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ECONOMICS OF GRID-CONNECTED SMALL WIND TURBINES IN THE DOMESTIC MARKET

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INTRODUCTION

Exploitation of certain niche markets for small wind turbines is one strategy that could help speed the commercialization of grid-connected small turbines. We review the world's turbine manufacturers, the utility grid-connected applications and selected niche markets for grid-connected small wind systems (0.1 to 100 kilowatts). Wind turbine installation and purchase are handled under three different payment scenarios: paid in full up front, paid through a second mortgage, or paid as part of a first mortgage. We used a simple payback method to compare these scenarios and analyze the costs and energy produced for three different U.S. small wind turbines. When there is a buy-down program for the small wind turbine combined with other financial factors such as net metering, tax exemptions, and tax credits, a strong market incentive is created for the use of grid-connected small wind turbines.

OVERVIEW OF TECHNOLOGY AND APPLICATIONS

The majority of small wind turbines (between 0.1 and 100 kilowatts [kW]) power remote homes or mini-grids/village power, agricultural and livestock water pumping, or displace utility grid power. Due to their diversity of uses and operating conditions, small wind turbines have evolved over time, to increasing reliability and decreasing costs. Many small turbine manufacturers have product issues due to limited production runs, which have been helped by international sales.

There are a number of small turbines used in a variety of applications throughout the world. As of 1997, we found 55 small turbine manufacturers (eight U.S. and 47 international) offered 146 different turbine models (23 U.S. and 123 international). Of the international turbine models, 37% are Chinese or Russian. Figure 1 shows statistics for U.S. and international small wind turbines in three applications: water pumping, battery charging, and grid-connected.

Most (86%) small turbines are oriented upwind and most of these use a tail for yaw control. The rest are oriented downwind. Turbines control rotor overspeed by various methods, which are often used in conjunction with each other for redundant safety measures. Primary overspeed controls include furling or tilting up out of the wind (39%), active or passive blade pitching (36%), and fixed-pitch stall regulating (25%). As a redundancy, most turbines have either mechanical or electrodynamic brakes or manual furling capabilities.

As of the end of 1998, there were 21 companies (10 U.S.) that were known to be developing or testing 42 new small turbines. Many of these new turbines, like current models, are designed for more than one application. Twenty-three new turbine models can charge batteries, one can pump water, and 25 can be connected to the grid. Three of the new turbines are being developed under the U.S. Department of Energy's Small Wind Turbine Program.

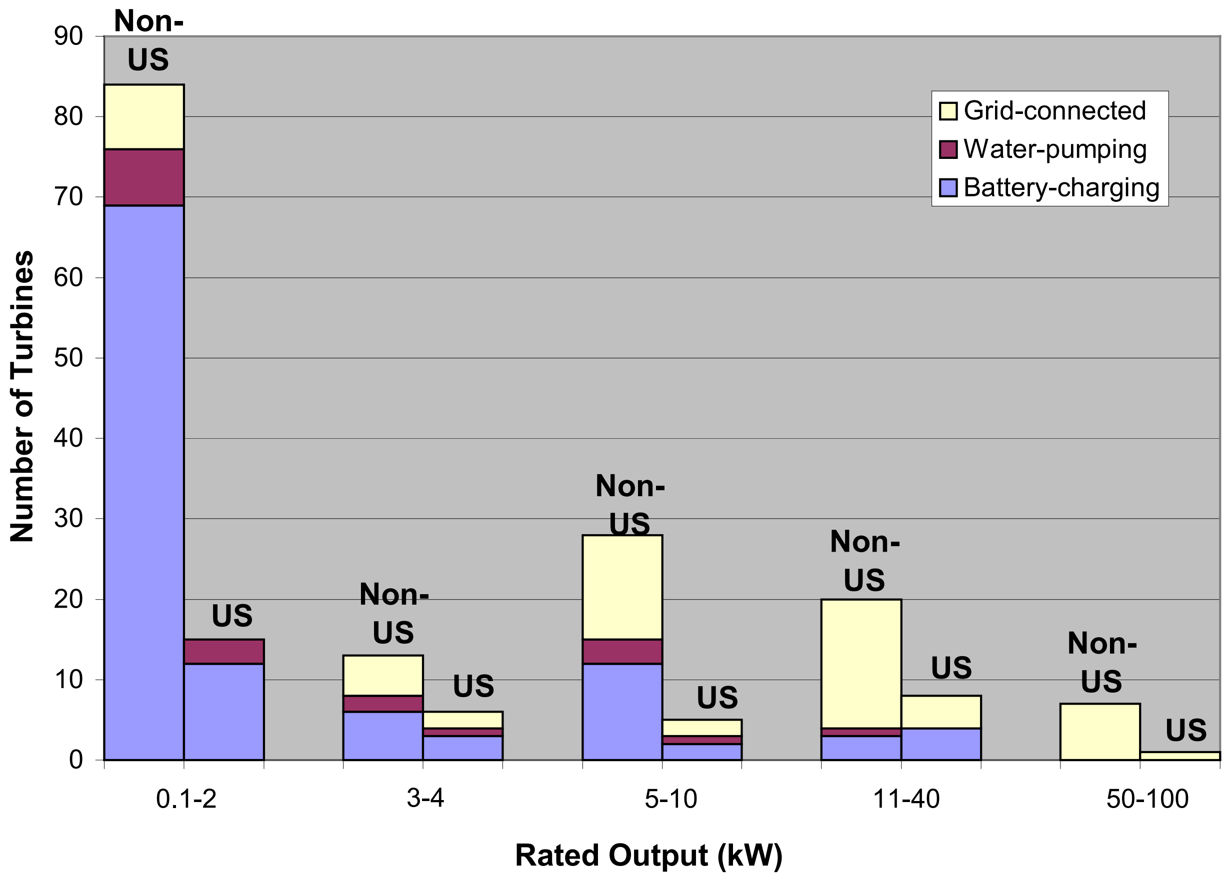

Figure 1. SMALL WIND TURBINE APPLICATIONS BY SIZE (as of 1997)

GRID-CONNECTED SYSTEMS

The grid-connected systems primarily include turbines rated between 10 and 100 kW. Although some turbine manufacturers offer turbines as small as 1 kW that can be grid-connected, they are not usually solely designed as such. There are three common configurations for grid-connected wind turbines shown in Figure 2.

In the third configuration, the turbine's output, either from a permanent-magnet alternator or wound-field synchronous generator, is variable voltage, variable frequency alternating current (AC) (usually three phase). The power must then be conditioned through an inverter before being fed to the utility grid. Two different types of inverters are commercially available: line-commutated and self-commutated. Self-commutated inverters (first configuration), due to their own oscillators need a reference from the utility grid to hold synchronization. When linked with a battery they may become part of an uninterrupted power supply, which is important in the event of a blackout. Line-commutated inverters (third configuration) are actuated by utility-line power. Both types of inverters produce sine-wave grid quality output, but act differently in the event of a grid blackout. Synchronous inverters, which are line-commutated, will cease to function during a blackout. In either case, commercially manufactured inverters for grid-connection are designed to not feed power to the grid in the event of a blackout. The first configuration shows a modified version of the third configuration except that a battery is added which keeps the inverter producing and thus allows for uninterrupted power.

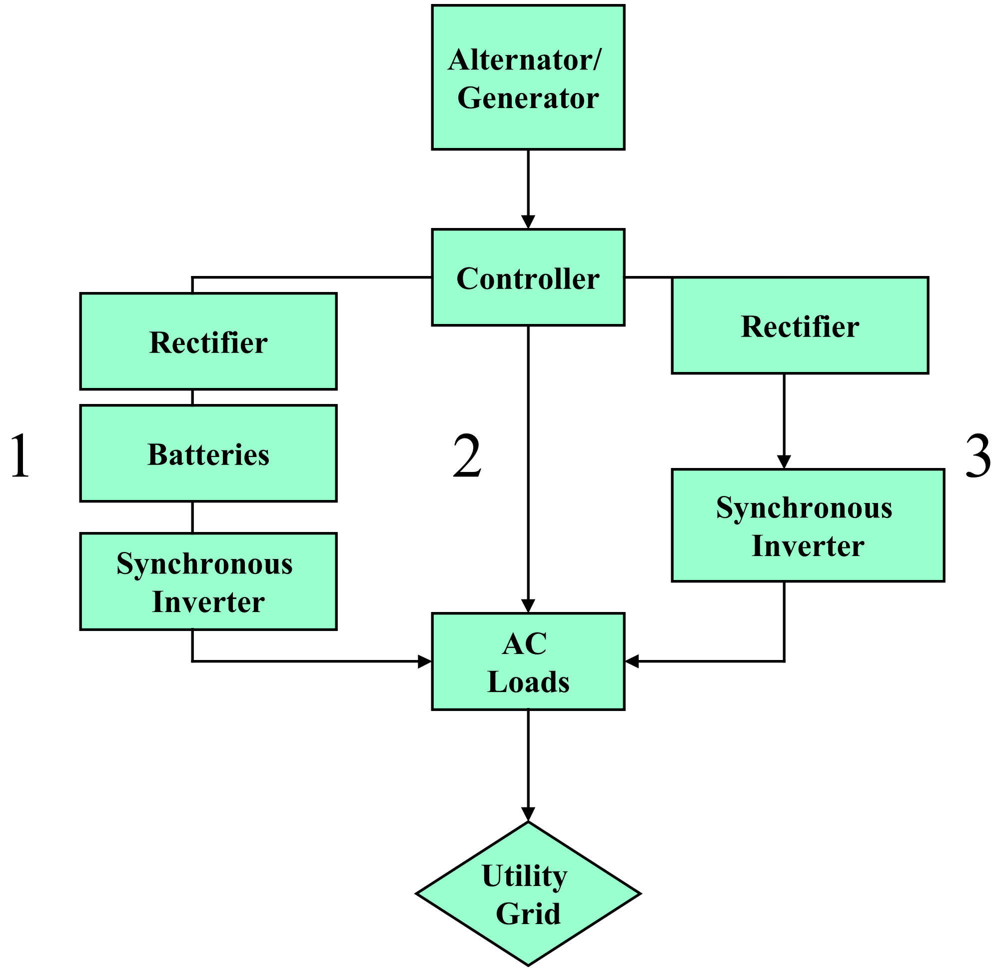

Figure 2. SMALL WIND TURBINE CONFIGURATIONS

In the second configuration, induction generators produce grid-quality, constant-speed, AC power without the need for an inverter. The output of induction generators is regulated by the utility power, therefore if the grid blacks out, the generator will not produce output

STATE FINANCIAL INCENTIVES

All of the above configurations can be used in a grid-connected application and take advantage of the applicable state incentives, which may make use of small turbines as a financial benefit. The state incentives, which will be discussed here, include net metering, buy-down programs, sales tax incentives, and property tax incentives. Sales tax and property tax incentives can change frequently, however the most recent listing (August 1998) of incentives by state can be found under the Database of State Incentives for Renewable Energy (DSIRE) Web site, http://www-solar.mck.ncsu.edu/dsirexls.htm. Ten states have sales tax incentives (AZ, CT, FL, HI, IA, MD, MA, MN, NJ, WA) and 16 states have property tax incentives (IL, IN, IA, MA, MN, MT, NE, NH, NC, ND, OR, RI, SD, TX, VA, WI) for installation of renewable energy systems.

Net metering is one incentive program that has grown in popularity during the past decade since it allows the customer the ability to offset power consumption up to 100% at the full retail value over the billing period (usually one month). Excess power produced is either granted to the utility with no buy-back, purchased by the utility at the avoided cost, or purchased at the average retail rate. Net metering rules are determined on a state by state basis sometimes by the legislature or the PUC. Often the PUC administers net metering programs for the state and as a result rural electric cooperatives (REC) do not have a net metering program. This is unfortunate since small wind turbines have historically been used in rural settings where the use of small turbines has a larger market.

Without net metering, small wind system owners are considered to be qualifying facilities under the Public Utility Regulatory Policies Act of 1978 (known as PURPA), and need only be paid the utility's avoided fuel cost (approximately 2¢/kWh) for their "instantaneous" excess generation. Combined with requirements to purchase a second meter, this arrangement gives little financial incentive to consumers for purchasing a wind energy system.

As shown in Figure 3, 27 states currently offer net metering for small wind energy systems. The treatment of net excess generation varies from state to state. Of the 27 states that have wind energy net metering, two buy back net excess generation at the retail electricity rate (MN, WI); eight have an avoided, or wholesale, buy-back rate between about 1.5 to 3.5¢/kWh (AZ, CT, ID, IA, IL, MA, NJ, ND, OH, OR*, TX). Three roll the monthly net excess generation to the utilities (IN, NV, OK); two roll the net excess generation to the next month (CO, NH). And eight pay nothing for the annual net excess generation from customers (CA, ME, MT, RI, VT, VA, and WA) and either the utility or the state public service commission (DE, PA) defines the remainder. (*Oregon offers net metering options of either avoided cost, credit to the following month at the end of the annual period the excess shall be granted to low income assistance, credited to the customer or other uses.)

Figure 3. Wind Energy Financial Incentives by State

In addition to net metering, there are several other state incentive programs designed to encourage the proliferation of grid-connected small wind energy systems such as buy-downs, income tax exemptions, state tax exemptions, accelerated depreciation, special grants, and loan programs. California has enacted a 50% buy-down program in addition to net metering, but will decrease the buy-down amount over the life of their buy-down program. Illinois also offers a 60% buy-down program. Minnesota offers an additional (over net metering) 1.5¢/kWh payment for net excess generation for wind energy projects less than 2 megawatts.

THREE NICHE MARKETS BY STATE

These states were chosen based on their strong wind resource and their variety of financial incentives. The states were chosen as the strongest examples of financial incentives currently offered. California has a buy-down program and net metering, and Minnesota has a net metering program (average retail rate for excess), sales tax exemption, property tax exemption, and a 1.5¢/kWh for net excess energy. Conversely, South Dakota has only a property tax exemption. We evaluated the payback period for three small wind turbines, a World Power Technologies Whisper 3000, a Bergey Excel, and Wind Turbine Industries Jacobs 26-17.5, using the incentive programs available for California, Minnesota, and South Dakota

The Whisper 3000 ($12,760) is a 3-kW machine on a 26-meter (m) tower; the Bergey Excel ($28,467) is rated at 10 kW on a 30-m tower; and the Jacobs 17.5-kW ($30,780) turbine sits on 37-m tower. (The prices for the turbine systems were used for our simple payback analyses and were collected from manufacturer's literature. These prices include different things for different manufacturers and are subject to change.) The above costs include inverter, turbine footings, wire, PVC conduit and ground rods. Annual operations and maintenance costs were assumed to be 1% of the installed turbine system costs and the life of these turbines was assumed to be 30 years.

Utility company fees ($300), township conditional use permit ($450), county conditional use permit ($450), backhoe and operator ($220), and electricians ($1500) have been approximated for each turbine at the same cost ($2,920). Note that these costs have been used for these analyses but will change in the future. Residential energy consumption was assumed to be 10,000 kWh/year with any energy production over 10,000 kWh being net metered to the utility (if applicable). Installation of these turbines was assumed to be done by the homeowner so there are no installation costs outside the backhoe operator and the electrician. Annual energy produced by the specific wind turbines was calculated based on the manufacturer's power curve and a Rayleigh distribution for annual average wind speeds.

California

The incentive programs in California include a 50% buy-down for turbines less than or equal to 10 kW, and net metering with a cap of 10 kW, with the net excess generation granted to the utility on an annual basis. The financial parameters in California, include a 7.5% sales tax, a property tax, and a 12.5¢/kWh retail cost of electricity, which are used in the payback period assessment.

Based on the Wind Energy Resource Atlas of the United States, California has locations of up to Class 6 wind resources, therefore, payback was calculated as a function of annual average wind speeds of 5.4 m/s, 5.8 m/s, 6.2 m/s and 6.7 m/s. Figure 3 shows the range of results of the average payback periods for the three wind turbines under three financial scenarios: A) paid up front, B) a home equity loan of 10 years at 10%, and C) a home mortgage of 30 years at 7% interest rate.

The best payback period in California is less than 7 years for scenario A given an annual average wind speed of 6.7 m/s. The longest payback period is 35 years for scenario C given a 5.4 m/s annual average wind speed. While the simple payback associated with net metering offers good payback, the addition of a buy-down results in much lower payback. In fact between net metering alone and buy-down alone, the buy-down offers a quicker payback. One issue with the buy-down program in California is the requirement to have the inverter UL listed. Although included in the graph, the payback for the Jacob's 17.5-26 did not include net metering since there is a size limitation in California of 10 kW for small turbines. All cases show simple payback under 30 years except for the mortgage scenario C, except for the 5.4 annual average wind speed case.

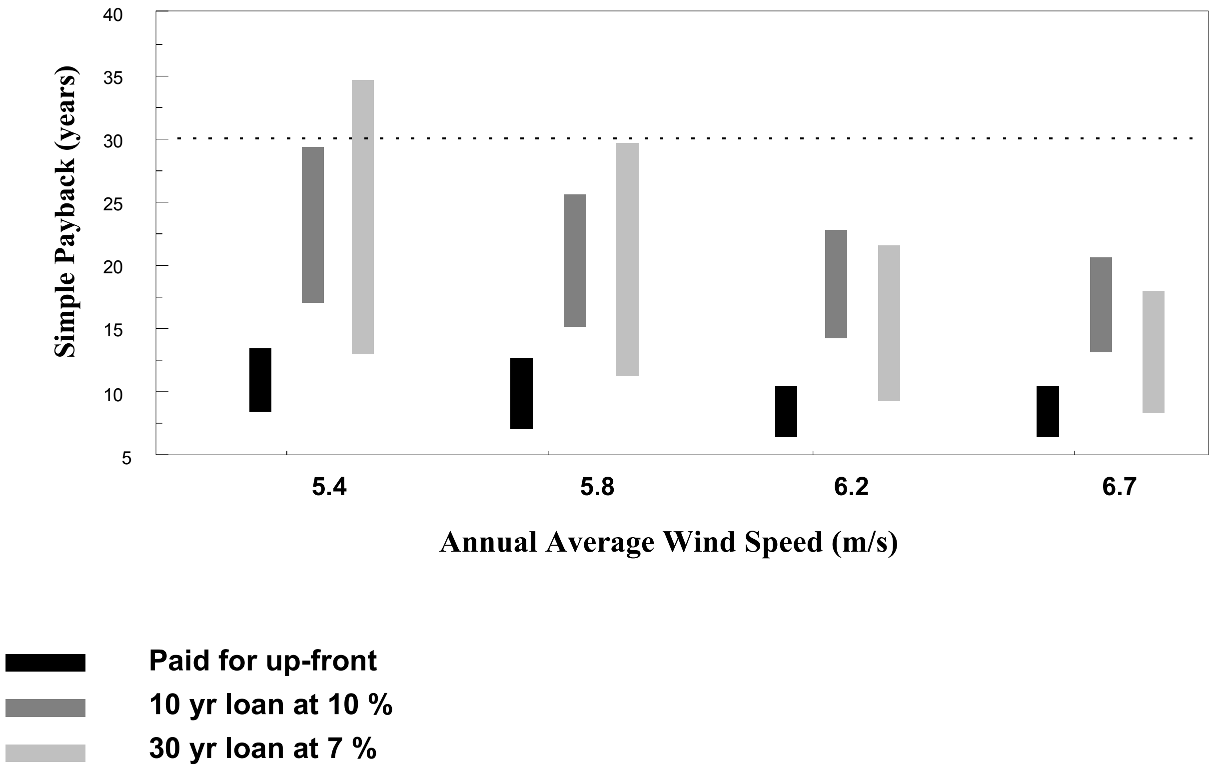

Figure 4. PAYBACK PERIOD FOR GRID-CONNECTED SMALL WIND TURBINES IN CALIFORNIA

Minnesota

The financial incentives in Minnesota include net metering for turbines rated 40 kW or less, exemptions from sales or property tax for small wind energy equipment, and an additional 1.5¢/kWh for net excess energy sold back to the utility. (As of July 1, 1999, Minnesota only offers the 1.5¢/kWh to landowners, Minnesota small businesses, non-profit organizations, and Native American tribes.)

Based on the Wind Energy Resource Atlas of the United States, Minnesota has locations of up to Class 5 wind resources, therefore, payback was calculated as a function of annual average wind speeds of 5.4 m/s, 5.8 m/s, and 6.2 m/s. Figure 5 shows the range of results of the average payback periods for the three wind turbines under three financial scenarios: A) paid up front, B) a home equity loan of 10 years at 10%, and C) a home mortgage of 30 years at 7% interest rate.

The results are shown in Figure 5 for wind speeds ranging from 5.4 to 6.2 m/s annual average wind speed. Under net metering, Minnesota offers the average retail rate for excess energy produced, currently this is found in only one other state. While the average payback period is longer than in California, the lowest payback number is 9 years for an average annual wind speed of 5.8 m/s. In Minnesota the net metering size limit is 40 kW allowing for all the consumption to be displaced by wind turbine energy production and the excess is paid for by the utility at the average retail rate with an additional 1.5¢/kWh. When an arrow is shown in Figure 5 it means that the simple payback period could be longer than 45 years. Note the dramatic difference between different average annual wind speeds under the 30-year mortgage scenario. Also for the paid up-front scenario A, all of the average annual wind speeds show payback within 30 years or the estimated wind turbine life.

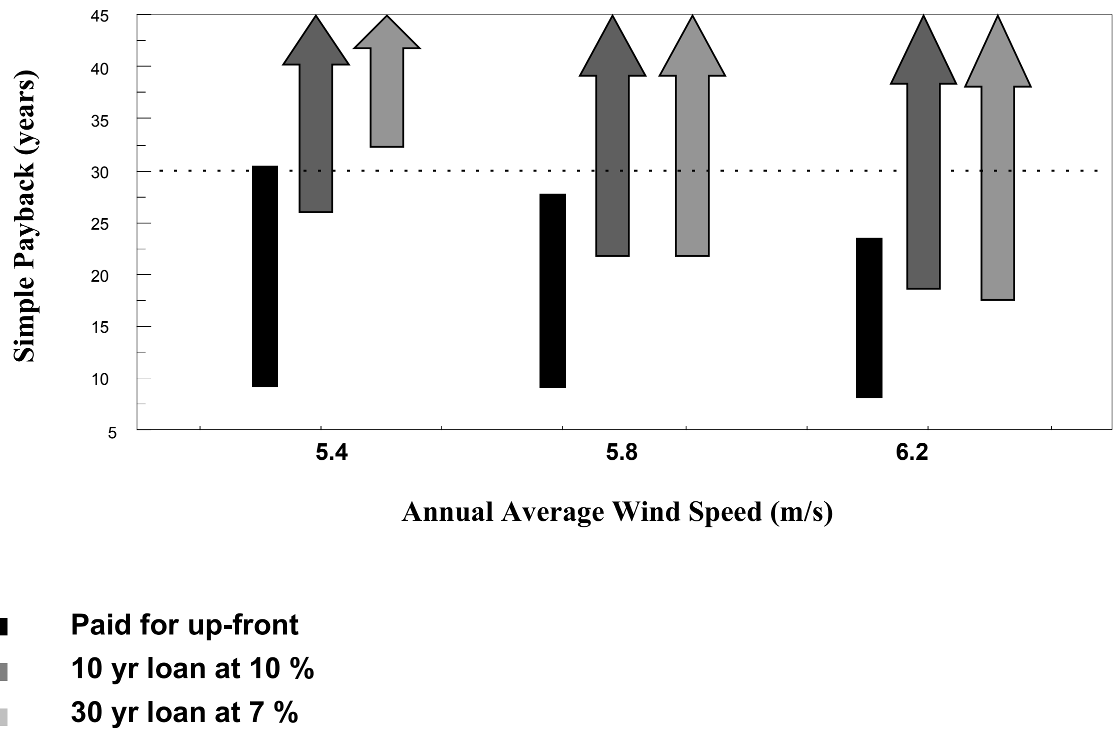

Figure 5. PAYBACK PERIOD FOR GRID-CONNECTED SMALL WIND TURBINES IN MINNESOTA

South Dakota

Now looking at one of the least financially attractive state for small wind turbines, South Dakota only offers a property tax incentive for small wind turbines. A 5% sales tax, a 1% property tax, and a 6.3¢/kWh retail cost of electricity are included in the calculation. Since there is no net metering in South Dakota, a 40% load to wind resource match was assumed.

Based on the Wind Energy Resource Atlas of the United States, South Dakota has locations of up to Class 5 wind resources, therefore, payback was calculated using annual average wind speeds of 5.4 m/s, 5.8 m/s, and 6.2 m/s. Figure 6 shows the range of results of the average payback periods for the three wind turbines under three financial scenarios: A) paid up front, B) a home equity loan of 10 years at 10%, and C) a home mortgage of 30 years at 7% interest rate.

The results for annual average wind speeds ranging from 5.4 to 6.2 m/s are shown in Figure 6 below. The payback periods for scenarios B and C are higher than 40 years with little variation. The payback periods for scenario A vary a lot from a low 23 years to more than 40 years depending on the wind turbine type. Even though there are good wind resources within the state, the lack of any substantial incentives for small wind turbines make South Dakota unappealing unless one chooses to live off the utility grid.

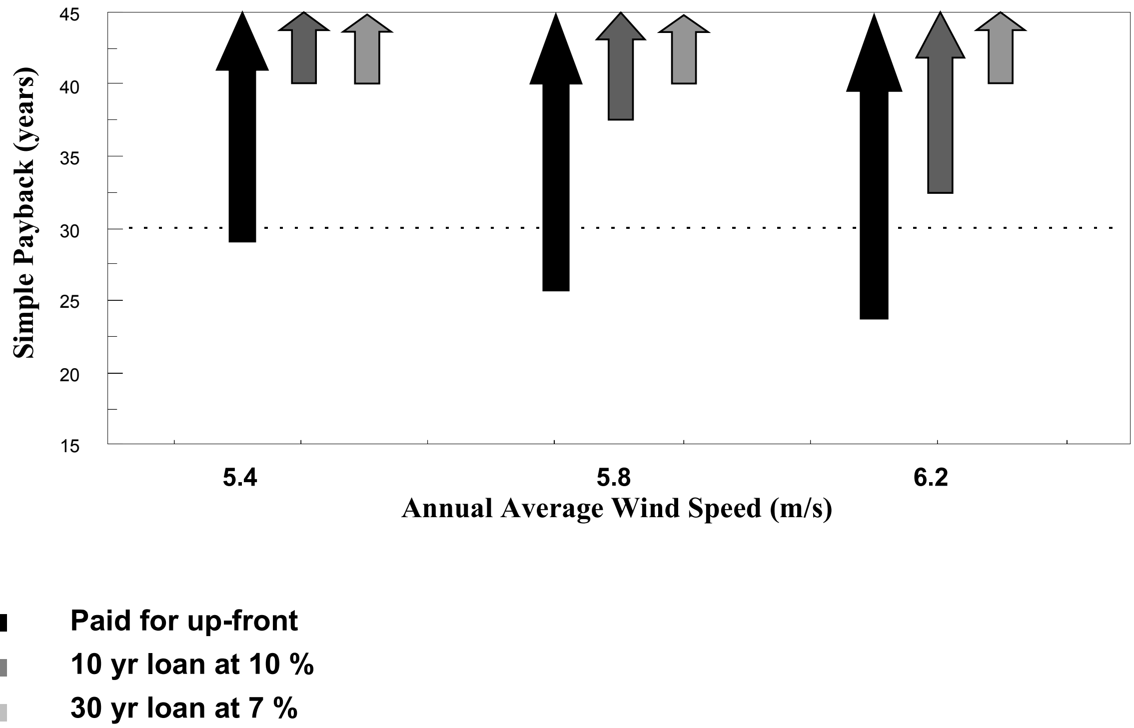

Figure 6. PAYBACK PERIOD FOR GRID-CONNECTED SMALL WIND TURBINE IN SOUTH DAKOTA

CONCLUSIONS

All three states have good harvestable wind resources with differing financial incentives. Currently, the shortest simple payback found is for California where they have high retail electricity rates and a substantial buy-down program. Minnesota, which has very attractive net metering rules also, offers a niche market for small wind turbines. Conversely South Dakota offers minimal financial incentive to use a small wind turbine. One can conclude that a buy-down program offers the strongest financial incentive for small wind turbine market. However, states with net metering and retail rate payback can also offer a strong market incentives although not as good as a buy-down program. On the other hand, South Dakota, which offers only property tax exemptions, does not create a strong market driver for small wind turbines.

Currently, the California market provides the best incentives for small wind turbines since the 1980s. Other states (IL, NJ) are exploring ways to use their systems benefit charges to set up incentives for renewable energy usage, like the California model. There is also a push for a national net metering policy, which will offer some incentive for wind turbines of certain size in areas with high retail electricity rates. In any case, exploitation of certain niche markets for small wind turbines is one strategy that could help speed the commercialization of grid-connected small turbines.

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