbine than someone who has grid power as a backup should the SWT fail (EPRI 2001b).

We'll now focus on the grid-connected segment of California's market, particularly since 1998, when the California Energy Commission (CEC) first implemented a "buy-down" program that offers $/W capital grants to buy down the capital cost of certain customer-sited renewable energy technologies, including photovoltaics (PV), small wind (<=10 kW), fuel cells using renewable fuels, and solar thermal electric technologies. The CEC initially budgeted $54 million for this program between 1998 and 2001; these funds have since been augmented to a total of roughly $100 million through 2002. From 2003-2007, funding for this program will likely be in excess of $24 million/year.

[6] Mike Bergey claims to be the sole survivor from among 45 competitors in the 1970s and 1980s (Bergey 2001a).

The CEC's program is by far the largest buy-down program in the nation. Similarly, customer response to this program – though lackluster during the first few years – has been much stronger than that seen in similar programs in other states. These factors make the CEC's buy-down program one of the best sources of data on both the number and actual installed costs of small wind turbines in the United States (with several caveats, discussed below in Section 4.4).

Note that to date, only wind turbines that do not exceed 10 kW in size are eligible for the CEC program.[7] Table 4.2 lists the 10 turbines that were eligible for the CEC program as of April 26, 2001 (i.e., the last time the list was updated). Only 3 manufacturers currently qualify for the buy-down in California: Bergey, Southwest, and Wind Turbine Industries (i.e., the buyer of the Jacobs technology). These manufacturers are the only three to have met the CEC's eligibility requirements of (a) safety and performance certification (e.g., UL-listing), (b) successful operation for at least one year at a site with an average annual wind speed of 12 mph, and (c) a 5-year warranty.[8] Note that the Jacobs 10 kW model has since been discontinued by the manufacturer, leaving Bergey to dominate the upper end of the eligible range.

Table 4.2. SWT Eligible for the CEC's Buy-Down Program

Manufacturer	Model	Capacity (W)
Bergey Windpower	BWC XL.1	1,200
Bergey Windpower	BWC 1500	1,500
Bergey Windpower	BWC EXCEL	10,000
Southwest Windpower	AIR403	472
Southwest Windpower	Windseeker 502	500
Southwest Windpower	Windseeker 503	500
Southwest Windpower	Whisper H40	900
Southwest Windpower	Whisper H80	1,000
Southwest Windpower	175 (Whisper 3000)	3,000
Wind Turbine Industries	Jacobs 23-10**	10,000

***Production of the Jacobs 23-10 has been discontinued*

Between early 1998 and August 14, 2000, 26 wind turbines totaling 93 kW (i.e., average turbine size of 3.6 kW) had been installed at an average cost of just over $5/W. Another 25 turbines totaling 51 kW (i.e., average turbine size of 2.1 kW) were in development at an average cost of around $4.5/W (see Section 4.4 on SWT costs below and Figure 4.2 for more detailed information on installed SWT costs in California). In other words, 2.5 years after the start of the CEC's buy-down program, only 144 kW of small wind was either installed or being installed in California under this program (CEC 2000). The slow pace of reservations during the first few years CEC's buy-down program was the product of:

- ***Slow development of satisfactory inverter technology:*** Because SWTs typically operate at variable speeds (i.e., direct drive), the voltage of their output also varies, which causes problems for typical off-the-shelf inverters that are designed to handle a constant voltage.

[7] Starting in 2003, the CEC is likely to allow wind turbines of up to 30 kW to qualify, in order to coordinate more effectively with the CPUC's Self-Generation Program, which offers an identical buy-down to systems of between 30 kW and 1 MW.
[8] Note that of these three manufacturers, only Bergey offers a 5-year warranty as standard practice. The other two manufacturers must either have agreements with individual dealers/installers to extend their standard warranties to 5 years, or else the dealer/installer is shouldering the risk once the manufacturer's warranty expires.

One significant manufacturer did not have a CEC-approved inverter until January 2000. A second is still dissatisfied with current inverter technology (EPRI 2001b).

- ***Poor customer awareness/interest:*** The CEC's own market research showed that nearly two years after its inception, only 14% of residential and 9% of business customers in California were aware of the buy-down program (CEC 2000).
- ***Local zoning requirements:*** Most suburban zoning laws are antiquated and restrict the height of any structure to just 35 feet – the height that early fire engine ladders were able to reach. Since most manufacturers recommend that SWT be "flown" at double that height (or higher), zoning laws have presented a major barrier to the SWT market (EPRI 2001b). (Note: A VAWT situated on the ground or on top of a short tower may circumvent this market barrier).

By early June 2002, the amount of small wind capacity installed under the CEC's program had risen to 530 kW, with another 596 kW in development – i.e., 1,126 kW total (Orta 2002). As of October 2002 – i.e., 4.5 years after the inception of the CEC's buy-down program – roughly 150 small (<=10 kW) wind turbines have been installed under the program (Brasil 2002). While this is clearly a modest showing over the entire period, the recent acceleration in buy-down reservations for SWT holds promise for the future, and is due to a combination of factors:

- ***Electricity Crisis:*** California's electricity crisis highlighted the viability of self-generation as an alternative to utility power, and helped to publicize the CEC's buy-down program. Furthermore, the sharp increase in retail electricity rates resulting from the crisis has made self-generation options more economical. For example, at the height of the crisis in the winter of 2000/2001, Bergey reportedly sold over 100 home units in California in the first two months of 2001, compared with just six in all of 2000 and 12 in all of 1999 (when Y2K fears boosted sales) (AWEA 2001).
- ***Increased Buy-Down Incentive:*** In response to the crisis, the CEC increased its buy-down incentive from $3/W to $4.50/W in April 2001, while leaving the 50% cap in place. Since SWT should theoretically cost less than $6/W, this $1.50/W increase in the buy-down level may not have had much of an effect on the SWT market (i.e., the 50% cap was likely binding both before and after the increase), other than perhaps to line the pockets of SWT installers (see Section 4.4 below).
- ***State Income Tax Credit:*** A 15% state income tax credit for solar and wind was enacted in September 2001.
- ***Permitting Legislation:*** In October 2001, California enacted legislation (AB 1207) requiring all local agencies of towns/counties to develop a permitting process for wind turbines, or else default to the statewide requirements, which are favorable to wind.

Despite these positive developments within the state (along with an expansion of net metering eligibility to include generators up to 1 MW in size), SWTs have not fared well under the CPUC's Self-Generation Program, which has been in place for over a year and offers an incentive for wind turbines (sized between 30 kW and 1 MW) that is identical to the CEC's buy-down – $4.50/W up to 50% of installed costs. In fact, through August 2002, *not a single wind turbine* had applied for funding under the CPUC's program.[9] A dearth of turbines at the low end

[9] In contrast, over 23 MW of PV has applied for funding under the CPUC program, implying that customer awareness of the program is not a major issue (or alternatively, that PV dealers are much more aggressively marketing the program than are small wind dealers).

of that size range could be one limiting factor.[10] Siting and permitting problems could be another, though as mentioned above, California has recently enacted legislation that should streamline the siting and permitting process. Whatever the reason behind the disparity, the fact that the CEC buy-down program is having some success with turbines of 10 kW or less, while the CPUC buy-down program has not funded a single turbine of 30 kW or more, may be particularly noteworthy for WindSail as it ponders what size turbine to pursue (at least for the U.S. market).

In light of California's aggressive incentives for small, grid-connected wind turbines – including both the CEC's buy-down program for turbines not exceeding 10 kW and the CPUC's buy-down program for turbines between 30 kW and 1 MW, the 15% state income tax credit, and the new legislation to facilitate siting and permitting – the limited number of small turbines that have been installed to date in California should raise a red flag as to the near-term market potential in the U.S. as a whole. In other words, it will be hard to find a state that offers a more favorable environment for grid-connected SWT than California, so the fact that only 150 small, grid-connected turbines have been installed in California over the past 4.5 years is disheartening. (Though the recent growth in demand is encouraging).

Market Growth Prospects

According to AWEA (2002a), the most recent publicly available market research for SWT was a DOE-sponsored A. D. Little study in 1981, which projected a domestic market potential of 3.8 million grid-connected systems. Assuming an average turbine capacity of 10 kW, this equates to 38,000 MW. AWEA (2002a) concludes that this study was conservative, because it excluded from consideration 100 counties with high population densities, but that have since installed SWT within their boundaries, proving the feasibility of doing so.

As noted above, the international wind consultancy Garrad Hassan recently concluded a private market study that projects that annual global SWT sales have the potential to increase five-fold from current levels to well over $750 million by 2005 (REFOCUS 2002). Unfortunately, we were unable to obtain data on the number of units or amount of capacity that $750 million represents, though if one (conservatively?) assumes a per-watt cost of $5/W and an average SWT size of 1 kW, $750 million equates to 150 MW of SWT capacity and 150,000 turbines annually by 2005.

In 2002, AWEA's small wind turbine committee released its own "roadmap" for the industry,[11] which includes projections of and goals for future growth. Table 4.3 projects that by 2020, there could be nearly 140,000 MW of SWT installed in the U.S. alone. Grid-connected homes are projected to be the largest market by far, as the industry's long-term vision is of a major new category of home energy appliance (AWEA 2002a).[12]

[10] The introduction of Bergey's 50 kW turbine has been delayed until 2003.

[11] The SWT committee consists of the major SWT manufacturers (chaired by Mike Bergey), as well as AWEA staff and consultants. Though an AWEA document, this roadmap was produced in conjunction with NREL, and can therefore likely be assumed to represent their best thinking on this topic as well.

[12] Along these lines, note that Target was reportedly carrying Bergey's 1 kW wind turbine in its on-line catalog, though the author was unable to locate any wind turbines at www.target.com.

Table 4.3. Market Potential for Small Wind Turbines in the United States in 2020

Market	Units	Avg Turbine Size (kW)	Total Capacity (MW)
Grid-Connected Homes*	15,100,000	7.5	113,250
Commercial Buildings	675,000	25	16,875
Public Facilities	160,000	50	8,000
Off-Grid Homes	150,000	3	450
Off-Grid Communities	200	250	50
Water Pumping	350,000	1	350
Telecommunications	2,000	2	4
Total	**16,437,200**	**8.5**	**138,979**

Source: AWEA 2002a

*AWEA estimates that there will be 43.2 million grid-connected homes sited on more than one-half acre of land in 2020, but excludes 65% of this gross amount to account for homes that are sited either: (a) in Class I (i.e., poor) wind resource areas, (b) close to airports or other sensitive areas, or (c) in communities with restrictive covenants or prohibitive zoning.

AWEA's goal is to reach 50,000 MW by 2020, more than a third of total estimated potential from Table 4.3, and equivalent to about 3% of U.S. electricity consumption, or 6-8% of residential electricity demand in 2020 (AWEA 2002a). Growing the domestic market from its current installed capacity of 15-18 MW to 50,000 MW in 2020 would require a doubling of the market each year for several years, followed by sustained sales growth in the range of 50%-55% per year. Under this scenario, the domestic SWT industry would reach annual sales of $1 billion and employ approximately 10,000 people in manufacturing, sales, installation, and support (AWEA 2002a).

Even though 2020 is still a ways away, AWEA's 50,000 MW goal is clearly very aggressive and should be considered a high-end projection, with the Garrad Hassan estimates (i.e., ~150 MW and 150,000 turbines annually by 2005 on a global basis) providing perhaps a more realistic (though perhaps still optimistic) future market assessment. Because they are detailed and broken out by application, however, the AWEA (2002a) numbers presented in Tables 4.3 and 4.4 are interesting nonetheless.

To be setting goals as lofty as 50,000 MW by 2020, the SWT industry must feel that the market has explosive growth potential and, with state buy-down programs and other financial incentives, is on the cusp of a "tipping point." For example, Figure 4.1 (taken from a presentation by Mike Bergey) projects that as the payback period of a SWT approaches 5 years, turbine sales will shoot through the roof (Bergey 2001b).[13]

[13] Note that it is not clear whether Figure 4.1 represents Bergey's view of the market, or whether the figure is solely intended to be illustrative. Furthermore, we note that Bergey (2001b) also claims to have achieved a 5-year payback in California (given state incentives), yet we know that only a few hundred (i.e., not 50,000) SWTs have been installed or are planned in California, implying that development hinges on more than economics alone.

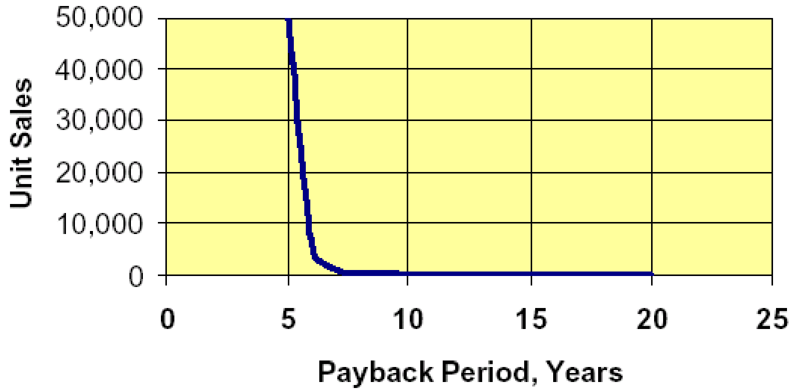

Figure 4.1 Effect of Payback Period on Unit Sales ***(Source: Bergey 2001b)***

In the off-grid market, Table 4.3 lists a potential for 150,000 SWT at off-grid homes. The EIA estimates that there are currently 200,000 off-grid homes in the U.S. (AWEA 2002a). In addition, AWEA (2002a) states that Alaska has 91 villages with a population of 42,000 that are powered by diesel generators. Singh (2001) places the number of remote villages in Alaska a bit higher at 175, and estimates that SWT could penetrate up to 130 MW, assuming that wind displaces half of the 259 MW of installed diesel capacity in Alaska as of 1988. Alaska already has three hybrid wind/diesel projects (Kotzebue, Wales, and St. Paul Island), with SWT's share of the generation ranging from 1/3 to 2/3. In addition, Canada has at least 500 MW of installed diesel in 300 remote communities. There are also a number of islands off of New England that may be suitable for small wind systems (Blanko et al. 2002).

AWEA's roadmap also provides projections for the potential size of foreign markets in 2010 and 2020. According to Table 4.4, foreign markets currently have an 80,000 MW potential, which will increase to 210,000 MW in 2020. Single homes installing very small turbines (average size of 400 W in 2020) make up about half of this market. Note that while the indicated turbine sizes are averages, that the largest average size is only 10 kW (for village power applications). As WindSail ponders what size turbine to produce, this table (and Table 4.3 for domestic applications) may provide some guidance as to where the industry thinks the market is going.

Table 4.4 Potential Markets for Small Wind Turbines in Foreign Countries

	2000			**2010**			**2020**		
System Type	Number (millions)	Avg Size (kW)	Total (MW)	Number (millions)	Avg Size (kW)	Total (MW)	Number (millions)	Avg Size (kW)	Total (MW)
Single Home	150.0	0.2	30,000	195.0	0.3	58,500	260.0	0.4	104,000
Village	3.8	10.0	38,000	4.9	10.0	49,000	6.6	10.0	66,000
Facilities	7.0	1.0	7,000	9.1	1.5	13,650	12.2	2.0	24,400
Misc	5.0	1.0	5,000	6.5	1.5	9,750	8.7	2.0	17,400
Total	**165.8**	**0.5**	**80,000**	**215.5**	**0.6**	**130,900**	**287.5**	**0.7**	**211,800**

Source: AWEA 2002a

While AWEA's roadmap does not break out foreign markets by country, Bergey (2000) notes that there is a World Bank project to install 30,000 hybrid systems in China, and another State

Planning Development Commission (SDPC) program that proposes to install 35,000 5-10 kW wind/diesel systems in China. Both programs would build upon China's 190,000 existing SWTs (over 30,000 of which are apparently in need of renovation). Bergey (2000) also cites Chile as a potentially large market for wind/diesel systems (though he cites only thirty 3-40 kW wind/diesel systems that are planned).

The potential market for small wind in developing countries is clearly quite large. 1.5 billion people are without electricity on a worldwide basis. In China alone, despite incredibly aggressive efforts to electrify the countryside, 16,000 villages and 7 million households remain unelectrified. China, in fact, has the largest small wind market in the world by a sizable margin, with 12,000 small wind systems manufactured in 2000 alone, with most installed in Inner Mongolia. Most of these turbines are well under 1 kW in size, though larger, village-electrification projects are under development. This market has been strongly supported by government policies and incentives.

Village electrification projects that combine wind and diesel generators have held particular interest for some time in developing country contexts. Another potential market for small wind is in electrical wind water pumping (mechanical wind pumps are already in significant use in some countries – with costs that reportedly range from $2500-$13000 each for larger systems) (Karekezi 2002, Karekezi and Kithyoma 2002, Harries 2002). Yet, few such systems have been installed to date. While developing countries clearly hold promise as potentially large markets where SWT technology could be a cost-effective alternative to grid extension or alternative forms of generation (e.g., diesel or PV), one of the main barriers to SWT market expansion in developing countries is a severe lack of capital among the target market. As a result, capitalizing on these markets will most likely mean partnering with national or multinational governmental efforts, such as the World Bank and SDPC programs mentioned above. The historic dearth of U.S. tied aid has also put U.S. manufacturers at a disadvantage to European manufacturers, where tied aid is more common. Finally, a reliable maintenance and servicing infrastructure for small wind systems has often been difficult to develop.

4.2 Drivers of Market Growth

While off-grid applications are often least-cost alternatives and are therefore driven by economics alone, the grid-connected market in the U.S. is driven by a number of different factors, including:

- **Financial Incentives:** While there are currently no federal incentives for the installation of SWT, many states offer some combination of rebates (i.e., buy-down programs), grants, tax credits (production, sales, or property), loan funds, and net metering (see next bullet). In particular, AWEA (2002b) notes that 10 states offer rebates or grants, 14 states offer personal or corporate income tax incentives, 10 states offer sales tax exemptions, 18 states offer property tax exemptions or abatements, 15 states offer loan funds, and 33 states allow net metering. Forsyth (2000) examined the impact of various incentives on payback periods, and concluded that buy-down programs (i.e., rebates or grants) offer the strongest financial incentive, followed by net metering and then tax incentives.

- **Favorable Policy:** Net metering policies allow a self-generator to "bank" excess generation on the grid (and at the more valuable retail rate) by spinning the meter backwards. To take advantage of net metering, however, a customer must first be able to interconnect to the grid. Depending on the utility involved, the interconnection process can be onerous and expensive for the customer – often enough so to discourage the customer from proceeding with the project (Alderfer et al. 2000). The renewable energy industry (and particular the PV industry) has for years called for a simplified and standardized model interconnection agreement, and FERC recently released a draft *national* interconnection standard for public comment.
- **High Retail Electricity Prices:** The higher the price of power that on-site wind generation offsets, the more favorable on-site generation looks. This is particularly true with net metering.

4.3 Barriers to Market Growth

EPRI (2001b) cites the most important research needs to overcome barriers to SWT development in the U.S. as:

- **Raising consumer awareness:** Most consumers do not know that SWT are a viable option for the home.
- **Implement accommodative zoning regulations:** Current height restrictions in many residential areas prohibit the use of recommended-height towers, thereby greatly eroding the performance and economics of SWT.
- **Resource assessment:** The SWT industry complains that the DOE's wind power maps are not of high enough resolution to be useful for those interested in SWT. Furthermore, industry charges that the DOE has confused many potential SWT customers by generally failing to distinguish between the resource needs of large and small wind turbines. For example, the DOE's focus on Class IV or better wind sites applies only to the utility-scale market – most SWT will work in Class II or better – yet this is seldom stated in a clear manner.
- **Better inverters:** Develop better inverters that can handle variable voltage output (most are built to handle constant voltage); i.e., make inverters specific to small wind turbines, as Bergey has done with the GridTek 10 (manufactured for Bergey by Trace).
- **Move towards mass production:** The SWT industry is poorly tooled for mass production, yet the small size of the current market makes acquiring the necessary tools difficult to justify.

To this list of barriers, Bergey (2001a) adds:

- **A lack of federal tax incentives for SWT:** Whereas PV, geothermal, and large wind installations are all currently eligible for federal tax incentives, small wind is not.
- **Onerous interconnection standards**, which can double the cost of a grid-connected system and stifle market growth. In an effort to facilitate interconnection of distributed generation and curb any discrimination by utilities, FERC has recently released a draft national interconnection standard for public comment.

Finally, concerning village power applications, unsubsidized electricity prices in Alaskan villages are $0.42/kWh on average, but the Alaskan state government subsidizes electricity prices down to $0.20/kWh using state oil revenue. This "hidden cost" of using diesel reduces the economic incentive to install wind power.

4.4 SWT Costs

As with utility-scale wind turbines, cost information for small wind turbines is hard to come by. On the one hand, turbine equipment costs are somewhat transparent, given the retail nature and residential focus of the market. On the other hand, installation costs seem to vary widely, making total installed costs difficult to peg, particularly since turbine equipment costs typically represent only 12%-48% of the total installed cost of a small wind-electric system (Sagrillo 2002). Below we present what information we have been able to find on installed capital costs, as well as operating and maintenance costs.

Capital Costs

EPRI (2001b) cites the installed cost of SWT as ranging from $1.5/W to $4/W, and also provides a breakdown by turbine size, as depicted in Table 4.5. The cost of power ($/kWh) shown in the final column of Table 4.5 varies widely based on different assumptions for both the quality of the wind resource as well as financing structure.

Table 4.5. Installed Capital and Energy Costs of SWT

Turbine Size	Application	Installed Costs	$/kW	$/kWh
1-2 kW	On-grid	$3,000-$12,500	$3,000-$12,500	0.25-1.25
10 kW	On-grid	$24,500-$35,000	$2,450-$3,500	0.13-0.76
	Off-grid	$61,500-$87,000	$6,150-$8,700	0.30-2.00
50 kW	On-grid	$85,000-$100,000	$1,700-$2,000	0.05-0.28

Source: EPRI 2001b

Data from two Atlantic Orient AOC 15/50 projects imply that EPRI's cost estimates for 50 kW turbines in Table 4.5 are optimistic. Reports from the Turbine Verification Program indicate that the installed cost of the first three AOC 15/50 turbines in Kotzebue, Alaska came to approximately $3/W (EPRI 1999). More recently, the Long Island Power Authority (LIPA) has installed the first of five AOC 15/50's on farm sites in Suffolk County, reportedly at a cost of $4.50/W (AWEA 2002c). Reasons for this disparity in installed costs are not clear, and AOC was not reachable for comment. One possibility, however, is that the Kotzebue costs covered three turbines, potentially resulting in economies of scale not available to the single LIPA turbine.[14] Another potential factor is that the AOC 15/50's in Kotzebue are actually rated at 66 kW (through the use of larger blades) rather than 50 kW, perhaps making them more cost-effective on a $/W basis (depending on the relative cost of the larger blades).

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[14] Though any economies of scale would presumably be offset by exorbitant shipping charges to Alaska (north of the Arctic Circle), as well as any additional cold weather features necessitated by the harsh environment.

Moving down the size scale, AWEA (2002a) contends that in 2002, the installed cost of a typical 5-15 kW residential wind turbine is about $3,500/kW. By 2020, the industry hopes to reduce installed costs to between $1,200/kW and $1,800/kW (a >50% reduction), which would bring the 30-year life cycle cost of energy to $0.04-$0.05/kWh (AWEA 2002a). The SWT industry estimates that high-volume manufacturing could contribute 15%-30% to this cost reduction (AWEA 2002a).

Information provided by SWT manufacturers largely supports this data (which should not be surprising, since all major domestic SWT manufacturers were instrumental in developing the AWEA roadmap). Bergey's website lists prices for a number of "value packages" (including two wind/solar hybrid packages) that include all the hardware necessary for a complete system, targeted to different applications. For complete installed costs, one would have to add the cost of shipping, sales tax, permit costs, foundation and anchoring, wire run, turbine and tower erection, electrical hook-up, battery racks or vaults (depending on package), and inspection fees. Bergey suggests both a low and high estimate of these installation-related costs, depending on whether the package is installed by the customer or a certified dealer.

Table 4.6 lists the five wind-only (i.e., non-hybrid) packages offered by Bergey, along with equipment costs and low and high estimates of total installed costs (all in $/kW). Note that equipment prices for some of the packages are suggested retail prices, which are the prices that Bergey dealers typically charge. Bergey also provides factory-direct prices (Bergey.Direct), which could be up to 5% lower than the equipment prices shown for some of the packages (particularly the smaller sized packages) in Table 4.6.

Table 4.6 Cost Data for Bergey's Value Packages

Bergey Value Package	Application	Equipment Cost ($/kW)	Estimated Installed Cost Low ($/kW)	Estimated Installed Cost High ($/kW)
1 kW Remote	Remote Home	$3,275	$3,775	$4,775
2 kW Home.Sure	Bill Reduction & Backup Power	$4,745	$5,245	$6,745
7.5 kW Home.Sure		$5,988	$6,655	$8,655
7.5 kW Remote	Remote Home	$4,757	$5,290	$7,423
10 kW GridTek	Bill Reduction	$3,073	$3,323	$3,873

Source: www.bergey.com

Bergey's on-line cash flow calculator calculates that a cash purchase of Bergey's 10kW GridTek system for $35,000 (installed) will have a simple payback period of 20 years. This assumes a capacity factor of 14%, a retail electricity rate of $0.12/kWh (escalating at 2%/year), O&M costs of $0.005/kWh (escalating at 3%/year), and no state or federal incentives. This same system in California – now mysteriously costing $45,000,[15] offsetting a retail electricity price of $0.22/kWh, and taking advantage of the CEC's 50% rebate and the state's 15% income tax credit – pays for itself in only 7 years, thereby demonstrating the power of both incentives and high retail rates.

[15] This $10,000 California price premium is perhaps a subconscious acknowledgement of the price gouging that has occurred in California following the surge in demand during the state's electricity crisis (more on this below).

Table 4.7 shows a breakdown of installed costs for a Bergey 10 kW system. Equipment costs (turbine and tower) make up 78% of the total, while delivery and installation account for 15% and permits and taxes the remaining 7%.

Table 4.7. Installed Cost Breakdown for Bergey 10 kW System

Item	Description	Price	% of Total Installed Costs
1	10 kW Excel-S Turbine & Inverter	$20,900	58%
2	100 ft GL Tower Kit	$6,900	19%
3	Tower Wiring Kit	$930	3%
4	Shipping & Delivery	$1,000	3%
5	Foundations	$1,000	3%
6	Wire Run (300 ft)	$900	2%
7	Electrical Contractor	$650	2%
8	Turbine Set-Up (including crane)	$950	3%
9	Misc. Costs	$500	1%
10	Building Permit	$400	1%
11	Sales Tax (7.25%)	$2,033	6%
	Total:	**$36,133**	**100%**

Source: Bergey 2001a

Most of the data presented so far in this section is sourced from Bergey and the SWT industry. While it is useful to know what the industry thinks about the installed cost of SWT, for data on *actual* installed costs of *real* projects, we now look to data provided by the CEC in conjunction with its buy-down program. Figure 4.2 breaks out the average cost of all completed SWT installations (blue bars, primary y-axis) through March 2002 by turbine size category (x-axis). The number of turbines in each size category is also shown (red dots, secondary y-axis). In total, the data represents 119 turbines with an average cost of $6/W. Most of the installations (88 of the 119 total) are concentrated in either the smallest (0-1 kW) or largest (8-10 kW) size category. This is perhaps not surprising, given the limited number of turbines that qualify for the CEC's program, and the bi-modal size distribution exhibited by those turbines (see Table 4.2).[16] Also note that, as one would expect, the average installed cost declines as turbine size increases, with the 0-1 kW category averaging $7.50/W and the 8-10 kW category averaging just over $4/W (i.e., higher than Bergey's "high" estimate for the 10 kW GridTek value package).

[16] In fact, given the list of eligible turbines presented in Table 4.2, one might wonder how there could be any installations of between 3 and 8 kW. Though not entirely clear, we believe that these six installations must represent combinations of multiple smaller turbines.

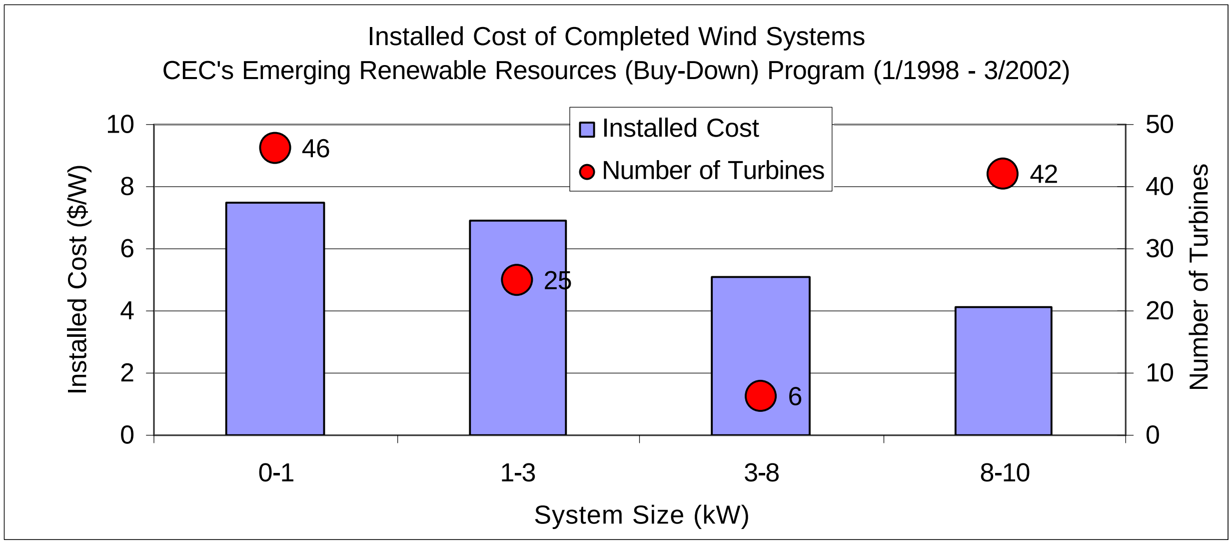


Figure 4.2. Average Installed Cost of Completed SWT Systems, January 1998-March 2002

While the CEC buy-down program represents perhaps the best source of actual installed SWT costs in the U.S., one must keep in mind several factors that potentially influence the data. One problematic feature of the CEC program is that it sets a single incentive level ($4.50/W up to 50% of installed costs) for all systems regardless of technology, be it PV, small wind, or renewable fuel cells. In effect, this means that for small wind, the 50% cap will virtually always be binding, which can lead to gaming of the system in several ways. For example, if an installer knows that the CEC will pay for half of whatever he can talk the customer into buying, he is much more likely to attempt to "gold-plate" the system and sell the customer unnecessary bells and whistles. Furthermore, the CEC has yet to set any strict requirements on the specific items it will pay for, which has led to instances of blatant abuse whereby PV installers (for example) have attempted to have the CEC pay half the cost of a new roof for a customer that also installs a PV system (i.e., claiming that the new roof was a necessary upgrade to enable the installation of the PV system). There have also reportedly been a few suspicious reservation requests for wind projects totaling $9/W installed – the exact amount that maximizes the dollar incentive. In other words, the design of the buy-down incentive has affected the way that dealers and installers are pricing their systems, and anecdotal evidence suggests that installers are padding their costs to maximize the incentive. If anything, this context implies that the prices exhibited above are conservative, and that small wind could be profitably installed for less, though how much so is not clear.

O&M Costs

We were unable to find any reliable estimates of operations and maintenance (O&M) costs for small wind turbines. As noted above, Bergey includes $0.005/kWh O&M costs (escalating at 3%/year) in his on-line cash flow calculator. We view this as a low estimate, however, since experience with grid-tied PV installations suggests that inverters seldom last longer than 7-10 years, implying that over its 30-year design life a SWT will burn through at least two inverters (assuming similar lifespan of SWT inverters). The costs of inverter replacement alone could easily exceed $0.005/kWh.

At the other end of the spectrum, Forsyth (2000) assumes that annual O&M costs are 1% of the installed turbine costs. Taking 1% of the $36,133 installed cost of the Bergey 10 kW system shown in Table 4.7 yields annual O&M costs of $361. Spreading $361 over 12,000 kWh/year (i.e., the same 14% capacity factor that Bergey's payback analysis uses) yields variable O&M costs of $0.03/kWh – substantially higher than Bergey's assumption of $0.005/kWh.

Blanko et al (2002), meanwhile, estimate annual O&M costs for a 50 kW AOC turbine to equal $2000, while a Northern Power 100 kW turbine is estimated to have annual O&M costs of $3500. At the same 14% capacity factor as above, this equates to O&M costs of 2.8-3.4 cents/kWh.

Though they vary considerably, the Bergey, Forsyth, and Blanko estimates are merely modeling assumptions; obtaining actual field data (or even marketing claims) on O&M costs is a challenge to say the least. This is perhaps not surprising, given the small and decentralized nature of the market, as well as the variety of applications for which SWT can be utilized. Furthermore, today's SWTs are designed for reliability with only 2 or 3 moving parts, and many SWT manufacturers therefore like to claim that their turbines are "maintenance-free." In other words, highlighting no (rather than low) O&M costs seems to be the preferred marketing strategy.[17]

O&M cost data is lacking for even the most highly documented SWT project we encountered. The development and operation of the Kotzebue Electric Association's wind/diesel hybrid system utilizing Atlantic Orient's AOC 15/50 turbines (66 kW each) has been painstakingly documented through the DOE's Wind Turbine Verification Program (TVP). While the TVP reports for the first and second year of operating experience provide detailed information on turbine availability and outages, they are unable to provide an estimate of O&M costs because most of the O&M occurred under warranty with AOC (the project is only a few years old). That said, if WindSail is interested in detailed technical information on the development and operating experience of large (66 kW) SWTs sited in a harsh climate (north of the Arctic circle) and operating in conjunction with diesel generation, the three TVP reports on the Kotzebue project are worth reading (EPRI 1999, 2000, 2001a).

Unfortunately, perhaps more often than not, SWTs that have ceased to function properly after the warranty period may simply be shut down, rendering O&M costs somewhat meaningless and elevating the importance of "time in service" as an indicator of turbine quality. Along these lines, Sagrillo (2002) states that experience from the field indicates that the "heavyweights" – heavy duty, metal, slow-speed turbines – will last their 20-year design life and even longer (and then can be completely overhauled and placed back in service), while the light-weight, high-speed turbines may last only half (10 years) or a quarter (5 years) as long, assuming diligent maintenance. For this reason, Sagrillo (2002) favors the "beasties," and considers $/pound and weight/tip-speed-ratio to be the two most important indicators when comparing turbines. Heavyweight turbines (e.g., Bergey, Jacobs, Proven) cost more up-front, but are more

[17] Sagrillo (2002) points out that despite the manufacturers' claims, it is unrealistic to expect something as complex as a wind turbine, operating continuously in a harsh environment, to work flawlessly with no maintenance. Most of the catastrophic failures he has seen over the years were attributable to something as minor as a bolt coming loose and not being attended to. He therefore advocates a thorough inspection of the entire system once a year, at a minimum.

economical over the long term. In this sense, being "built like a Russian tank" may prove to be an asset to WindSail.

4.5 The Competition: Other Technologies, Other Small Wind Turbines

Other Technologies

The two main competitors facing SWTs are diesel generators and PV systems. Fortunately, SWT can and have worked well in harmony, rather than competition, with both. Below we present a bit of information that we've come across on diesel and PV, in addition to that previously presented in Chapter 2 (i.e., an earlier memo).

Diesel

Diesel generators have historically been the default technology for powering remote, off-grid villages. However, wind/diesel or wind/diesel/solar hybrid systems are gaining favor because the combination of technologies provides a more cost-effective and reliable power system than is possible using any of the technologies on their own. Table 4.8 depicts the complementary nature of wind and diesel generation.

Table 4.8. Complementary Nature of Wind and Diesel

Characteristic	Wind	Diesel
Capital Cost	High	Low
Operating Cost	Low	High
Logistics Burden	Low	High
Maintenance Requirements	Low	High
Available On-Demand	No	Yes

Source: Bergey 2000

At least two wind/diesel hybrid power systems in the U.S. have been well-documented: the Kotzebue Electric Association's project in Alaska (involving wind turbines from both Atlantic Orient and Northern Power Systems) and the U.S. Navy's installation on San Clemente Island off the coast of southern California (involving four 225 kW NEG Micon turbines).

The following paragraph, taken directly from McKenna and Olsen (1999), estimates the operating cost of the Navy's diesel generating system on San Clemente Island:

> "The diesel system operating costs are derived partly from San Nicolas Island cost data because the San Clemente Island (SCI) information is incomplete. Fuel costs are based on various memos, email and verbal conversations with the PWC. Since a full breakdown of SCI power system costs was not available, we resorted to the rate SCI charges its customers: $0.390/kWh, which gives $2,971,205 for 7,618,475 kWh. The inherent assumption is that this rate reflects true and total life-cycle costs for the SCI power system without profit, since its customers are other Navy entities and their subcontractors. We suspect the true diesel system costs are lower, but don't have any other basis to work with at this time. The fuel price also is known, at $0.206/liter ($0.78/gal), and adding transportation and other hidden costs bring the total fuel cost up

to $0.264/liter ($1.00/gal). That translates into $0.082/kWh for fuel using the baseline fuel and energy totals for 1998. The remaining amount of $0.308/kWh is included in the O&M item in the economic analysis spreadsheet, but it must cover O&M, diesel overhauls, and eventual replacement. However, some of these costs are fixed and part variable. We will assume they split half-and-half, based on experience with similar facilities. Therefore the variable part is $0.154/kWh, and the fixed part is 0.5*(0.308*7,618,475) = $1,173,245."

McKenna and Olsen (1999) also report the results of some modeling they did, which shows that the four 225 kW NEG Micon turbines reduce the cost of energy from the diesel system from $0.476/kWh to $0.447/kWh (a 6.1% reduction), giving an IRR of 14.8% and a 6.3 year payback period on the wind turbines.[18]

Similar data is not available for the Kotzebue Electric Association (KEA), which runs six diesel generators totaling 11.2 MW, though data from the last five years (prior to the addition of the wind turbines) indicate that KEA used 1.4 million gallons of diesel fuel per year with an average efficiency of 14-15 kWh per gallon of fuel (EPRI 2001a). The efficiency of the diesel generators on San Clemente Island is similar, at around 13 kWh/gallon (McKenna and Olsen 1999).

Using wind to supplement diesel in wind-diesel hybrids has also been found to be potentially economic in some of the islands off of the New England coastline (Blanko et al. 2002). In that study, a diesel only system is estimated to cost 31 cents/kWh. Supplementing the diesel gen-sets with 6 250 kW wind turbines was estimated to reduce the cost of delivered electricity to 26 cents/kWh. Another New England island that relies entirely on diesel has an estimated cost of 39 cents/kWh.

LBNL data on 67 different diesel generators from 3 different manufacturers suggests that equipment costs can range from $127-$878/kW, while installation costs (for a subset of the generators) range from $39-$433/kW, bringing turnkey costs to between $175-$1,311/kW (http://der.lbl.gov/). Fixed O&M costs of $26.5/kw-yr are assumed. These data are now at least 2-years old.

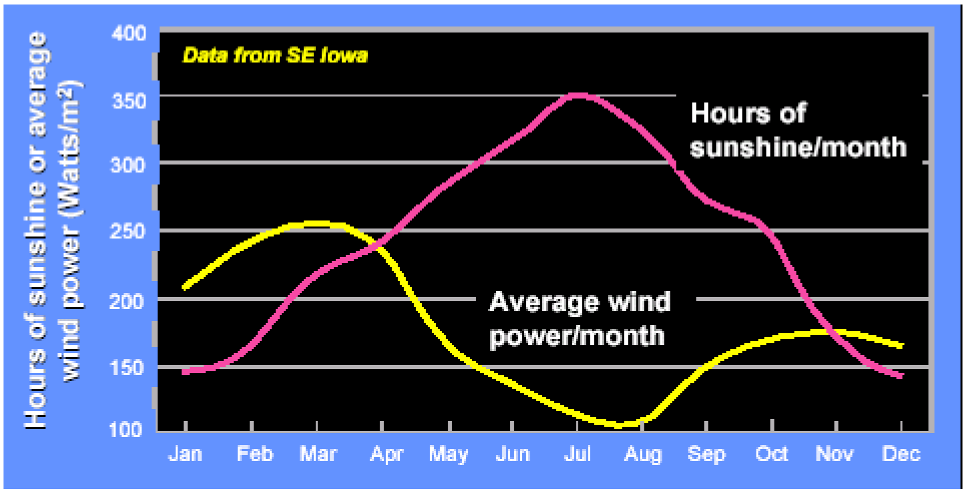
Finally, Chinese documents indicate that rural electrification with diesel gen-sets alone can cost as much or more than 36 cents/kWh.

Photovoltaics (PV)

While the cost of energy from PV systems is typically several times more expensive than the cost of energy from a small wind turbine, PV has the advantage of being highly modular, easy to transport, easy to site, and relatively easy to maintain (with no moving parts), thereby making it a preferred renewable energy technology for remote off-grid homes, particularly in developing countries. Furthermore, at very small turbine sizes, PV may even look economical relative to small wind. In other words, the smaller the wind turbine, the more expensive it is, and therefore the more competitive PV appears to be.

[18] The reason for the discrepancy in diesel costs between this paragraph and the previous (i.e., $0.476/kWh vs. $0.39/kWh) is not entirely clear, though it may simply be that the $0.476/kWh is the product of a modeling exercise, whereas the $0.39/kWh is the actual rate that the Navy charges its customers on the island.

As with diesel, however, wind power often complements PV production rather than directly competing with it, since the wind tends to blow more strongly when the sun is at its weakest (i.e., in winter). Figure 4.3 shows the complementary nature of solar and wind power in southeast Iowa.



Source: Bergey 2000

Figure 4.3 Complementary Nature of Wind and Solar

Compared to the U.S. SWT industry, which consists of a handful of companies, there were 21 U.S. companies involved in the production of 88,221 kWp of photovoltaics in 2000, up from 13,813 kWp a decade ago (EIA 2002). The average cost was $3.46 per peak watt for modules and $2.40 for cells, compared with $5.69 and $3.84 a decade earlier.[19] This represents a 540% capacity increase (20% annualized), and a 38% price decline (4.7% annualized).

Table 4.9 breaks down total U.S. PV production in 2000 by end use application. Grid-tied generation leads the pack at nearly 22 MW, compared to just 469 kW in 1990, while remote generation comes in second at 15 MW, compared to just over 3 MW in 1990. This is an interesting flip-flop of the dominance of grid-connected and off-grid markets, suggesting that PV is becoming more mainstream. Whether on- and off-grid SWT have similarly crossed paths yet is unclear, though Table 4.3 projects that, at least in the U.S., grid-connected SWT will far outnumber off-grid SWT applications by 2020.

[19] Note that these costs are for PV modules and cells only, and do not include balance of system components or installation costs. Total installed costs of residential PV systems have been running between $8/W and $11/W in the U.S.

Table 4.9. Fate of U.S. PV Production in 2000

PV Application	**kW(peak)**	**% of Total**
Grid-Tied Generation	21,713	25%
Remote Generation	14,997	17%
Transportation	12,804	15%
Communications	12,269	14%
OEM Applications**	12,153	14%
Water Pumping	5,644	6%
Consumer Goods	2,870	3%
Health	2,742	3%
Other	3,028	3%
Total:	**88,221**	**100%**

***Original Equipment Manufacturers (OEM) fabricate products for sale to end users*
Source: EIA 2002

Total PV production on an annual basis worldwide is currently ~250-300 MW, with aggregate installed capacity of over 1000 MW worldwide. The 250-300 MW of annual PV production compares to the much smaller small wind industry of ~30 MW, estimated earlier.

Other Small Wind Turbines

As mentioned earlier, there are over fifty SWT manufacturers in the world today, offering a variety of different models. AWEA (2002a) notes, however, that while large utility-scale wind turbines are in their 7th or 8th generation of technology development, SWT are only in their 2nd or 3rd. In fact, the old Jacobs turbines, which have not been manufactured for over 50 years, are still considered by many to be top-of-the-line technology, which is why several companies are now engaged in the business of refurbishing the old Jakes (Sagrillo 2002). Given the relatively "unrefined" state of SWT technology, WindSail – being a new entrant to the market – may not be at as much of a disadvantage as it would otherwise be trying to break into the utility-scale market. On the other hand, WindSail's envisioned gearless technology may not hold as much of an advantage in the SWT market as it otherwise might in the utility-scale market: most SWTs are already direct drive, variable speed systems with permanent magnet generators. Furthermore, AWEA (2002a) notes that "Some new entrants to the industry have significantly underestimated the engineering rigor and expense required to deliver a reliable small wind turbine product." Exaggerated claims have led to consumer confusion and mistrust, spurring AWEA to call for the creation and implementation of small wind turbine standards and certification programs – something for WindSail to keep an eye on as it designs its product.

Table 4.10 provides basic information on all of the SWT manufacturers we were able to find, as well as web links where WindSail can pursue further information on each. Immediately following Table 4.10, we provide more detailed information on the most prominent domestic HAWT manufacturers, as well as basic data (and pictures) for all VAWT manufacturers that we came across (prominent or not), given WindSail's interest in VAWT technology. While looking through this information and considering the merits of each company's product (and WindSail's), keep in mind the SWT industry's vision of the "turbine of the future" (AWEA 2002a):

- Will have to be specially designed to work in low wind resource areas, having larger rotors to capture more energy
- Will still need to be robust, because even low wind speed areas experience severe weather
- Must be extremely quiet
- Must be able to operate for 10-15 years between inspections and/or preventive maintenance
- Must offer a reasonable expectation of a 30- to 60-year operating life
- Must be affordable without subsidies

Table 4.10. SWT Manufacturers (or in some cases, distributors)

Company Name	Web Address	Country	Product Range
Horizontal Axis			
Amp Air	www.ampair.com	UK	100W
Atlantic Orient Corporation	www.aocwind.net	US	50kW
Bergey Windpower	www.bergey.com	US	1-50kW
J.Bornay Wind Turbines	www.bornay.com	Spain	250W-6kW
Gazelle	www.mkw.co.uk/renewable.htm *or* www.northenergy.co.uk/	UK	20kW
Aerogen Wind Turbines (LVM)	www.unlimited-power.co.uk/Aerogen_wind_turbines.html	UK	48-360W
Pitchwind	www.pitchwind.se/	Sweden	20-40kW
Proven	www.provenenergy.com/	UK	600W-6kW
Southwest Windpower	www.windenergy.com/	US	400W-3 kW
Synergy Power Corporation	www.synergypowercorp.com/	Hong Kong	125W-30kW
Vergnet	www.vergnet.fr/index3.html	France	1-225kW
WindStream Power Systems	www.windstreampower.com/	US	120W
Wind Turbine Industries Corporation	www.windturbine.net/	US	20kW
MGx LLC	www.mgx.com/	US	1.5-3kW
Abundant Renewable Energy	www.ahanw.dhs.org/abundantre/ (re-manufactures Jacobs turbines and distributes African Wind Power turbines)	US	2.4-3.6kW
Northern Power Systems	www.northernpower.com/framesets/sub1_products.html	US	100kW
Mass Megawatts	www.massmegawatts.com/	US	modular
Marlec Engineering	www.marlec.co.uk/ (Rutland Windchargers)	UK	25W-??
Aerocraft	http://www.aerocraft.de/	Germany	120W-1kW
Westwind Wind Turbines	http://www.westwind.com.au/	Australia	3-20kW
Fortis Windenergy	www.fortiswindenergy.com/	Netherlands	100W-30kW
Vertical Axis			
Wind Harvest	www.windharvest.com	US	25kW
Sustainable Energy Technologies	www.sustainableenergy.com/renewable/wind.html	Canada	250kW
Shield (Jaspira)	www.shield.fi/	Finland	20W-10kW
WindSide	www.windside.com/	Finland	20W-7.5kW
Ropatec	www.ropatec.com	Italy	0.5-6kW
Ampair	www.ampair.com	UK	4W
Terra Moya Aqua (TMA)	TMA does not have a web site	US	20-750kW
The Turby	www.turby.nl	Netherlands	2 kW

Major Domestic SWT Manufacturers

• ***Bergey Windpower (www.bergey.com)***

Since its establishment in 1977, Bergey Windpower has completed over 2,100 turbine installations, reportedly in all 50 states and 90 countries (Bergey 2001a).[20] For example, more than 600 BWC 1000 (1 kW) turbines were sold between 1980, when the turbine was introduced, and 1990, when it was replaced by a 1.5 kW model (i.e., the BWC 1500, which itself was replaced by the Bergey XL.1 in early 2002). Originally facing 45 competitors born out of the energy crises of the 1970s, Bergey claims to have captured leading market share in 1983 with the introduction of the 10 kW Excel S, which now enjoys 80% market share in the 5-15 kW size range, with approximately 700 installations (i.e., 7 MW) to date (Bergey 2001a). Bergey's claims of market dominance are at least anecdotally supported by the SWT selected to participate in the DOE's *Field Verification Program for Small Turbines*: 13 of the 16 participating turbines were Bergey Excel C/E 10 kW, tested in various applications (DOE 2002).[21] Bergey currently offers the industry's longest warranty, at 5 years (most other manufacturers offer 2-3 years at most).

Though Bergey has traditionally produced turbines of 10 kW or less (with current models including turbines rated at 1 kW, 7.5 kW, and 10 kW), Bergey announced in June 2000 the development of a new 50 kW model under the DOE's Advanced Small Wind Turbine Program. Introduction of the 50 kW model, which is now expected to begin serving both the on- and off-grid markets in late 2003, has been delayed due to technical challenges involving the "bleeding edge" technologies used in the turbine, which sports only 3 moving parts and claims to be the simplest machine of its size ever built. Pricing for the 50 kW turbine has not been finalized, though we have noted three different installed cost estimates provided by Bergey in the past year or so, ranging from $100,000 ($2/W) to $130,000 ($2.6/W). More information on the new 50 kW turbine, as well as Bergey's other products, is available at www.bergey.com.

• ***Southwest Windpower (www.windenergy.com)***

Southwest appears to be the market leader in small battery-charging turbines. The company recently complemented its line of 400W "Air" turbines with the addition of the 900-3000W "Whisper" line that had previously been manufactured by World Power Technologies, which Southwest acquired in May 2000.

The following is taken directly from a press release announcing that Southwest had won the 2002 Small Business Exporter of the Year award from the Export-Import Bank of the United States (Ex-Im Bank):

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[20] Note that 2,100 turbines is not a particularly large number, given the 25-year life of the company (i.e., <100 turbines/year). While this cumulative number is no doubt "back-loaded," with a greater number of installations in recent years, the fact that the "market leader" is only producing several hundred wind turbines per year should give pause to WindSail's hopes of achieving mass production on a grand scale in the near future. A similar example comes from the U.K., where Proven Engineering (the English equivalent of Bergey) – having sold just one turbine during its first year of production in 1990 – is currently producing only 100 turbines a year (expected to double with a new factory next year), and is struggling to break even (The Herald 2002).

[21] The remaining three turbines participating in the field verification program include one 900W Whisper H40 (then manufactured by World Power Technologies, which was bought out by Southwest Windpower in May 2000), and two 50 kW AOC 15/50 turbines.

"Since its inception in 1986, Southwest Windpower has produced more than 60,000 wind generators, of which 10,000 were produced in 2001 alone. The products are used to produce electricity on telecommunication towers, remote homes, off-shore platforms, remote monitoring sites, schools, and homes in emerging markets.

Founded by two young entrepreneurs out of a garage in rural Arizona in 1986, Southwest Windpower's vision from the start was to sell its products in the global market and to make a difference in the world through low-cost renewable energy. Since it began using Ex-Im Bank's export credit insurance program in 1996, the company has been able to offer its small foreign distributors open accounts, easing their cash flow and allowing them to place larger orders.

"The results have been tremendous," said Southwest Windpower Vice-President Andrew Kruse. "Last year more than 50 percent of our revenues came from export sales. We now have 50 employees, factories in Flagstaff and Duluth MN, and our products are sold in more than 50 countries. We're excited about looking at other Ex-Im Bank products to help us fill future orders. The Ex-Im Bank has become a strategic partner in our effort to further expand our export sales.""

• ***Atlantic Orient Corporation (AOC) (http://www.aocwind.net/)***
Based in Vermont, with turbines manufactured in Nova Scotia, AOC makes a 50 kW turbine suited for cold, harsh climates. The AOC 15/50 has been developed in conjunction with the DOE and NREL under the Advanced Wind Turbine program, and is based on an earlier Enertech 44 kW turbine. The AOC 15/50 has been widely deployed in harsh environments throughout the world, with installations in northern Alaska, Siberia, England, Scotland, Morocco, Greece, Canada, Vermont, Maine, Texas, and most recently, New York. The AOC 15/50's performance in a wind/diesel hybrid application in northern Alaska has been widely documented through the DOE's Turbine Verification Program (EPRI 1999, 2000, 2001a). Reports from the Turbine Verification Program indicate that the installed cost of the first three AOC 15/50 turbines in Kotzebue, Alaska came to approximately $3/W (EPRI 1999). More recently, the Long Island Power Authority (LIPA) has installed the first of five AOC 15/50's on farm sites in Suffolk County, reportedly at a cost of $4.50/W (AWEA 2002c). Reasons for this disparity in installed costs are not clear, and AOC was not reachable for comment. One possibility, however, is that the Kotzebue costs covered 3 turbines, potentially resulting in economies of scale not available to the single LIPA turbine. Another potential factor is that the AOC 15/50's in Kotzebue are actually rated at 66 kW (through the use of larger blades) rather than 50 kW, perhaps making them more cost-effective on a $/W basis (depending on the relative cost of the larger blades).

Despite what has seemed to be a steady (though slow) string of new orders (e.g., the 5 turbines currently being installed on Long Island), it is rumored that AOC has recently been liquidated as a result of financial problems. AOC's Canadian partner that manufactures the turbines has reportedly purchased a controlling stake in the company.

• ***Northern Power Systems (http://www.northernpower.com/framesets/sub1_products.html)***
Since 1979, hundreds of NPS' HR3 turbines have served remote telecommunications applications in harsh environments. NPS' newest turbine – the 100 kW Northwind 100/19 – is a direct drive turbine designed for extreme cold weather applications. The NW100/19 was

awarded R&D Magazine's prestigious "R&D 100 Award" for the most innovative technology in the year 2000. The turbine features a tubular tilt-up tower for easy maintenance.

From the NPS web site: “The NW100/19 turbine was developed by NPS with support from cooperating agencies within the U.S. government, including the National Aeronautics and Space Administration (NASA); the National Science Foundation (NSF); the Department of Energy (DOE); and the DOE-funded National Renewable Energy Laboratory (NREL). Siemens-Westinghouse acted as a subcontractor to NPS in developing the innovative direct drive generator subsystem.

Extensive field-testing has been carried out on the first turbine since its installation in Graniteville, VT in late 1998. The NW100/19 design was finalized based on these tests and performance verification. In the fall of 2000, several test sites will be solicited throughout the New England area for grid-connected applications through a DOE sponsored testing program. These projects are being implemented specifically to monitor the turbine in cold weather and distributed generation applications in order to gain operational experience. A fully tested and certified design is scheduled for 2001.”

Since May 2002, a Northwind 100 has been operating alongside Atlantic Orient’s AOC 15/50 turbines (and several diesel generators) in Kotzebue, Alaska. An article on the Kotzebue Electric Association’s web page (http://www.kotzelectric.com/wind/wind_northwind100.html) indicates that only two other NW 100/19’s exist – one in Vermont at the manufacturing facility, and the other at NREL in Colorado. This article also raises the prospect of a future market for wind turbines on the planet *Mars*, where global dust storms can often cloud the sun for weeks at a time, rendering solar power ineffective (hence NASA’s sponsorship of the development of this turbine).

For technical specifications of the NW 100/19, see Northern Power Systems’ web page.

• ***Wind Turbine Industries (http://www.windturbine.net/)***
Purchased the rights to the *Jacobs* name in 1986. Currently has only one active model listed on its web site (20 kW), although the CEC had approved a 10 kW WTI turbine for its buy-down program (production of this turbine has since been discontinued).

Global VAWT Manufacturers

• ***Terra Moya Aqua, Inc. (TMA) (no web site)***
TMA is a Wyoming-based VAWT manufacturer that has reportedly built turbines of various sizes (up to 1 MW). TMA has built four 250 kW units to sell power under a 20-year PPA to Tri-State G&T cooperative, and in June 2001, installed a 20 kW VAWT in Curt Gowdy State Park in Wyoming, which reportedly cost $84,000 to install ($4.20/W) (Girt 2001). TMA has also been talking to the City of Vallejo (CA) for a year or more about building 1,000 MW of VAWTs (750 kW units) as part of that city’s well-publicized efforts to become energy independent through the use of renewable energy. Vallejo’s Director of Community Development reports that the city is still in discussions with TMA, but is waiting for TMA to find appropriate sites and obtain the necessary permits before formalizing any type of agreement (da Silva 2002). Press reports

indicate, however, that TMA has proposed to sell power to Vallejo for 20 years at 7.5 cents/kWh, which, though high, beats the rates that the city is currently paying PG&E (Doyle 2002). The Vallejo project stalled in January 2002 when TMA could not find financial backing, but in April 2002 TMA announced that it had partnered with Siemens AG, who will reportedly provide capital and engineering services to develop up to 1,000 MW of wind power on 3,000 leased acres outside Fairfield near Travis Air Force Base.

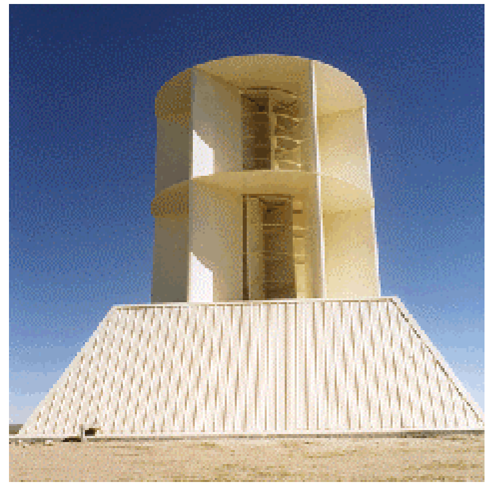

Figure 4.4. TMA VAWT

In addition, the U.S. Air Force is also in discussions with TMA over the installation of a single VAWT at the F.E. Warren Air Force Base outside of Cheyenne, Wyoming. The Air Force is reportedly interested in testing the turbine because it is less likely to interfere with radar than a HAWT on a tall tower.[22] If the turbine works as promised, and if radar and security impacts are minimal, the Air Force could be interested in pursuing more installations at various bases.

TMA's "stacked" and "ducted" VAWT technology relies on an external shell of "ducts" or "air intakes" used to direct the wind into the blades at the optimum angle (see Figure 4.4). Because the blades are protected inside the ducted shell (which resembles a small building), they can be screened with netting to prevent avian impacts.

• ***Ropatec (http://www.ropatec.com/)***
Italian manufacturer of VAWTs ranging from 500W to 6 kW. According to the company's web site, these turbines have been tested under extreme conditions in remote "refuges" in the Alps (see Figure 4.5).

Figure 4.5. Ropatec VAWT

• ***WindHarvest (http://www.windharvest.com/)***
Makers of the 25 kW WindStar VAWT (see Figures 4.6 and 4.7), Wind Harvest is based in Point Reyes Station, California, with offices in Palm Springs. Steel for the turbines comes from Stockton, while the aluminum blades are made in the Netherlands. All other components are reportedly off the shelf. Their web site claims that 20 WindStar VAWTs have been tested in real-world conditions. Personal communication with company co-founder George Wagner reveals that this testing has occurred mainly at two sites: in Wales (the U.K.) and San Gorgonio pass (near Palm Springs). In Wales, Wind Harvest – in a joint venture with Enron – reportedly had secured a lucrative long-term contract of $0.17/kWh through the Non-Fossil Fuel Obligation (NFFO) tendering process. Enron apparently walked away from the deal, which involved 5 WindStar turbines, following the energy giant's

[22] Several planned wind farms throughout the world, including a recent project in Nevada, have been scrapped over objections from the military concerning radar interference. Because they sit lower to the ground, VAWTs may not pose such problems.

recent bankruptcy. Wind Harvest has also installed a dozen or so VAWTs in San Gorgonio over the past 10 years (to see one in operation, view the video on their web site), though they currently only have 4 new turbines there (having had to move the others).

Wind Harvest's strategy is to look for high wind regime areas where they can infill WindStar VAWTs among the larger HAWTs. Wagner indicates that they can place 3-4 WindStars around the base of an existing HAWT, thereby boosting the existing wind farm's output by 20%-25%. WindStar turbines are placed only 18 inches apart – a design feature that they have recently patented – to create a "vortex" effect that boosts wind speeds through some combination of the Venturi or other augmentation/diffuser effects. WindStar turbines are manufactured for turbulent and high wind speeds, and have reportedly produced power in winds up to 80 mph. When asked about the limitations (in wind speed) of being sited close to the ground, Wagner responded that this is not always a disadvantage – on many ridge lines, you get an acceleration effect by being close to the ground (i.e., the impact is site-specific).

Wind Harvest's biggest problem is finding buyers for their power under long-term power purchase agreements – a prerequisite to being able to finance the construction of a project. This problem was exacerbated by California's electricity crisis. Wind Harvest was present at the first board meeting of the newly formed California Power Authority (CPA) in August 2001, back when it appeared as if the CPA would be signing long-term contracts for renewable power. While this never came to pass, Wind Harvest's testimony at that meeting reveals that a 25 kW WindStar turbine costs about $40,000 ($1.6/W), but that with production of 1000 units, the company is optimistic that costs would drop below $1/W (CPA 2001). George Wagner provided similar numbers, stating that the installed cost of a turbine manufactured "onshore" (i.e., as they are currently produced) would be $1.50/W, but with mass production "offshore" (e.g., sourcing steel from the Czech Republic instead of Stockton), costs would drop to $0.8-$0.9/W. These numbers assume the infill of WindStar turbines among existing HAWTs, thereby minimizing infrastructure costs (e.g., roads, wiring, substation, etc.).

In response to a question about the impact of the apparent stigma surrounding VAWT technology, Wagner responded that wind developers who truly know the WindStar technology "love them" and are not scared off by the VAWT stigma (at least in part because Wind Harvest pays them lease fees). Financiers they have approached, however, initially chuckle at the fact that they are a wind power company, then they laugh at the fact that they are a *small* company manufacturing *small* turbines, and then, finally, they laugh at the fact that they are manufacturing VAWTs as opposed to HAWTs. A common question they get from financiers is: if the WindStar technology and infill strategy is so promising, why hasn't Vestas or one of the other "big boys" acquired them as a second product line. Wagner acknowledges that they may have to partner with a more established player in order to secure financing,[23] though he did note that California utilities have finally begun to return their calls, looking to establish "a relationship" in response to the recent passage of the state's renewables portfolio standard (which obligates the utilities to increase their share of renewable energy generation by 1%/year until reaching 20% by 2017).

[23] As reported earlier, TMA has recently partnered with Siemens for this very reason.

Figures 4.6 and 4.7. 25 kW WindStar VAWT

• ***Sustainable Energy Technologies (www.sustainableenergy.com)***

Though this company was experiencing financial difficulties earlier in the year, it was able to raise additional equity through a private placement in May and continues to pursue development of a 250 kW 4-bladed full Darrieus VAWT known as the Chinook 2000 (see Figure 4.8). According to Director of Business Development David Carten (2002), they are reportedly looking at a number of financing options and partners for building the "qualification turbine" of the 250 kW Germanischer Lloyd-certified design, and have had several offers from groups in Alaska to erect Chinooks there. They have also recommissioned two of the earlier (150 kW) prototypes in Pincher Creek, Alberta. While Chinook turbines are larger than our 100 kW size threshold, we include them here anyway because of their VAWT design.

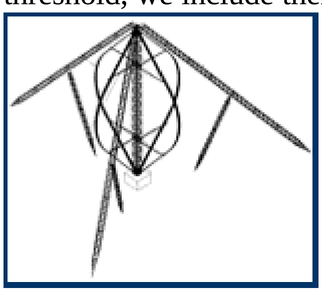

Figure 4.8. Rendering of Chinook 2000 Darrieus Turbine

• ***WindSide (http://www.windside.com/)***

WindSide is a Finnish VAWT manufacturer that supposedly has machines installed in 16 countries (and also the Antarctic). The turbines are generally small (< 1 kW), though they appear to make a 9 kW and 22.5 kW unit as well, and claim that they could conceivably scale the design to 3 MW. Because of the sculptural nature of WindSide blades, the turbines are often featured in "wind art" (see Figure 4.10), providing power for artistic lighting or water pumping. Like the VAWTs of another Finnish manufacturer (Shield, see below), WindSide turbines are also fairly portable, and can even be attached to a tree (see Figure 4.9).

Figures 4.9, 4.10, and 4.11. 3 Different Applications of WindSide VAWTs

• ***Shield (www.shield.fi)***
Shield is the Finnish VAWT manufacturer of Jaspira turbines ranging from <1kW to10kW. At the low end of this range is a hand-held, portable, lightweight, and collapsible wind turbine that can be carried by one person (see Figure 4.12).

Figure 4.12. Jaspira Turbine

Figure 4.13. Ampair Dolphin

• ***Ampair (www.ampair.com)***
Ampair – better known for its small HAWTs – has come out with a very small VAWT (4W) known as "The Dolphin" whose purpose is to top off or maintain the charge on a battery (see Figure 4.13).

• ***Mass Megawatts (www.massmegawatts.com)***
Mass Megawatts is a publicly traded company (symbol MMGW) developing a 50 kW "multi-axis" wind turbine prototype (see Figure 4.14) to be tested near Bakersfield, California. The

company reportedly has generated interest for several installations in Iceland, and Winrock Financial recently selected Mass Megawatts to build a 25 MW project in Colombia.

Figure 4.14. Mass Megawatts "Multi-Axis" Wind Turbine Prototype

• ***The Turby (www.turby.nl)***

This 2kW H-Darrieus from the Netherlands (designed at the Delft University of Technology) is specifically designed to be installed on rooftops, riding the European trend towards installing artistic-looking VAWTs in urban environments (see Figure 4.15). The Turby does not yet appear to be commercially available.

Figure 4.15. The Turby, with specifications

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