Wind Hybrid Electricity Applications

IOWA
Department of Natural Resources

Prepared by the

IOWA WIND ENERGY INSTITUTE

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Introduction

Wind energy is widely recognized as the most efficient and cost effective form of new renewable energy available in the Midwest. New utility-scale wind farms (arrays of large turbines in high wind areas producing sufficient energy to serve thousands of homes) rival the cost of building new conventional forms of combustion energy plants, gas, diesel and coal power plants. Wind energy is not subject to the inflationary cost of fossil fuels. Wind energy can also be very attractive to residential and commercial electric customers in high wind areas who would like to be more self-sufficient for their energy needs. And wind energy is friendly to the environment at a time when there is increasing concern about pollution and climate change.

However, wind energy is an intermittent source of power. Most wind turbines start producing small amounts of electricity at about 8-10 mph (4 meters per second) of wind speed. The turbine does not reach its rated output until the wind reaches about 26-28 mph (12 m/s). So what do you do for power when the output of the wind turbine is not sufficient to meet the demand for energy?

This paper will discuss wind hybrid technology options that mix wind with other power sources and storage devices to help solve this problem. This will be done on a variety of scales on the impact of wind energy on the utility system as a whole, and on the commercial and small-scale residential applications. The average cost and cost-benefit of each application along with references to manufacturers will be given. Emerging technologies that promise to shape the future of renewable energy will be explored as well.

Wind Turbine Technology

First, the key component of a wind hybrid system, the wind turbine will be considered. Current wind turbine technologies are far more efficient and reliable than their predecessors. As of this writing, utility-scale wind turbines have rated outputs from 600 kilowatts (600,000 watts) to two megawatts (2,000,000 watts). The rotor consists of three blades at least 80 feet long each. The nacelle (housing for the generator and rotor hub) sits on a tower from 50-70 meters tall (165 to 230 feet). Each turbine will generate enough electricity to power hundreds of homes.

A wind farm is an array of turbines often spaced about a quarter of a mile apart.

The turbines have an availability factor of about 97 percent. That means that outages and servicing causes the turbine to go off line only about three percent of the time. This makes wind turbines more reliable than conventional generators. The turbines are usually arrayed across land that is high and exposed, yielding the best wind resource. Arrays, commonly of 50 or more turbines, are called wind farms. The wind farm's reliability is increased by the fact that the turbines can be serviced one at a time. Often, in a conventional power plant of similar capacity to the wind farm, the entire plant would need to be shut down for servicing.

Wind farms remove less than four percent of agricultural land from crop production.

Wind turbines are low impact. The tubular towers for large turbines are often only 12 feet in diameter at the base. Lattice towers have a slightly larger footprint but still take up a small space on a farmer's land. Together with access roads, a typical wind farm removes less than four percent of the land from agricultural production while roughly doubling the income from the farm area to the landowner who leases the space for the turbines. Row crops and livestock grazing can continue right up to the base of the turbine.[1]

Wind electricity is the fastest growing energy sector in the world, expanding at double-digit rates. Several European countries have wind energy in excess of ten percent of their energy portfolio. Some areas have as much as 30

percent of their energy from wind.[2] The U.S. has excellent wind resources, especially in the Midwest. Iowa is said to have sufficient resources to power five percent of the entire nation.[3] The U.S. Department of Energy in its "Wind Powering America" initiative has set a goal to bring the nation to five percent by 2010.

Along with the boom in utility-scale wind applications have come improvements in commercial and residential wind applications. Here, single turbines are placed near a commercial facility or home to deliver power directly. These are called distributed wind generation as opposed to centralized wind farms. Distributed generation turbine sites are usually not in as optimal wind areas as wind farms. The buildings and trees in the vicinity of most commercial and residential areas cause some obstruction to the wind.

These areas are rarely on the very highest ground. However, direct interconnection of the wind turbine to the home or business avoids the demand wind farms put on the electricity transmission system. Electricity must be moved from large wind farms to the load centers by transmission lines. Often, the capacity on these lines is limited or the rates charged for "wheeling" (transporting the power across transmission lines) the power reduces the cost effectiveness of the wind farm. So there can be efficiencies gained by distributed generation in certain applications.

Residential and Small Commercial Wind Turbines

Choosing the Right Size Turbine

Small wind turbines are manufactured with rated outputs from about 300 watts to 100 kilowatts. The most popular range in size from 1,000 watts to 50 kilowatts. When considering a wind turbine purchase, it is important to calculate the "capacity factor" for the chosen wind turbine site. The capacity factor is the percentage of energy that is actually delivered of the rated

capacity. For instance, a 1,000-watt turbine with a typical capacity factor of 25 percent will deliver 1,000 watts in high wind, no energy in low wind and an average of 250 watts of power.

The capacity factor of a wind turbine is the average percentage of rated output that is actually delivered.

The capacity factor is calculated from the hourly wind speed and temperature record at hub height (the height of the tower). Denser (cooler) air has more power. Wind power density is based on the speed and density of the air. The increase in the wind's power is a function of the cube of the velocity. That is, power increases exponentially with speed. For example, the power available at 16 mph is nearly double the power available at 13 mph. A first order estimation of the monthly and annual capacity factors and outputs of typical turbines for locations in Iowa can be found on the web site of the Iowa Energy Center at www.energy.iastate.edu/wind.

Considering the right size will depend upon the type of arrangement that can be made with the local utility for buying back excess power generated. If the utility won't buy back the power or will only pay a token amount, then the turbine will be most economical if used only to offset the use of electricity and not generate any extra power. To determine the right size in this situation, the daily and monthly pattern of use should be reviewed. These records are available from the utility. A typical home use pattern is shown in *Figure 1*. One way of estimating the proper rating of the turbine in this situation will be to calculate its size so that the average capacity factor each month does not exceed the lowest use period of the month. In this type of estimation, capacity factor of the turbine usually comes out to be about 25 percent of the total electricity use.

Small wind turbines are more economical when the power is used locally.

If "net-billing" or a method of storing excess energy is available, then the turbine can be sized so that its estimated total output equals the total amount of electricity consumed (see section on "Interconnection" below).

Picking the Best Site for a Turbine

Small differences in wind speed greatly affect a turbine's output.

Small differences in the average wind speed of the turbine site will greatly affect the amount of electricity produced. The terrain and local obstructions significantly affect wind speeds. Therefore, the site must be carefully chosen and

monitored to make an informed economic decision about a wind turbine purchase.

The most important factor for siting a turbine is its exposure to the wind. The exposure should be clear especially in the prevailing wind directions. In Iowa, this is to the north and northwest for the cooling winds and south to southeast for the warming winds. Ideally the site should be higher than the surrounding terrain for several miles. It should be fairly flat or gradually sloped. It should be free of turbulence creating objects like buildings, trees, or silos. The turbine will cost about the same to purchase and install no matter where it is placed. However, the capacity factor and output will vary from site to site based on the elevation and terrain.

The Effect of Tower Height on Wind Turbine Output

In Iowa, it is usually best to place a wind turbine on the tallest tower affordable. The higher the turbine is off the ground, the higher the wind speed will be. The most important task is to get above the initial ground turbulence. After the first 80 feet the wind speed gain is a little less but still constant. Residential scale turbines are usually on towers about 80-100 feet tall. Utility scale turbines are usually on towers from 130 to 230 feet tall. The effect of tower height on turbine output can be calculated using the Iowa Energy Center web-based wind turbine output calculator at: www.energy.iastate.edu or by applying the formula:

Wind Speed A = Wind Speed B times $(A/B)^{.15}$.
where:
A equals the proposed height
B equals the height of measured wind speed
.15 is the shear exponent

Turbine Installed Cost

Utility-scale wind turbines today usually have an installed cost of about $800-1,200 per kilowatt. Smaller turbines tend to be twice as expensive per kilowatt. The price of smaller turbines is falling as the demand for them increases. For example a 750 kW turbine installed with tower and foundation

will cost $600,000-$750,000. There will be additional cost to interconnect this turbine to utility transmission lines and transmit the power. A 20 kW turbine with tower installed will cost at least $25,000. A 1 kW turbine will cost about $2,500 installed with a tower and electrical controls. These are average costs as of this writing. For up-to-date information, contact wind turbine manufacturers. A list of manufacturers and web site links are provided in the appendices and can be found at the web site of the American Wind Energy Association: www.awea.org

Interconnection

Wind turbines can be interconnected in a number of ways. In a wind farm, the output from all the turbines is collected by underground cable to a substation. At the substation the voltage is transformed to match the line voltage of the transmission line. The energy is then carried by the transmission line to meet the load requirements of all the communities that the transmission line serves.

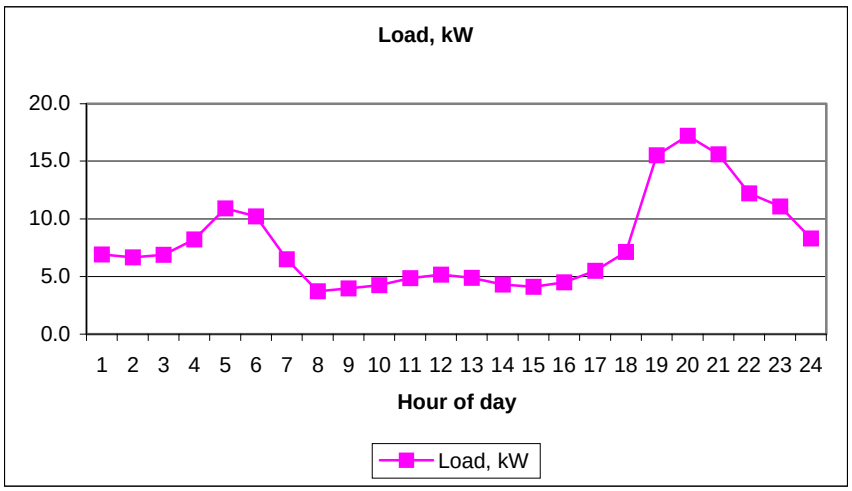
In a commercial or residential system the turbine can be connected directly to a meter. This requires utility approval. In this type of interconnection, power from the turbine or the grid depending is drawn based on the demand and the amount of power the turbine is producing. Excess power generated when the demand is less than the wind/hybrid generation will be fed back to the utility. The utility may buy back this power at an agreed rate.

Net-metering" sometimes referred to as net-billing is a method of metering and billing for the energy consumed and produced at a home or commercial facility that has a wind or wind-hybrid system. Excess electricity produced by the wind-hybrid system will spin the existing home or business electricity meter backwards. When the customer needs more energy than the wind-hybrid system is producing, the meter spins forwards. At the end of each month, the customer pays only for the net amount the meter moved forward. Under this arrangement, the customer effectively gets full retail value for all the energy produced by the wind-hybrid system, whether it is used locally or whether it is excess energy absorbed by the grid. Net-metering is very important to make home and commercial scale wind-hybrid applications economically viable and reliable.

Net-metering (net-billing) allows the meter to run backward when the wind turbine produces excess power.

However, at the time of this writing, net-metering legislation is not enforceable in Iowa. Providing this type of arrangement is solely at the discretion of the utility. Most Iowa utilities will not approve net metering. They will require two meters, one for the excess energy from the turbine and one for energy drawn from the utility.

Figure 1: Daily Electric Use Pattern of Typical Home



The Final Analysis

After considering the proper size of turbine, the site for the turbine, the proper tower and understanding the cost, there are a few more considerations to complete the final analysis. First, it is important to look at the daily and seasonal use pattern to see how much of the energy can be used directly. The following chart is an example of a typical residential use pattern. Wind energy is generally fairly constant day and night, whereas the use pattern in most homes spikes in the morning and night.[4] This is where wind hybrid technologies may come into consideration. An additional generation source or storage solution to help out when the wind turbine produces insufficient or too much energy may help create an efficient system.

Wind Hybrid Technology Definition

A wind hybrid energy system incorporates wind energy together with one or more forms of electric generation or energy storage to serve a specific energy load. A wind hybrid system revolves around a wind turbine with other energy sources or storage to help deliver energy on demand. For example, a diesel generator may be controlled to operate when the wind turbine is not producing sufficient power to meet the load requirements. Or a battery bank may be connected to the turbine to store excess power being generated. A combination of technologies can be used together, such as solar panels, batteries, a generator and a wind turbine. Also, there are some interesting emerging technologies such as flywheels and fuel cells, which promise to help make better use of intermittent low-cost wind energy.

In this paper all these options will be examined, from the utility-scale to the residential scale. We will also look at some applications where different forms of distributed generation are blended into a utility's energy portfolio to compliment wind generation. Specifically, we will examine re-powering decommissioned dams to create wind-hydro solutions and the blending of wind with the output from diesel peaking generators owned by many utilities. Then a review of commercial and home-scale renewable energy and energy storage technologies will be undertaken. We conclude with a cost-benefit comparison of all technologies to assist the reader in better understanding the applications and economics of different forms of energy generation and energy storage that can be coupled with wind generation. In many cases, the economics may not be favorable at the present time but may become favorable in the evolving environment of electric deregulation and changing fuel costs.

Utility-Scale Wind-Hydro Hybrids

Introduction and Background

Iowa has numerous small dams on its rivers. There are 34 dams and potential dam sites that are registered with the Federal Energy Regulatory Committee (FERC), plus other small dams not registered. There was renewed interest in re-powering many of these old dams after Iowa adopted its Alternate Energy Production (AEP) rules. Applications were made to FERC for licenses to study re-powering these facilities. If a dam site is not registered with the FERC, then developers didn't see any economic potential for re-powering, and the site is probably not a candidate for re-powering. Most of the older existing dams had hydroelectric generators installed at one time. Nearly all of these dams had their generators abandoned and scrapped because they were not economical to operate, maintain, or renovate due to their small size. Repair costs and operating labor costs made the power uncompetitive with power from large central station power plants, such as coal or nuclear. There are another 9 dams on the Mississippi River bordering Iowa. The economics of adding generation to these dams may be better than on the smaller interior rivers.

Figure 2: Iowa River Dam at Jackson, Minnesota

Figure 2 shows a small dam on the Iowa River at Jackson, Minnesota. This is immediately north of the Iowa border. Even though this dam is in Minnesota, it is typical of the small dams on Iowa's interior rivers. Many of the original powerhouse buildings have been removed, but the foundations remain. The powerhouse foundation is shown on the left side of the picture in *Figure 2.*

Figure 3: West Fork of Des Moines River, Rutland, Iowa

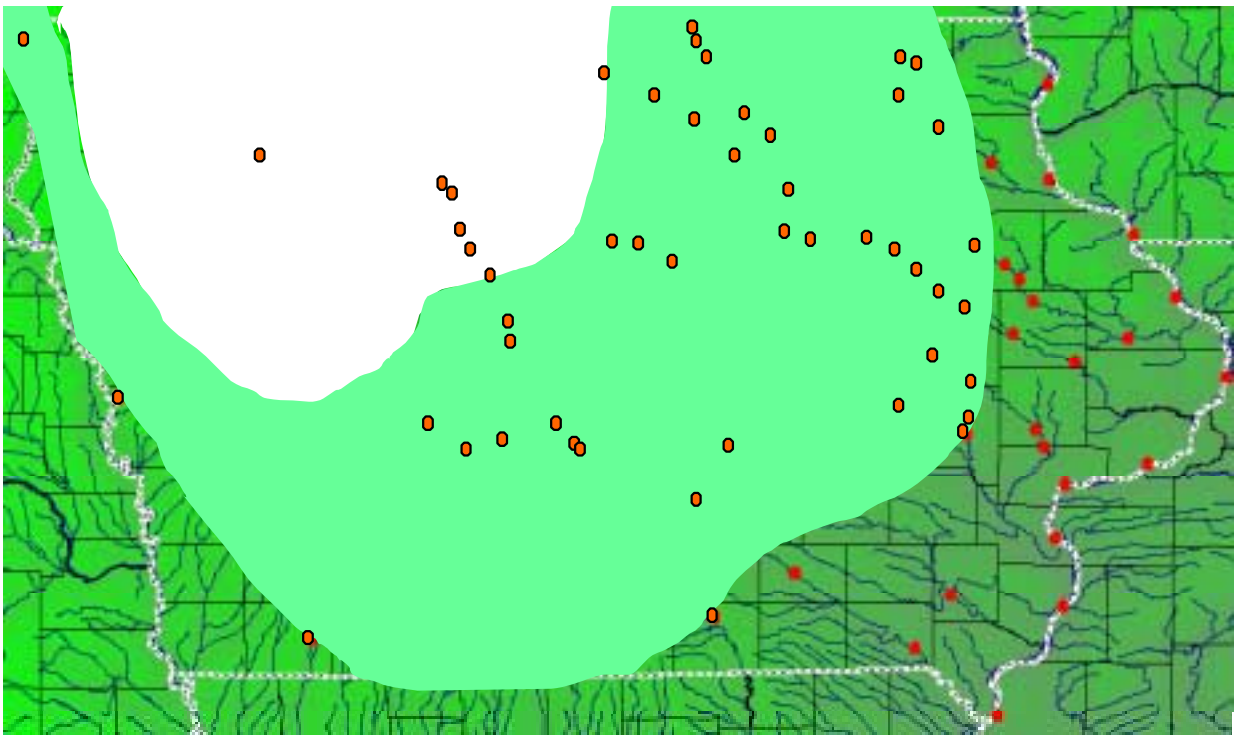
Figure 3 shows the small dam on the West Fork of the Des Moines

River at Rutland, Iowa, which is 20 miles north of Fort Dodge. The powerhouse is intact at this site, but the generators have been removed. Even with the powerhouse intact there would still be considerable renovation and expenses required in retrofitting the site with generators. The average river flow at this site is about 1,000 Cubic Feet per Second (CFS).

The table below summarizes the hydroelectric potential in Iowa.

Potential Hydroelectric Resources in Iowa		
	Number	Actual or Potential MW of Capacity
Existing Dam Sites with Generation	10	134 (9 w/o Keokuk)
Existing Dam Sites without Generation	64	239
Undeveloped Sites	3	41
Total Sites	77	414 (289 w/o Keokuk)

The two-page table following shows some information about the most likely dam sites in Iowa where hydropower could be added. *Figure 4*, the map below, shows the locations.



*Map provided by Wind Utility Consulting, Jefferson, Iowa

Figure 4: Map showing potential hydro re-powering sites.
Colors correspond to broad wind regimes: Yellow=Class 4, Light Green=Class 3, Dark green=Class 2

Summary of Iowa Hydro Power Potential

From the report "U.S. Hydropower Resource Assessment" by the Idaho National Engineering Laboratory of the Renewable Energy Products Department of the Lockheed Idaho Technologies Company

FERC Number	Plant Name Stream	Dam Status	Nameplate Rating (KW)	PESF **	PESF x kW
	DES MOINES RIVER BASIN				
7879	DES MOINES R CENTER STREET	WO	1,860	0.90	1,674
11346	DES MOINES R FORT DODGE MILL	WO	690	0.90	621
IA004	DES MOINES R OTTUMWA	W	3,000	0.90	4,842
11174	DES MOINES R RED ROCK (& 11502)	WO	30,000	0.75	22,500
10749	DES MOINES R SAYLORVILLE	WO	9,600	0.75	7,200
IA109	DES MOINES RIVER BONAPARTE	WO	2,990	0.90	2,691
IA102	DES MOINES RIVER BOONE MILLDAM	WO	760	0.90	684
IA108	DES MOINES RIVER FORT DODGE MILLDAM	WO	1,760	0.90	1,584
IA101	DES MOINES RIVER FRASER MILLDAM	WO	760	0.90	684
IA106	DES MOINES RIVER LEHIGH	WO	810	0.90	729
IA103	DES MOINES RIVER SCOTT STREET DAM	WO	1,470	0.90	1,323
IA005	M RACCOON R PANORA(232 IA NO)	WO	2,980	0.25	745
8741	M RACCOON R REDFIELD	WO	98	0.50	49
9882	RACCOON R ADEL MILL	WO	420	0.90	378
11344	W FK DES MOINES R HUMBOLDT MILL	WO	820	0.90	738
11343	W FK DES MOINES R RUTLAND MILL	WO	700	0.90	630
	16 Dams Subtotal of Above		58,718		47,072
	IOWA RIVER BASIN				
9278	CEDAR R CEDAR FALLS	WO	770	0.90	693
IA001	CEDAR R CEDAR RAPIDS	WO	1,600	0.90	8,640
9891	CEDAR R CHARLES CITY MILL	WO	220	0.75	165
11349	CEDAR R MITCHELL MILL	W	665	0.90	459
11283	CEDAR R NASHUA	WO	810	0.75	608
IA006	CEDAR R PROJECT 13 A	U	11,200	0.90	10,080
IA008	CEDAR R ROCHESTER	U	28,000	0.90	25,200
IA009	CEDAR R ST ANSGAR LOWER	WO	172	0.75	129
IA010	CEDAR R ST ANSGAR UPPER	WO	186	0.75	140
8111	CEDAR R WATERLOO	WO	1,840	0.90	1,656
1853	GENEVA CR,MISSISSIPPI R MUSCATINE 3	U	25,000	0.90	22,500
8110	IOWA R ALDEN MILL	WO	220	0.50	110
7066	IOWA R BURLINGTON STREET	U	2,000	0.90	1,800
11463	IOWA R CORALVILLE	WO	12,000	0.75	9,000
8691	IOWA R CORALVILLE MILL	WO	1,000	0.75	750
8109	IOWA R STEAMBOAT ROCK	WO	280	0.50	140
IA111	IOWA RIVER AMANA DAM	W	280	0.90	252
IA124	IOWA RIVER IOWA FALLS MILLDAM	W	540	0.90	486
11250	MISSISSIPPI R MISSISSIPPI L&D 16	WO	13,000	0.75	9,750
7103	MISSISSIPPI R MISSISSIPPI L&D 17	WO	10,500	0.50	5,250
11374	SHELLROCK R GREENE MILL	WO	800	0.90	333
11347	SHELLROCK R MARBLE ROCK MILL	WO	660	0.90	594
	22 Dams Subtotal of Above		111,743		98,734
	MAQUOKETA RIVER BASIN				
11485	MAQUOKETA R DELHI MILL DAM	WO	1,425	0.90	1,283
9893	MAQUOKETA R HOPKINTON DAM	WO	250	0.90	225
9892	MAQUOKETA R MANCHESTER MILL	WO	150	0.75	113
11342	MAQUOKETA R MONTICELLO MILL	WO	320	0.90	288
8184	MAQUOKETA R QUAKER MILLS	WO	160	0.90	144
11246	MISSISSIPPI R MISSISSIPPI L&D 10	WO	16,800	0.50	8,400

11247	MISSISSIPPI R MISSISSIPPI L&D 11	WO	14,000	0.50	7,000
11248	MISSISSIPPI R MISSISSIPPI L&D 12	WO	8,200	0.50	4,100
IA002	S FK MAQUOKETA R MAQUOKETA	W	1,200	0.50	2,070
8642	TURKEY R ELKADER	WO	500	0.50	250
	10 Dams Subtotal of Above		43,005		23,872
	MINOR RIVER BASIN				
IA121	BIG SIOUX RIVER KLONDIKE MILLDAM	WO	440	0.90	396
IA123	CEDAR RIVER OTRANTO DAM	WO	150	0.90	135
IA115	CEDAR RIVER PALISADES-KEPLER	WO	2,010	0.90	1,809
IA117	CEDAR RIVER WAVERLY MILLDAM	W	495	0.90	522
IA110	LITTLE SIOUX RIVER LITTLE SIOUX DAM	WO	690	0.90	621
IA125	NODAWAY RIVER CLARINDA DAM	WO	140	0.90	126
IA112	NORTH SKUNK RIVER LYNNVILLE DAM	WO	150	0.90	135
IA107	SHELL ROCK RIVER ROCKFORD	WO	150	0.90	135
IA122	TURKEY RIVER CLERMONT MILLDAM	WO	470	0.90	423
IA105	TURKEY RIVER FORT ATKINSON	WO	100	0.90	90
IA113	WAPSIPINICON RIVER ANAMOSA MILLDAM	W	250	0.90	630
IA114	WAPSIPINICON RIVER OXFORD MILLS	WO	570	0.90	513
IA118	WAPSIPINICON RIVER QUASQUETON DAM	WO	250	0.90	225
IA116	WAPSIPINICON RIVER TROY MILLS	WO	330	0.90	297
IA104	WINNEBAGO RIVER FERTILE MILLDAM	WO	130	0.90	117
IA119	WINNEBAGO RIVER MASON CITY MILLDAM	WO	100	0.90	90
	16 Dams Subtotal of Above		6,425		6,264
	MISSISSIPPI RIVER BASIN				
11278	MISSISSIPPI R L&D 15	WO	29,000	0.50	14,500
11249	MISSISSIPPI R MISSISSIPPI L&D 13	WO	15,200	0.50	7,600
11251	MISSISSIPPI R MISSISSIPPI L&D 18	WO	11,000	0.75	8,250
IA003	MISSISSIPPI R MISSISSIPPI L&D 19	W	103,831	0.50	51,916
8955	SKUNK R OAKLAND MILLS	WO	1,060	0.50	530
8105	WAPSIPINICON R CENTRAL CITY MILL	WO	640	0.50	320
10229	WAPSIPINICON R INDEPENDENCE MILL	WO	706	0.50	353
8098	WAPSIPINICON R LITTLETON DAM	WO	320	0.50	160
	8 Dams Subtotal of Above		161,757		83,629
	MISSOURI RIVER BASIN				
10747	CHARITON R RATHBUN DAM	WO	1,910	0.75	1,433
	Subtotal		1,910		1,433
	PLATTE RIVER BASIN				
8096	LITTLE SIOUX R LINN GROVE MILL	WO	310	0.50	155
	Subtotal		310		155
	WISCONSIN RIVER BASIN				
11245	MISSISSIPPI R MISSISSIPPI L&D 9	WO	10,000	0.50	5,000
9327	UPPER IOWA R DECORAH LOWER	WO	670	0.75	503
8097	UPPER IOWA R DECORAH UPPER	WO	450	0.50	225
	5 Dams Subtotal of Above		11,120		5,728
	Total Potential kW Capacity =		**394,988**		**266,886**

77 Dams and/or Sites Total with FERC Licenses
66 Dams Not Counting Mississippi River Lock & Dams
11 Mississippi River Lock & Dams

**** PESF is the "Project Environmental Suitability Factor", which is a rough indication of the environmental suitability for repowering the site. This factor was developed to gain some perspective on the potential for hydroelectric development in Iowa. The PESF was multiplied times the nameplate capacity to obtain a rough estimate of this potential for development. These factors were developed by Idaho National Engineering Laboratory of the Renewable Energy Products Department of the Lockheed Idaho Technologies Company. The table includes some minor corrections by Wind Utility Consulting.**

The table below provides some additional data about these sites.

Main Hydroelectric Sites in Iowa Registered with FERC				
	Number	Capacity in kW		
		Max.	Average	Min.
Interior Rivers (Excluding Mississippi)				
Dams with Operating Generators	9	3,000	980	250
Dams with No Generation (excl. Army Corp.)	50	3,000	700	100
Potential Dam Sites Suitable for Generation	3	28,000	13,700	2,000
Army Corp Dams (None Have Generation)	4	30,000	13,400	1,900
Total Number of Interior River Sites	66			
Mississippi River Dams with Locks				
Sites with No Generation	10	29,000	15,300	8,200
Sites with Generation	1		104,000	

Several of these existing dams could potentially be re-powered with new generators, although the cost per kilowatt (kW) of capacity would usually exceed $1,500 per kW. With such a high capital cost and relatively high operating cost per kilowatt-hour (kWh) due to their small size, the total delivered cost would likely be over 6 cents per kWh. Adding generators at the large Army Corps dams might provide power prices less than 6 cents per kWh in some cases. Today's wholesale power costs for firm base-load fossil-fired generation is in the 3 cents range. A minimum 3 cents premium for renewable hydro energy would be needed to justify re-powering at the best hydroelectric sites in Iowa. These calculations can be viewed in the wind hybrid cost calculator at the end of this report.

A 3¢per kWh premium would be needed to justify repowering Iowa's best hydroelectric sites.

The small dam on the Cedar River in Mitchell, Iowa was re-powered in 1998. The Mitchell County Conservation Board owns the dam but leases the powerhouse to a developer who re-powered the facility. The dam was extensively damaged in the flood of 1993. With the help of FEMA money and countless hours of volunteer labor, the Conservation Board repaired the dam and floodgates after that flood. The dam repair cost ran into the hundreds of thousands of dollars. After a lengthy project planning period and negotiations, a long-term Power Purchase Agreement (PPA) with Alliant Utilities was signed which allowed the facility to be re-powered by a private company. The PPA provided a purchase rate of 6¢ per kWh. Re-powering the facility required new trash racks, bulk head gates, turbines, transformers, and concrete

repairs. New Russian-made 285 kW and 380 kW Kaplan turbines with generators were installed. With flashboards providing an 18-foot head, the facility is projected to generate an average of about 2.9 million kWh annually, which is a 50% load factor. The mean flow of the river is about 500 CFS. The final cost of the re-powering was $813,000, or $1,225 per kW. This did not include the cost of the dam repair after the flood. The Conservation Board receives some royalty revenue from the hydroelectric generators to help defray the upkeep cost of the dam. This project was financially marginal, even with the help of a zero interest $250,000 loan from the Iowa Energy Center. Had it not been for the deep commitment of the Conservation Board, the community, and the project partners, the project would not have been done. This indicates the cost of re-powering was 6 cents per kWh and could have been even higher, especially if dam repair costs were included. Many of the small interior dams have lower heads than Mitchell, which tends to increase the cost per kW for re-powering. Therefore, re-powering small dams in Iowa is not competitive with other power supply options. Daily cycling of a hydro generator would provide more generation to be shifted to daily peak hours. However, it is very doubtful that the FERC would allow this type of operation for Iowa's small dams.

None of the large Army Corps of Engineering dams on the interior rivers have hydroelectric facilities. The dams at Redrock, Saylorville, and Coralville would be fairly good candidates for re-powering because of their higher head, higher flows, and steady controlled output. The water storage behind the dam allows more leveling of the flows resulting in more electric generation. Only the Keokuk dam on the Mississippi River has electric generation. It totals about 105 MW. Generators could be added to many of the other lock and dam facilities, but the resulting cost of power would likely cost at least five cents per kilowatt-hour, a price that is not currently competitive in the wholesale market. As our electric generation industry becomes more dependent on natural gas, higher gas prices might tip the balance to enable these larger dams to be competitive. Also, if carbon emissions are controlled, then these facilities will likely be built.

Higher gas prices or increased emissions credits may make hydro re-powering competitive.

Comparison of Wind and Water Resource Patterns

Iowa-based hydroelectricity is likely the second most economically competitive renewable resource. However, there will likely be only a couple of locations in Iowa where this combination would possibly be economically feasible. A comparison was made of the seasonal pattern of river flow and the pattern of wind generation. Five years of hourly wind speed data was taken from the site of the Iowa

Economically, hydroelectricity is second only to wind energy.

Distributed Wind Generation Project (IDWGP) site southeast of Algona, Iowa. This wind speed data then was converted to electric power by applying a power curve from an Enron Z750 wind turbine with a 50-meter rotor. This simulated hourly power output for each month was then graphed. Next, river flow data was taken from the nearest US Geological Survey (USGS) measuring station that recorded daily flows. This station was on the West Fork of the Des Moines River in Humboldt, Iowa, which is about 22 miles south of the IDWGP wind farm. Although the river flow and wind speed data are not taken at the same location, the data from them can still be compared to draw conclusions about how complementary these two renewable resources are. The river flow data is taken daily and is measured in cubic feet per second, or CFS. This river flow is fairly proportional to the output of a hydroelectric generator at the site. An increase in river flow results in higher energy output, up to the maximum capacity of the generator. Due to economic considerations, the generators are sized to produce maximum power when the river flow is some value over the long-term average. During very high river flows, the generator output starts to decline due to a loss of head and then goes to zero during floods when the head declines even further. *Figure5* is a picture of the Waverly hydroelectric facility at the peak of the very severe 1993 flood. The generators were shut down anyway because of water coming into the plant. During drought periods, the generators may be taken off line to maintain the required minimum flow over the dam for aerating the water for the downstream fish.

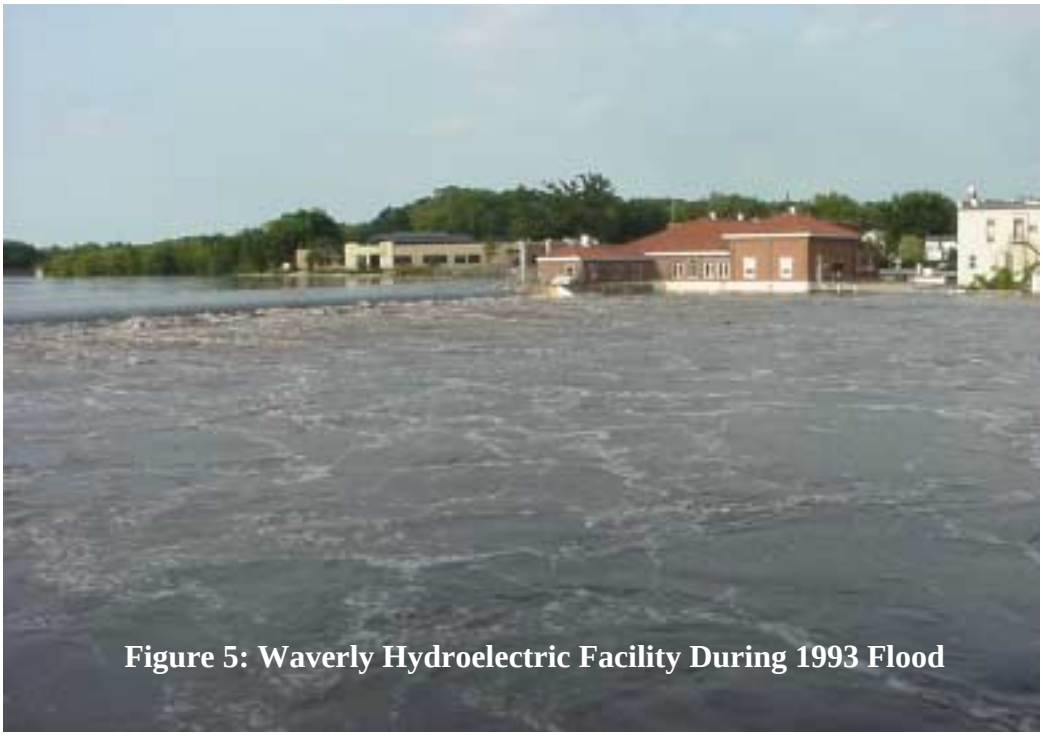


Figure 5: Waverly Hydroelectric Facility During 1993 Flood

After analyzing and graphing 5 years of wind speed data, the river flow data was then overlaid on the graph with the wind generation. *Figures 6-17* depict this comparison for 12 months.

Figure 6:

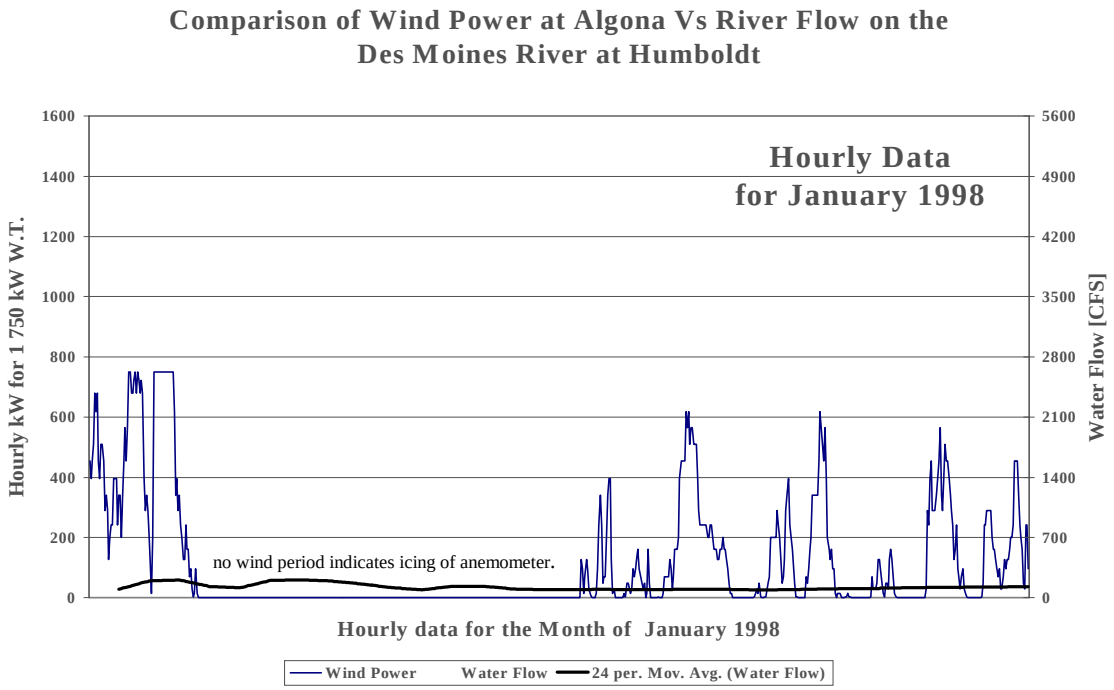


Figure 7

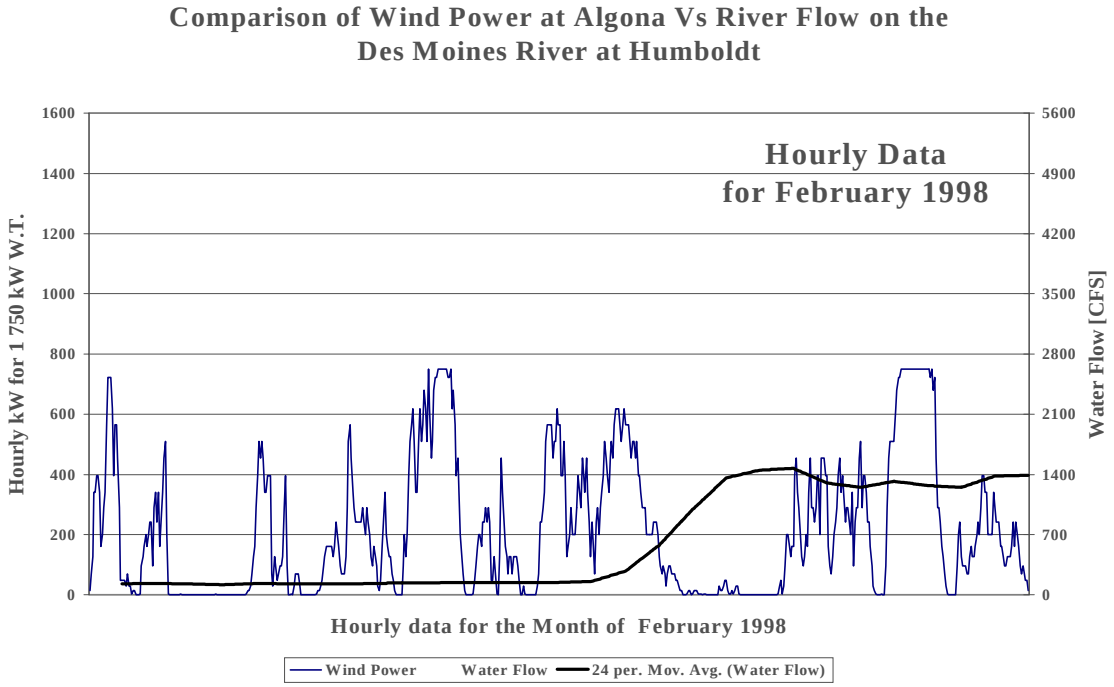


Figure 8

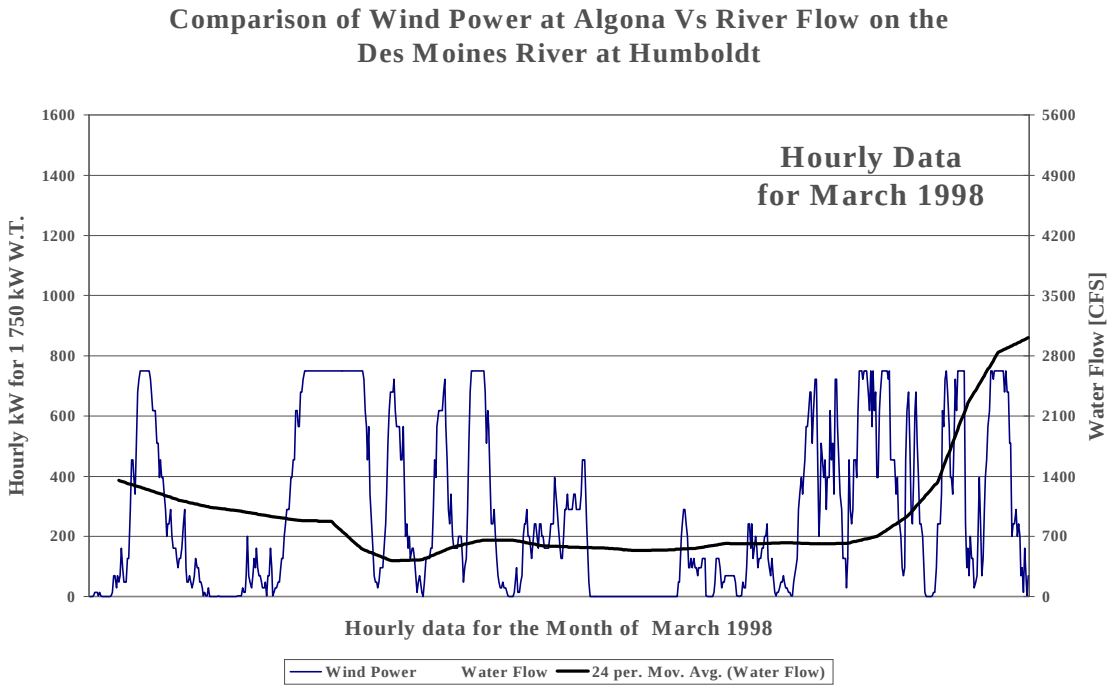


Figure 9

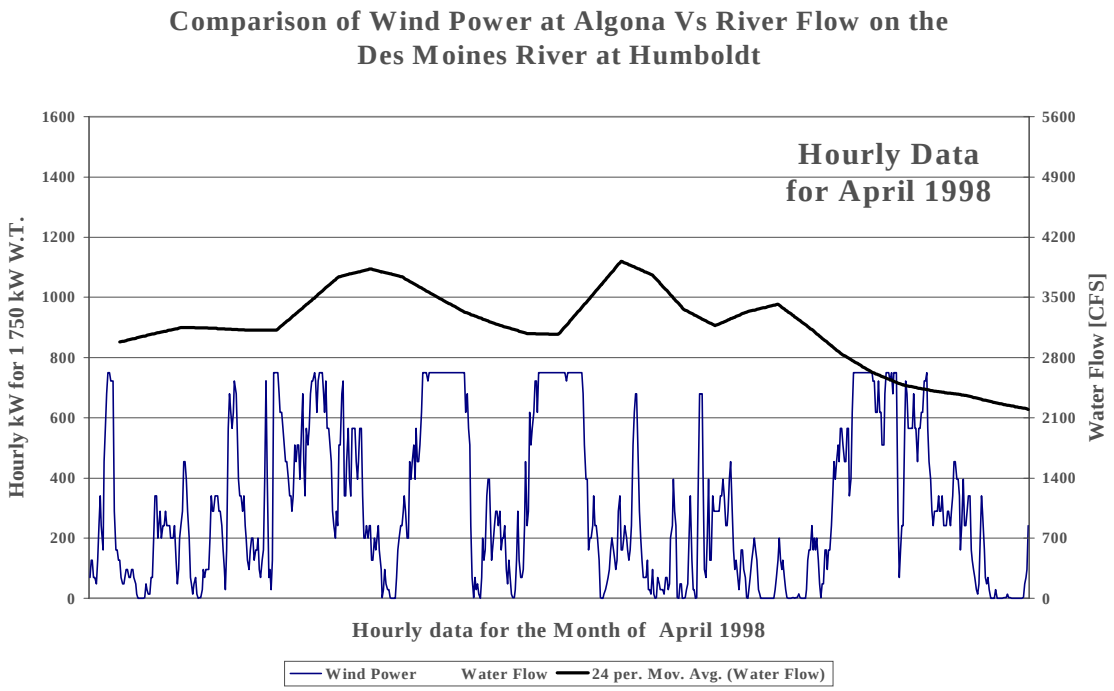


Figure 10

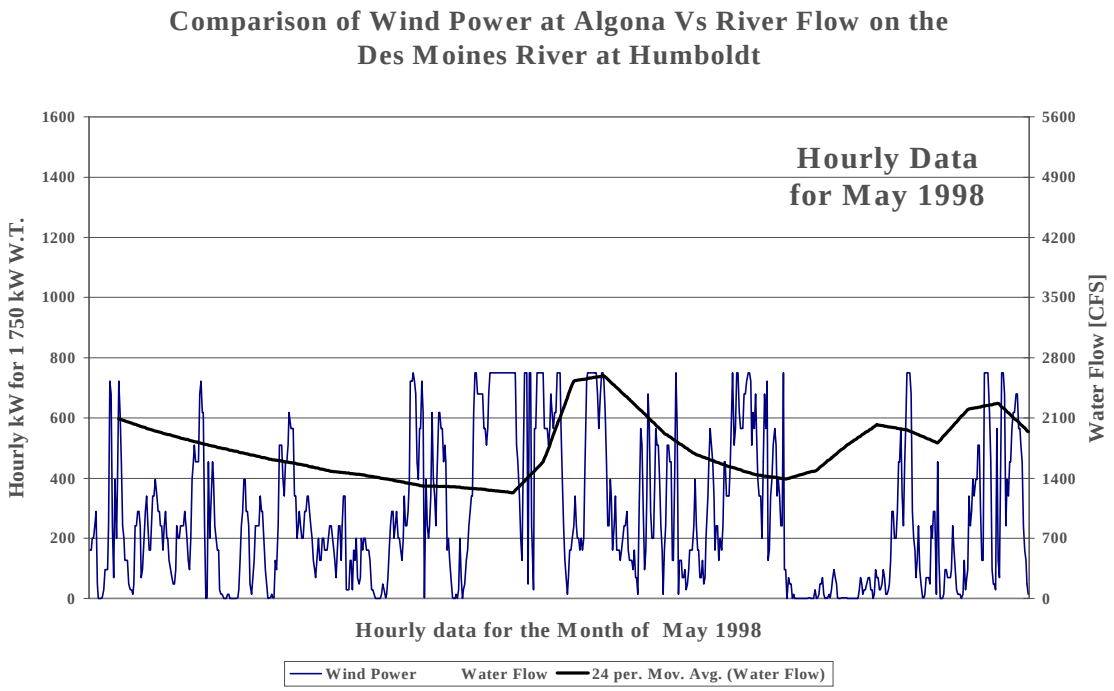


Figure 11

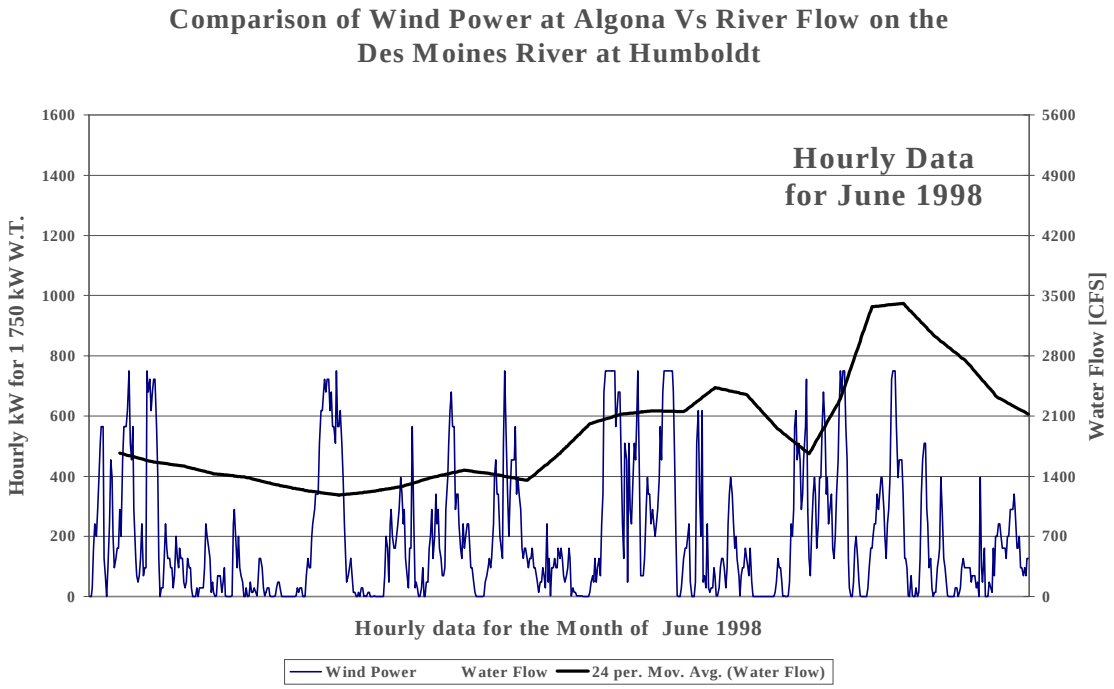


Figure 12

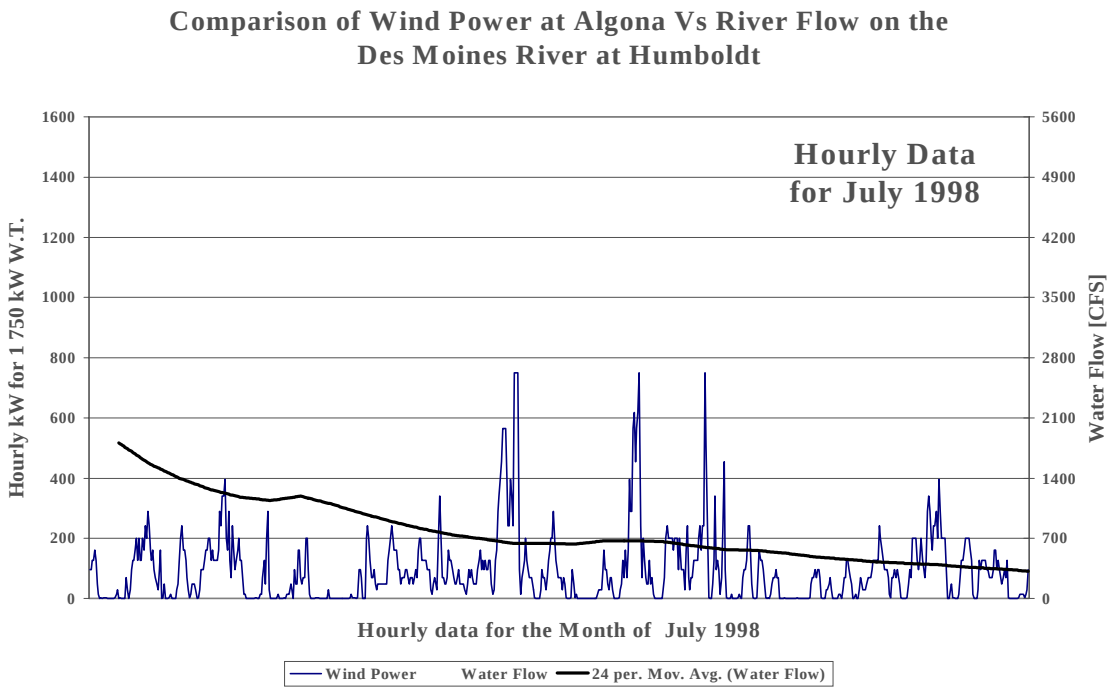


Figure 13

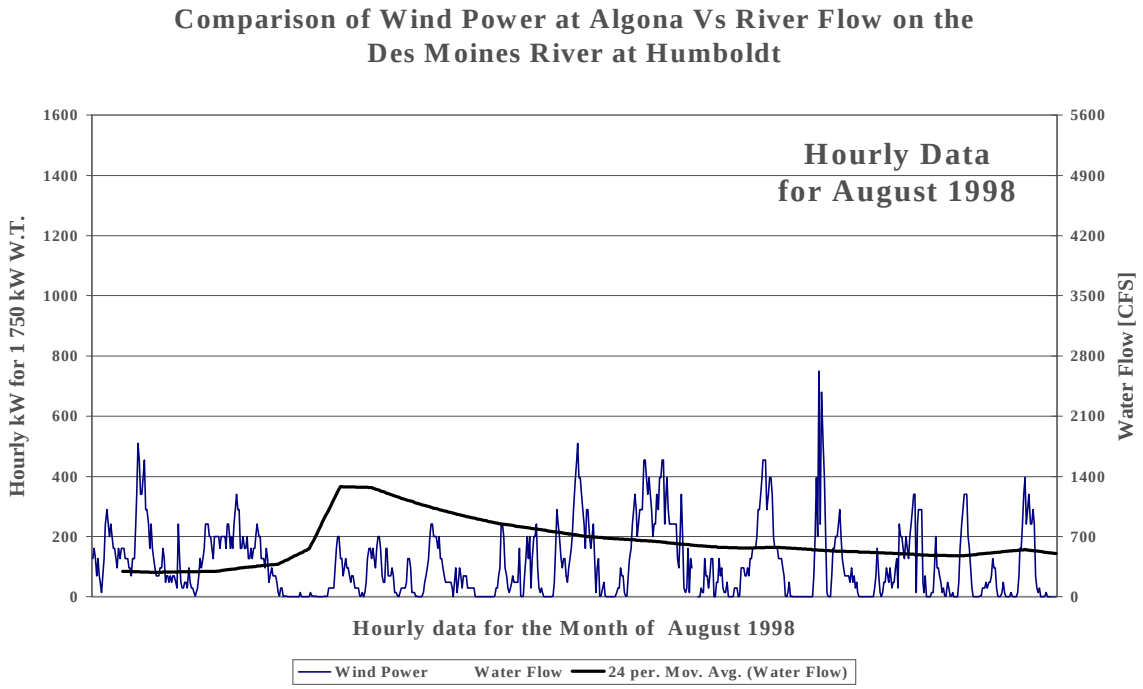


Figure 14

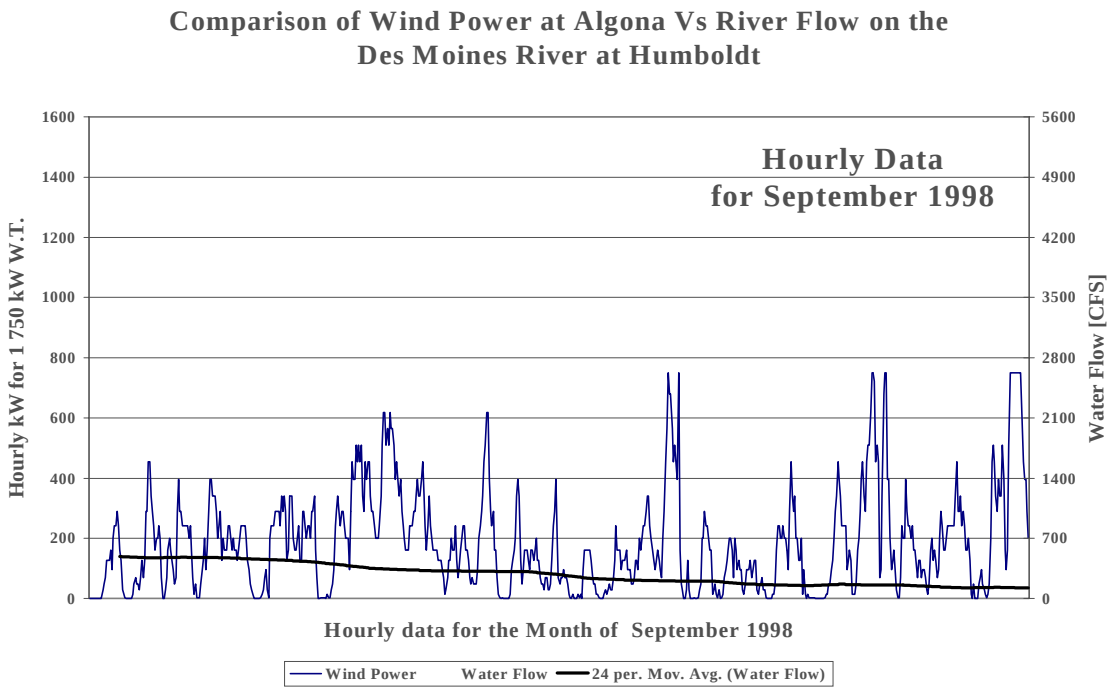

Comparison of Wind Power at Algona Vs River Flow on the
Des Moines River at Humboldt
Hourly Data
for September 1998
Hourly kW for 1 750 kW W.T.
Water Flow [CFS]
1600
1400
1200
1000
800
600
400
200
0
5600
4900
4200
3500
2800
2100
1400
700
0
Hourly data for the Month of September 1998
Wind Power
Water Flow
24 per. Mov. Avg. (Water Flow)

Figure 15

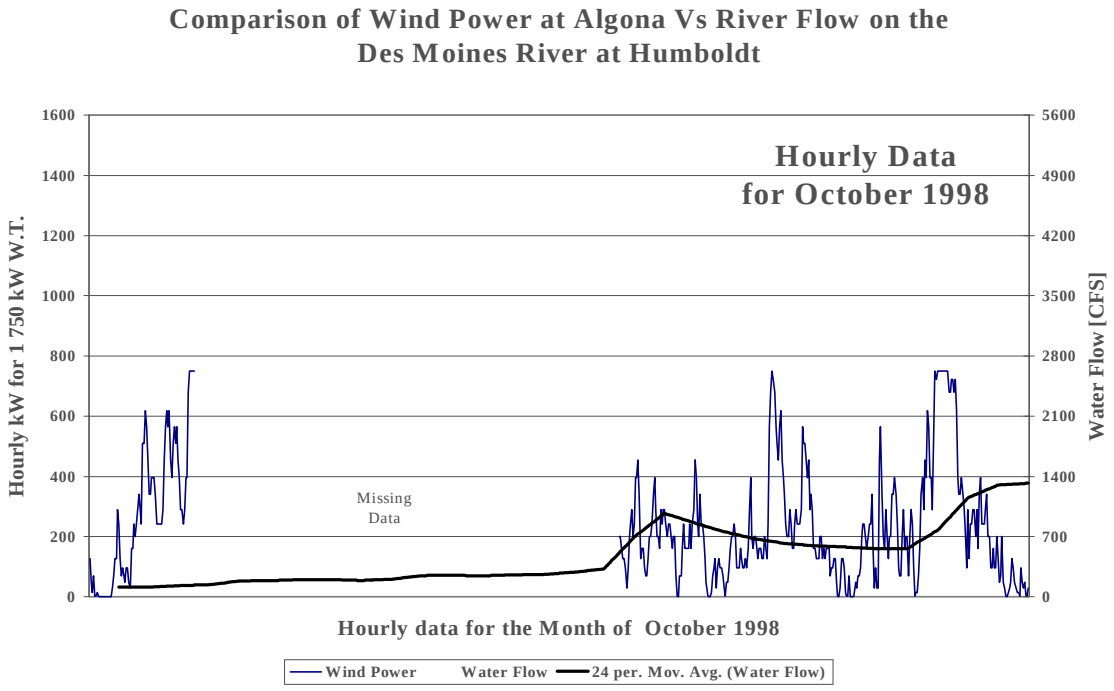

Comparison of Wind Power at Algona Vs River Flow on the
Des Moines River at Humboldt
Hourly Data
for October 1998
Missing
Data
Hourly kW for 1 750 kW W.T.
Water Flow [CFS]
1600
1400
1200
1000
800
600
400
200
0
5600
4900
4200
3500
2800
2100
1400
700
0
Hourly data for the Month of October 1998
Wind Power
Water Flow
24 per. Mov. Avg. (Water Flow)

Figure 16

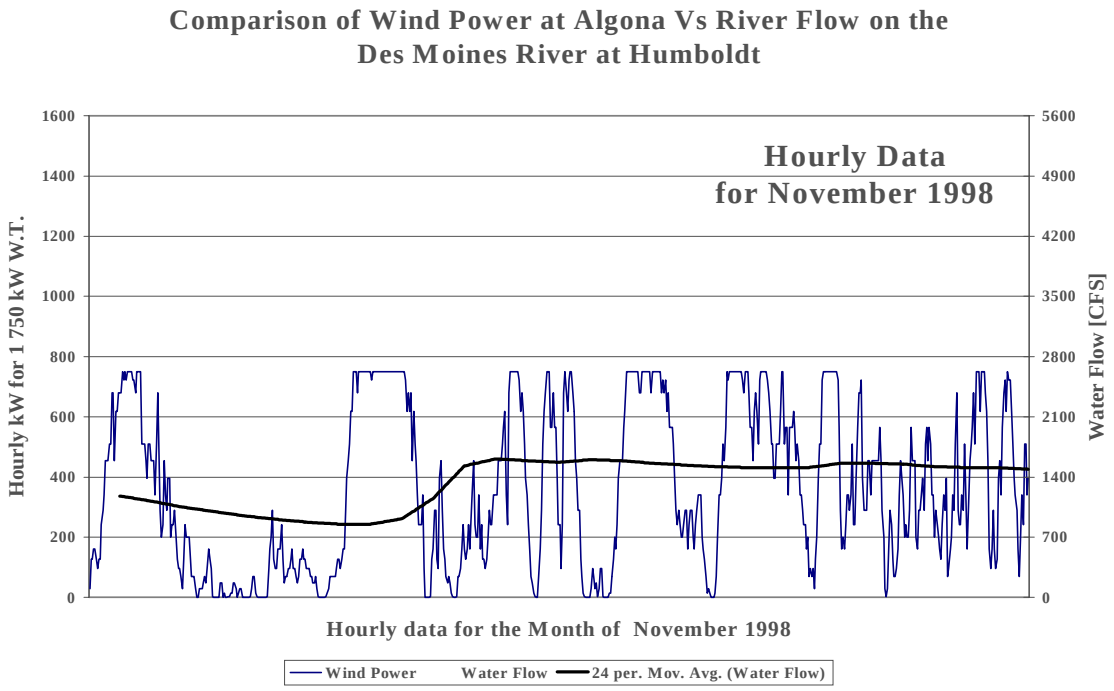
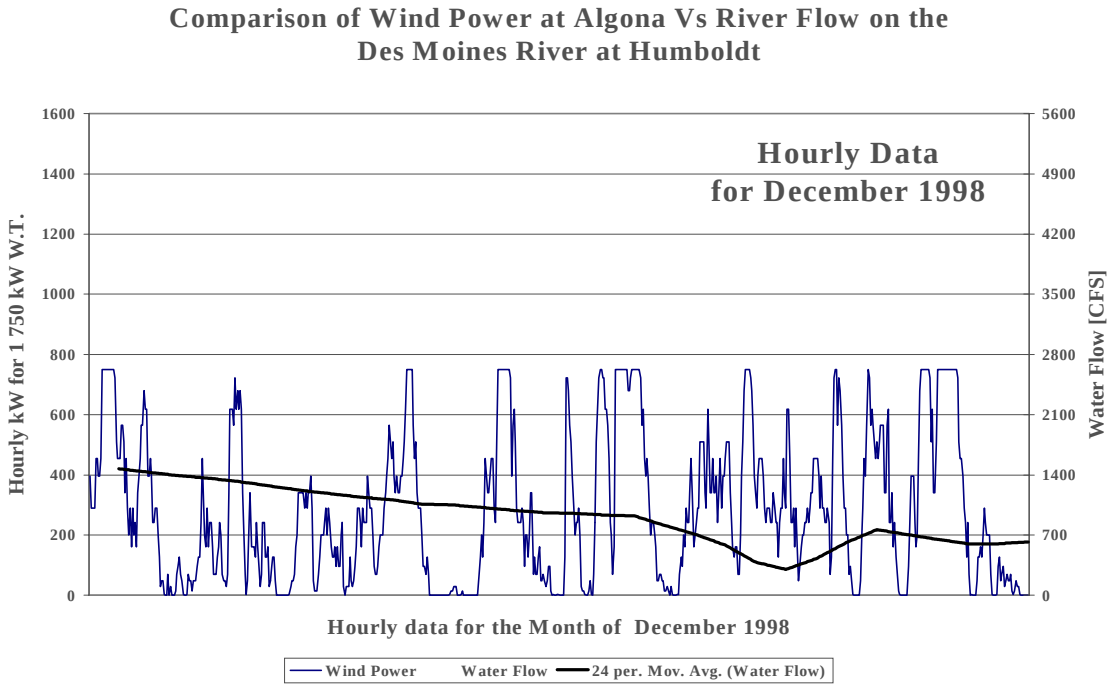


Figure 17



As the graphs illustrate, the wind turbine's output varies a lot from hour to hour, going from zero to full load many times during the month. In contrast, the output of a hydroelectric plant on the river doesn't vary much from hour to hour or day to day. Occasionally, heavy thunderstorms in the upstream river basin will increase the river flow over a period of days and raise the hydro generation output. Nevertheless, the hydro generation output is very steady compared to the wind generation output. This constancy from hour to hour certainly complements the high variability of the wind generation output. The hydroelectric generation was very low in the late summer in 1998 due to dry weather in the area.

The constancy of hydro generation compliments the variability of wind generation output.

Figures 19-23 compare the average daily wind generation output with the river flow on an annual basis for the years 1995 through 1999. This comparison provides some idea about how the wind and hydro generation compare on a seasonal basis. For the two resources to be complementary, one resource should be higher than average when the other resource is lower than average. Additionally, higher output during hot weather when electricity usage is high is also desirable.

Figure 18

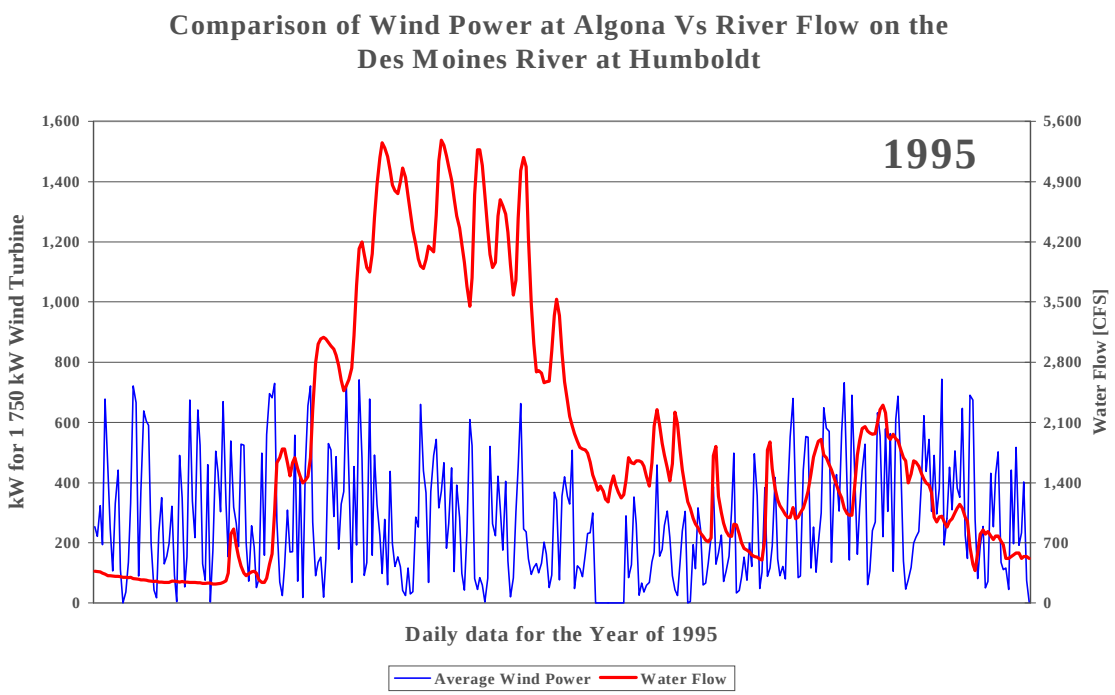


Figure 19

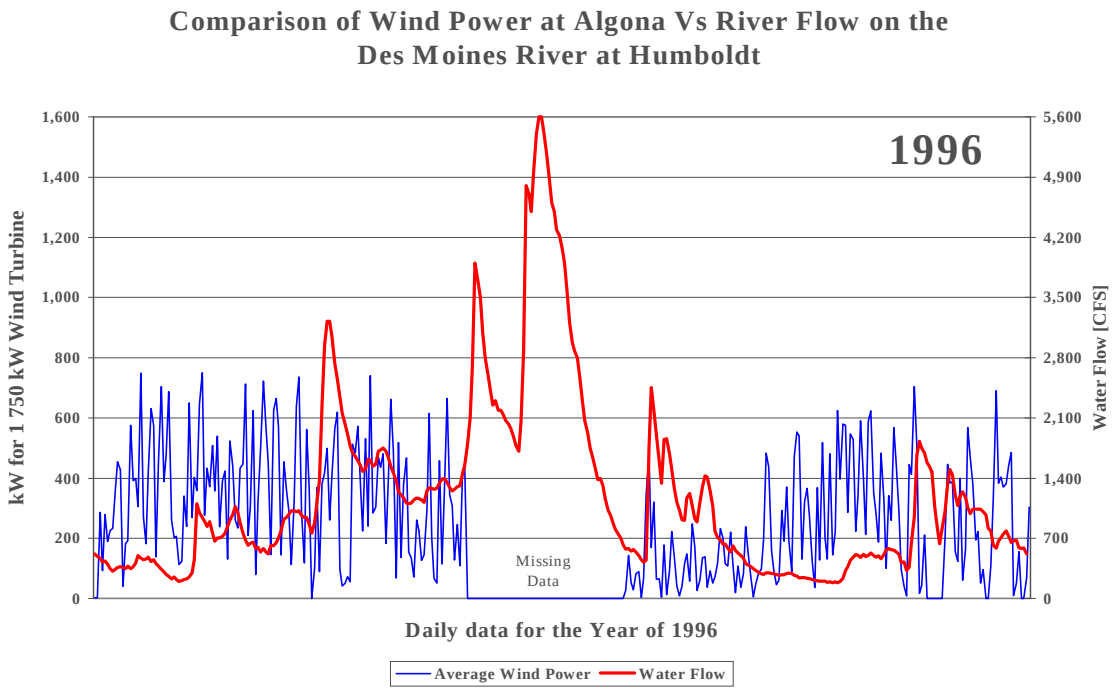


Figure 20

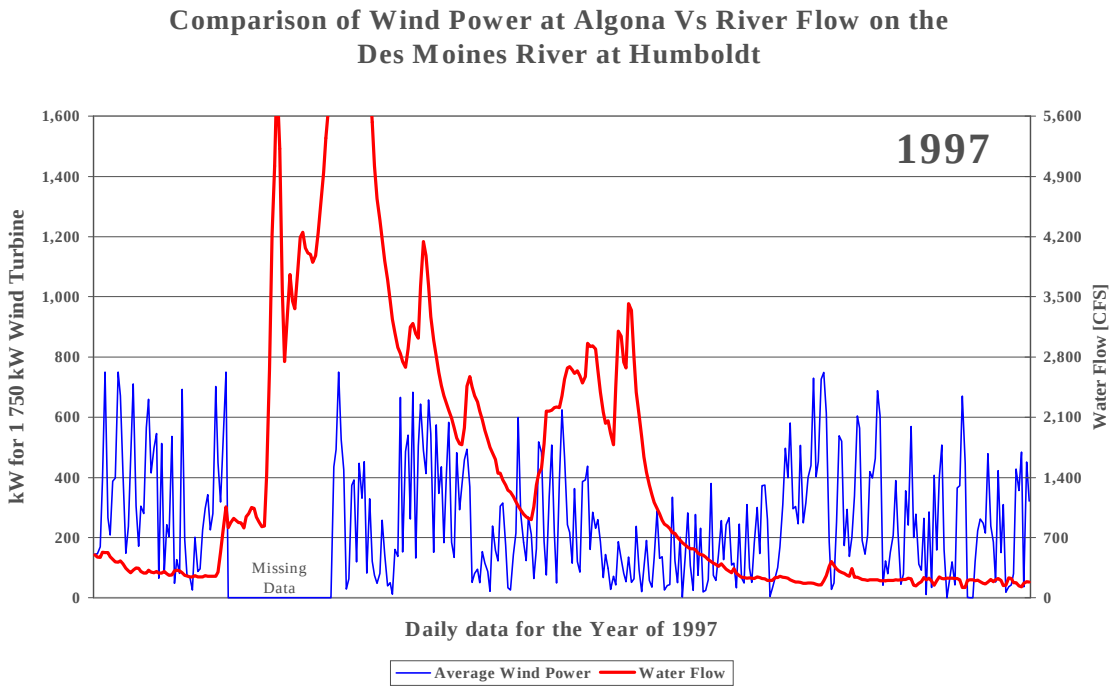


Figure 21

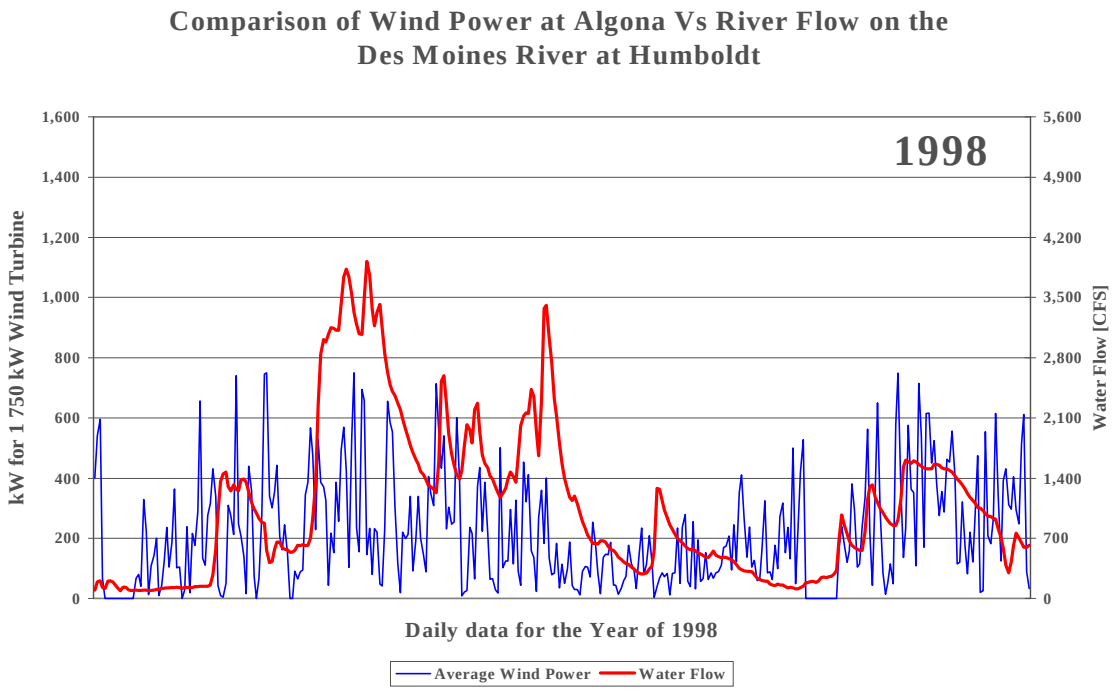


Figure 22

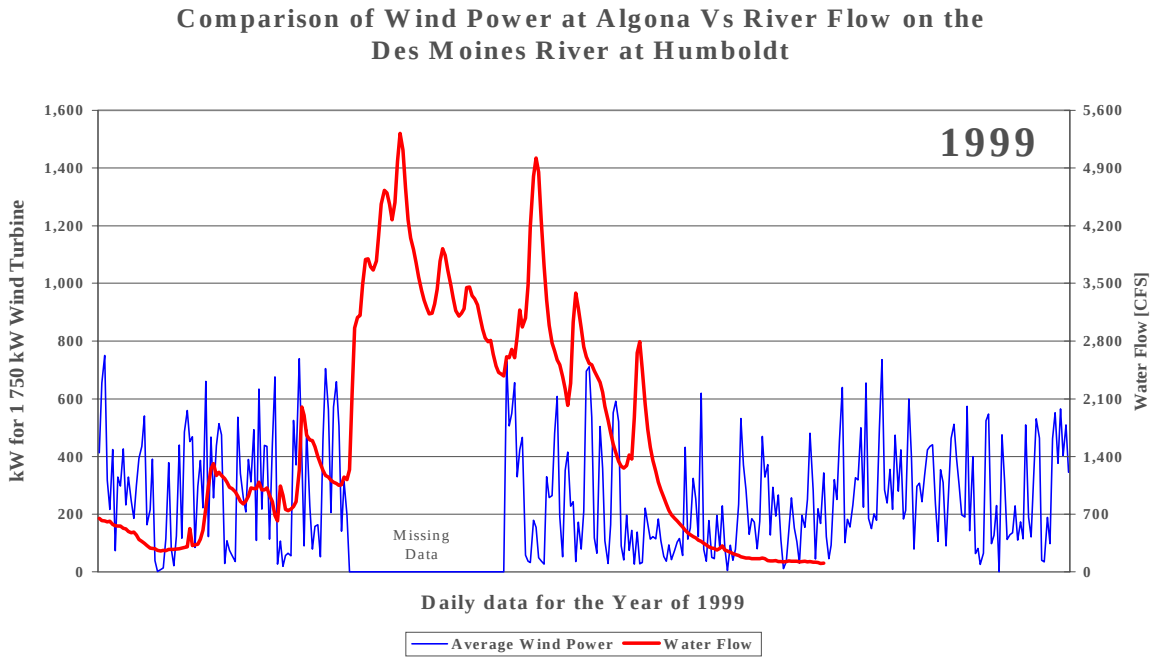
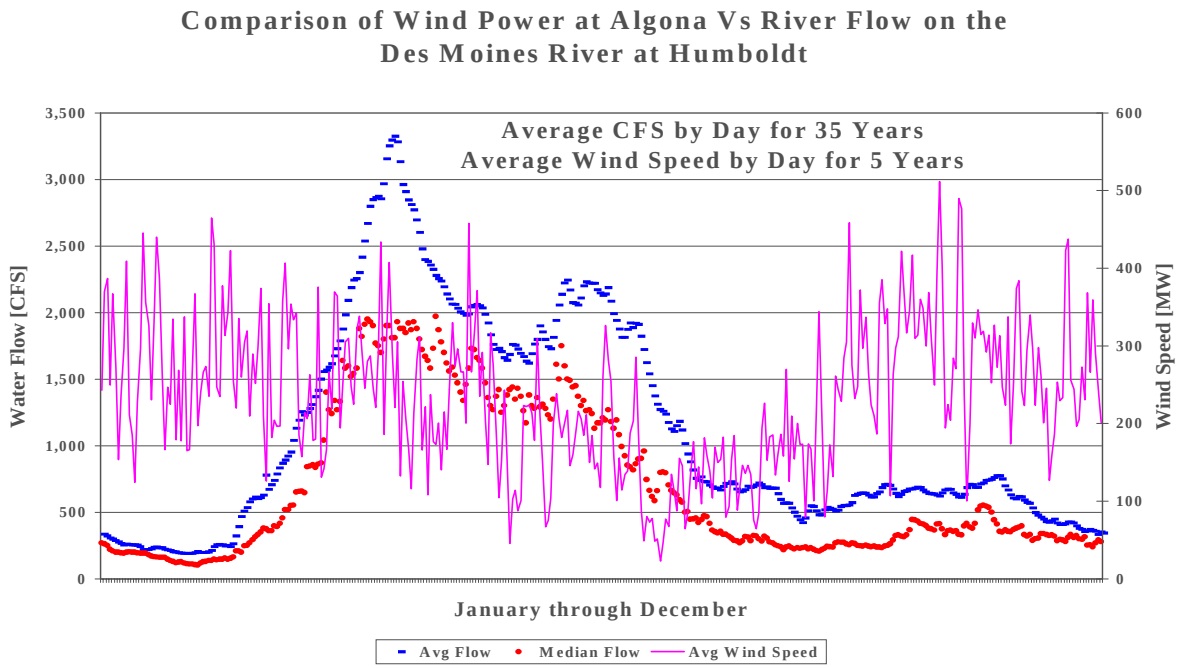


Figure 23 shows the monthly averages for the five years of data. Even though there is a lot of variation in the river flow data from month to month, this

graph indicates that on a longer-term basis, the river flows are low during the winter and later summer months. Wind is at its minimum in the late summer. So these two resources tend to complement each other in the winter, but not in the late summer. Both resources are high in the spring. Therefore, on a seasonal basis, the two resources are complementary to some extent, but fail to be a reliable source of power during the summer.

Figure 23



River flow data was also obtained and analyzed from three other sites in Iowa to obtain daily and monthly patterns of flow. This data was used for the analysis in this report. The other sites include:

1. Little Sioux River at Linn Grove - This is near Enron's Buena Vista wind farm in northwest Iowa.
2. Iowa River at Iowa City - This data is below the Coralville dam, so it shows the impact of the large amount of storage on the river flow.
3. Des Moines River at Tracy - Like the Iowa City data, this data reflects the controlled releases from the Army Corps' Red Rock reservoir.

Potential Applications

If wind generation and hydroelectric power can both be sold into the grid separately and thus integrated with the other dispatchable generation, then there is probably no economic incentive to integrate the two together in a hybrid scheme which is then connected to the grid.

However, there may be a few instances where integrating the two might possibly make sense. Any such application would likely involve the following conditions:

1. A single wind turbine and a small hydroelectric facility that were used to serve a specific customer's facilities, rather than selling power to a utility or marketer. The power would be mixed to serve the load behind the customer's meter. The value of this mixed power would be equal to the avoided retail cost of electricity to the customer. In order to make this economically feasible, the customer would have to put some additional value on using renewable resources.

2. An electric customer that for some reason does not want to be connected to the grid. The hydro generation would provide a much steadier source of power to the customer, which would reduce the need for engine-driven backup energy. This scheme would require an intelligent control system and a resistive dump load to manage the variable output of the wind turbine. The net cost of power from such a scheme would most likely be much more expensive than buying power from the local utility.

Advantages and Disadvantages of a Wind-Hydro Hybrid

The potential advantages of combining these two renewable resources in a project include:

1. The hydroelectric generation is much more stable from minute-to-minute, hour-to-hour, and day-to-day.

2. The combination would provide a high percentage of renewable power to the owner's electric load.

The disadvantages of combining these two resources include:

1. Since hydro generators are on rivers that usually are at lower levels, the location may be some distance from higher elevations more suitable for installing a wind turbine. A distribution line would be needed to connect the two facilities to the customer's facilities.

2. The combined output of the hydro and wind generators needs to be about the same or less than the customer needs, because any excess power sold back to the utility will not have much value due to the relatively low avoided cost buy-back rates.

3. The grid will still be needed to provide a steady source of power, unless the facility uses an engine-driven generator so that it can operate completely isolated from the grid.

4. Since the hydro capacity is fixed by the height of the existing dam and the river flow, it cannot be expanded to meet any increased needs of the customer.

Case Study

The recent re-powering of the Mitchell dam provides some cost data and a basis for a case study for a wind-hybrid combination. The sketch in Figure 24 illustrates this case study.

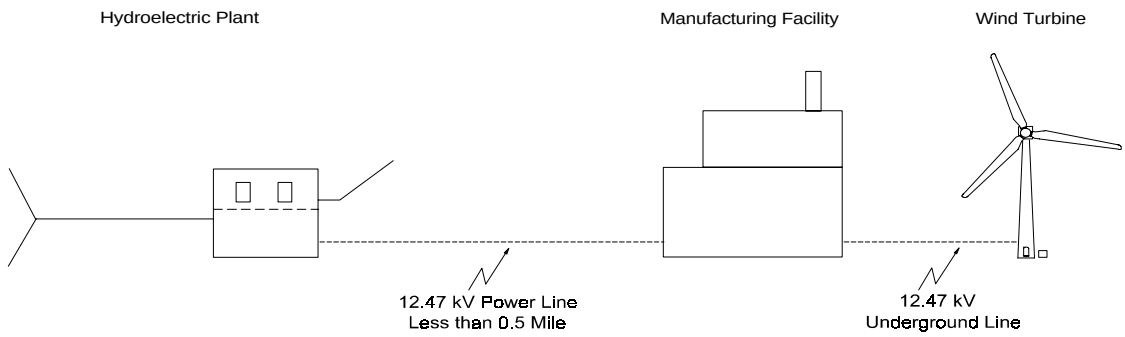


Figure 24

In this study it is assumed that a manufacturing facility is located within a half mile of the Mitchell dam. Furthermore, the facility has enough property with good wind exposure to install a Vestas V44/660 kW wind turbine beside its facility. If this manufacturer placed a high premium value of using renewable energy in its manufacturing process, then it could re-power the dam and install the wind turbine to help supply the energy needs of its facility. The Mitchell dam will provide an average of 2.9 million kWh and the wind turbine would average 1.7 million kWh. Together they net 4.6 million kWh. For this combination to be utilized well, the manufacturing facility would need to use a third to half more energy than this, assuming the facility does not receive net billing from the utility. A facility this size might be the largest electric customer in this rural county. The facility would be on a two-part rate with both demand and energy charges and would likely be paying a relatively low rate for electricity due to its size. Assuming the customer retained electric service from the utility, the wind-hydro generation would reduce the facilities energy charges each month and would normally reduce the customer's demand charges to some extent, depending upon several factors. In this case study, it is assumed that the customer pays an average of 5 cents per kWh under a two-part rate, with the energy component at 3 cents per kWh and the demand component at $9.00 per kW-month. The table below illustrates the power used, generated and purchased with and without the wind-hydro combination, based on the several assumptions and estimates.

Power Used, Generated and Purchased with and Without the Wind-hydro Generation		
Energy	Prior to Wind-Hydro	With Wind-Hydro
Annual kWh Needed	7.0 million kWh	7.0 million kWh
Annual kWh Purchased	7.0 million kWh	3.4 million kWh
Annual kWh Generated	0.0 million kWh	4.6 million kWh
Annual kWh Sold to Utility	0.0 million kWh	1.0 million kWh
Cost of Purchased Energy	$210,000	$102,000
Demand		
Average Monthly Demand	1,300 kW	1,300 kW
Average Demand Supplied by Utility	1,300 kW	775 kW
Average Demand Supplied Wind-Hydro	0 kW	525 kW
Cost of Purchased Demand	$140,400	$83,700
Total Cost of Purchased Power	$350,400	$185,700
Revenue from Power Sales to Utility	$0	$20,000
Production Income Tax Credit	$0	$17,000
Net Savings in Power Bill and Taxes		$202,000
Note: There may be corporate tax benefits from the 5 year accelerated depreciation of wind turbine.		

Based on several assumptions, the manufacturing facility would save about $200,000 per year in power costs and income taxes due to the federal Production Tax Credit (PTC). The actual cost of the Mitchell hydro facility was $813,000 and the cost of the wind turbine would be about $800,000. Additional electrical lines and interconnections would bring the total capital cost to about $1,650,000. The estimated operating cost of the hydro and wind generators is $75,000. This would include labor, parts, equipment reserve, insurance, property taxes, and lease of the dam site. If the $1.65 million investment were financed with a 20-year loan at 9% interest, the annual loan payment would be $181,000, which is more than the operating savings. The result would be a negative $56,000 cash flow during the loan payback period.

Mitchell Hydro Project Cost	
Cost of Hydro facility	$813,000
Cost of Wind turbine	$800,000
Cost of interconnection equipment	$37,000
Total loan amount	$1,650,000
Annual Profit/Loss	
Net Savings on power purchases	$200,000
Operating costs	($75,000)
Loan Payments (20 years at 9%)	($181,000)
Net Income/Loss per Year	($56,000)

If the income tax impacts are considered, then the quick five-year accelerated depreciation of the wind turbine provides significant after-tax savings for five years, assuming the facility's owners have enough income tax liability to take advantage of this depreciation. The operation cost savings would of course be larger if there was some premium paid for carbon emission reductions or if the interest rates were lower.

In summary, the wind-hydro project would result in a pre-tax loss, but an after-tax savings for most corporate owners. However, the calculations were based on a 20-year loan payback. Most industrial facilities require their investments to pay off in a matter of a few years at most, not 20. If the owners placed a high value of using renewable resources, then this slower payback on electric generation infrastructure may be an acceptable premium.

The better hydro sites in Iowa will likely be developed when the market price for new renewable resources increases to the 5-6¢ range.

Although Iowa doesn't have much hydroelectric resource potential, a few of the better sites will likely be developed if the market price for this type of renewable resource power increases to the 5-6 cents range. Because of the steadier output that can be controlled to some extent, hydroelectric power will always have a higher value to the electric system than wind generated power.

Observations and Conclusions about Wind-Hybrid

Re-powering a hydroelectric dam facility has a high cost per kW of capacity. Due to the variable nature of the river flow and FERC operating restrictions, the hydroelectric generator will have a limited ability to regulate the power output. However, the power output is relatively constant from hour-to-hour and day-to-day when compared to a wind turbine's output. This constancy better matches the power needs patterns of a typical electric customer. Combining a wind turbine and hydroelectric facility creates very modest additional benefits from this synergism when compared to using either of these renewable resources separately. These modest additional benefits come from the slightly different seasonal generation patterns of the two. For example, wind generation is generally higher in the winter when the hydro generation is often very low. This modest diversity of generation can potentially reduce the demand charges for the remaining power purchased from the utility.

There aren't many dams in the northwest quarter of the state where the wind resources are the best. This creates limited opportunities for these two resources to be combined in a project. It would be prohibitively expensive to build a new dam with electric generation on a small river. Therefore, it is unlikely that combining a wind turbine and a small hydroelectric unity would be economically attractive for most electric customers.

Utility-Scale Wind-Diesel Hybrid Systems

Introduction and Background

For many years, wind generators have been connected to small isolated electric systems around the world that are powered by diesel generators. There are numerous technical reports about how various type of wind-diesel systems can be operated to provide a steady continuous source of power. In nearly all but the most remote rural locations in the US mainland, the electric grid is available to supply power where needed. Therefore, a diesel engine generator would usually not be justified unless it was for backup emergency power. There are a surprising number of diesel backup generators installed for that very purpose in the US and the number continues to increase as the reliability of electric service becomes more essential to various businesses, government services and institutions. In some cases, utility incentives help pay for some part of these backup generators when they can be brought on line to help reduce the utility's peak load.

Large 1-4 MW diesel generators now cost about $350 to $400 per kW installed. Many are being installed now primarily by smaller consumer-owned utilities to meet local peak load demands. Most are operated on #2 diesel fuel oil and run for 50 to 200 hours per year, depending upon peak load. With #2 oil costing $0.75 per gallon, the operating cost is 5.5¢ per kWh. The fixed ownership costs are about $50 to $65 per kW-year for the 1 to 4 MW sized units, depending upon the capital amortization period.

If grid power is available, the high operating costs of engine-driven generators relegates their use for peak shaving and emergency conditions. Occasionally gas-fired engine driven generators are used to convert landfill or biogas to electricity on a base-load basis.

Picture courtesy of the American Soybean Association

If a diesel generator is run on 100% soy oil, then it is powered by a renewable fuel.

Biodiesel fuel is a blend of processed soybean oil and diesel fuel. Blends are typically from 20% soy oil (B20) to 100% soy oil (B100). If a diesel generator were run on 100% soy oil, then it would be essentially 100% powered by a renewable fuel, other than the small faction of crankcase lube oil that is consumed by combustion. A 100% soy oil fuel costs about $2.40 per gallon for tanker loads. Since soy oil is essentially a byproduct of soybean processing, its price is not as sensitive to the cost of soybeans. Cost is more sensitive to supply and demand for soy oil. Based on longer-term estimate of $2.50 per gallon, the operating cost of the diesel generator on 100% soy oil would be about 17¢ per kWh, instead of 5.5¢ with diesel fuel.

Potential Applications of Wind-Diesel Hybrid Systems

Since the grid power is available everywhere in Iowa, an engine driven generator would only be used during peak load periods or emergencies. One potential application with a wind turbine would be to use an engine-driven generator to manage a facility's peak demand charges from the utility. The wind turbine would provide power to reduce the facility's energy purchases. If the wind turbine were not generating during a peak demand period, then the engine-driven generator would be automatically started. This application would only be cost effective when the utility's tariff had a specified time period, such as a 4-hour window from 3 PM to 7 PM, where the demand was measured. A computer could then determine if the engine-driven generator would be needed during that time period. The engine-driven generator run time would be limited to a few hours per day if the wind turbine was not generating and the facility was at a high load. Many utility tariffs do not have a specified time window where the demand is measured. Under these tariffs, the facility could set their peak demand at any hour of the day.

A diesel generator could be used during peak load measurement periods while the wind turbine reduces energy purchases.

If the facility does not pay a demand charge, but only an energy charge, then there would be no reason to manage the demand or add an engine-driven generator. In general, if the utility's tariff has no demand charge and only an energy charge, then there is more incentive to install a wind turbine. If the utility has a high demand charge and low energy charge, then adding a wind turbine is probably not economical. Wind turbines are good energy producers, but poor demand reducers.

The Lac Qui Parle School in Minnesota has a wind turbine and engine-driven generator. A 225 kW wind turbine was added along with an 275-kW engine-driven generator to manage the school's peak demand, which was measured

during a specified period of time. When the net load of the school less the wind turbine's output was above a target demand level during the demand measurement period, the engine-driven generator was run to reduce the demand below the target level. Due to the lack of significant financial incentives, this demand reduction scheme is not currently being used. *Figure 25* shows the school and wind turbine. *Figure 26* shows a 60 kW diesel generator set.

Figure 25: Lac Qui Parle School wind turbine

Biodiesel fuel could be burned in these types of installations, but the school or other facility would still consume a lot of energy from the utility that wouldn't be generated by renewable energy. Since the biodiesel fuel costs significantly more than regular diesel fuel, the system should be designed to minimize the engine-driven generator run time.

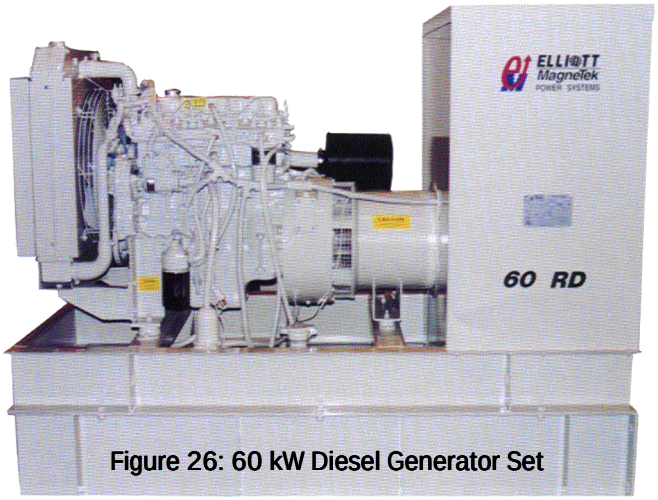


Figure 26: 60 kW Diesel Generator Set

Advantages and Disadvantages of Wind-Diesel Hybrid Systems

The advantages of adding an engine-driven generator to supplement a wind turbine is the ability to reduce a facility's demand charge from the utility. If the utility's tariff is designed to encourage this management of demand, then a wind-diesel system might be economical. The wind turbine would be responsible for reducing the energy purchased, while the diesel would reduce the billing demand charge.

The main disadvantage of wind diesel hybrids is the high operating cost of the diesel generator.

The main disadvantage of this type of hybrid system is the high operating cost of the engine-driven generator. Any significant amount of run time will likely make the additional installation of the engine-driven generator uneconomical.

Case Study of Wind-Diesel Hybrid Systems

The following case study shows a school system purchases power under a two-part rate with a high $15.00 per kW demand charge and a 3.0 cents per kWh energy charge. The average cost of energy was 7.6 cents per kWh. The utility only measures the school's demand from 4PM to 8PM Monday through Friday. The school normally has a 250 kW monthly peak demand, except during the summer, and it uses about 1,000 MWh per year. Their electricity cost $75,000 per year. The school has decided to install a new 250 kW wind turbine costing $375,000. It is projected to generate 613,000 kWh at this location. Based on a 15-year loan at 6 percent interest, the loan payments and operating expenses of the wind turbine total $47,000 per year.

	No Wind Turbine	With 250 Wind Turbine	Wind Turbine + 75-kW Diesel Gen.
Energy Charge	$29,565	$15,768	$13,963
Demand Charge	$45,000	$31,770	$18,000
Wind Turbine Loan Payments	-	$38,611	$38,611
Wind Turbine Operating Costs	-	$8,813	$8,813
Buyback Revenue	-	($3,066)	($3,066)
REPI Revenue	-	($2,606)	($2,606)
Diesel Loan Payments	-	-	$4,726
Diesel Operating Costs	-	-	$4,750
TOTALS			
During Loan Repayment Period	$74,565	$89,289	$83,191
After Loan is Repaid	-	$50,678	$39,854

As the table above indicates, adding an engine-driven generator backup in this particular instance does improve the economics. However, installing a new 250 kW wind turbine increased the total cost of operations. In order for a wind turbine and engine-driven generator to both be economical, high demand charges as well as high-energy charges would be needed. A utility incentive program for customers to install backup generators that can be used to reduce the utility's peak demand would also improve the economics. If a utility has a high demand charge and a low energy charge, then it will probably not be economical to add a wind turbine, since a wind turbine primarily reduces energy purchases.

Observations and Conclusions on Wind-Diesel Hybrid Systems

Diesel generators vary widely in cost with different sizes. A typical residential-scale backup generator might be a 3 kW size unit costing about $1,500. These units are not meant for continuous use and are more available to run on gasoline. A commercial-scale unit installed and ready for continuous operation would cost closer to $30,000 for a 25 kW unit. On the utility-scale, a 2,000 kW unit would cost about $700,000, which yields a low per kW price of $350.

There will likely be few instances where the addition of an engine-driven generator will improve the overall economics of a wind turbine installation for an electric customer in Iowa. Wind turbines are most economical where the energy charges are high. Since wind turbines produce intermittent power, they are usually not effective in reducing demand charges. The installation of engine-driven generators is usually only economical where demand charges are very high and there is a specific short period of time when the customer's demand is measured. Running an engine-driven generator during these short periods of time can be justified to reduce demand charges, even if the per kWh operation costs of the engine-driven generator are high.

Wind turbines are most economic where energy charges are high but are not effective at reducing demand charges.

Of course, if the engine-driven generator is needed for backup purposes anyway, then there may be instances where it would be economical to run it to reduce demand charges, even if the demand charge rates were not high.

The other advantage of an engine-driven generator is if backup power is essential.

In general, adding an engine-driven generator to a wind turbine installation will likely only be economical when the utility's demand charges are high or when there are additional benefits for having backup power for the customer, such as not having grid interconnection available at a remote site.

Transmission Constraints for Wind Hydro and Wind Diesel Hybrids

Large generation additions for or by utilities are increasingly being constrained by limitations on the bulk power transmission grid. The existing transmission grid has limited capacity to accept large amounts of additional generation in many areas, especially if they are some distance from the major load centers. Smaller generation additions, such as those discussed in this report, are not affected by these transmission constraints because these smaller generation additions are more closely matched to the local load levels. However, these additions don't necessarily relieve any existing transmission

constraints that may apply, for instance, to large wind farms.

Biodiesel

Hybrid wind-diesel engine energy systems are among the most popular hybrid renewable energy systems due to their relatively low capital costs and ability to provide constant power in the face of intermittent wind resources. Engine generator sets can be quickly started when wind speeds drop below levels required for wind power generation.

The engine generator set provides a degree of flexibility in the choice of fuel burned. Most commonly diesel fuel is used, but this fossil fuel is a poor choice from a renewable energy perspective. However, there are three renewable fuels that can be used for stand-by power generation from a diesel engine: biodiesel oil, producer gas, and biogas. Biodiesel is manufactured from oils extracted from soybeans. Producer gas is the product of gasifying any of a number of biomass materials, including wood chips, switchgrass or other grass crops, and agricultural residues such as cornstover or corn cobs. Biogas gas is obtained from anaerobic digestion of high-moisture biomass such as manure.

Biodiesel will not degrade diesel engine performance. Biogas and producer gas contain contaminants that make them better suited for spark ignition engines.

Since biodiesel is chemically similar to diesel fuel burned in vehicles today, it can be used in the conventional diesel engines without degradation in engine performance or engine components. However, biogas and producer gas are both relatively low-grade fuel that contain contaminants that may be harmful to an engine. Therefore spark ignition engines are often recommended for use with these fuels[5]. A common diesel engine can be adjusted to burn a mixture of diesel and biogas or producer gas. Spark ignition engines are able to run on pure biogas or producer gas fuels. The rule-of-thumb maintenance cost for biogas and producer gas engines is $0.0125 per kWh. [6]

A variety of grains and seeds contain relatively high concentrations of vegetable oils that are of high caloric value and can be used as liquid fuels. However, research has shown that the high viscosity of these raw vegetable oils (20 times that of diesel) would lead to increased residues on the injectors and rings. On the other hand, chemical modification of vegetable oils to methyl or ethyl esters yields excellent diesel-engine fuel without the viscosity problems associated with raw vegetable oil. Biodiesel is the generic name given to these vegetable oil esters. Suitable feedstocks include soybean, sunflower, cottonseed, corn, groundnut (peanut), safflower, rapeseed, waste cooking oils, and animal fats. Waste oils or tallow (white or yellow grease) can also be converted to biodiesel.

Biodiesel can be made from soybean, sunflower, cottonseed, corn, peanut, safflower, rapeseed, waste cooking oils, and animal fats.

In the production of biodiesel the oil is squeezed from the seed in an oil press. By-product meal can be sold as a feed additive. The vegetable oil is "transesterified" , aprocess by which triglycerides in the vegetable oil are reacted with methanol or ethanol to produce esters and glycerol[7].

The reaction is catalyzed by lye (NaOH or KOH) dissolved in 20% excess of methanol. The reaction proceeds rapidly to completion at room temperature in about an hour. Small amounts of soap are also produced by the reaction of lye with fatty acids. Upon completion, the glycerol and soap are removed in a phase separator.

The heat of combustion of biodiesel is about 95% by weight of conventional diesel but because it burns more efficiently, it generates essentially the same power as diesel fuel. Biodiesel can be used in unmodified diesel engines with no excess wear or operational problems. In over 100,000 km of tests using soybean oil methyl esters in light and heavy trucks, few significant problems arose other than the need for more frequent oil changes than conventional fuels because of the build-up of ester fuel in engine crankcases[8].

Biodiesel can be used in unmodified diesel engines with no operational problems.

There is no net gain of CO_2 to the atmosphere from the combustion of biodiesel fuels and particulate emissions are less.

Another advantage of biodiesel is that there is no net gain of carbon dioxide (CO_2) because the emission of CO_2 is equalized by the plants consumption of CO_2[9]. In addition, when biodiesel is burned there are less visible (particulate matter) emissions than the conventional diesel fuel. This helps keep the visible pollutants and greenhouse gases to a minimum. However, a disadvantage of biodiesel is the current high selling price, ranging between $2-5 per gallon.[10]

It is not readily available in the United States. Table 1 lists nine sources of biodiesel in the United States.[11]

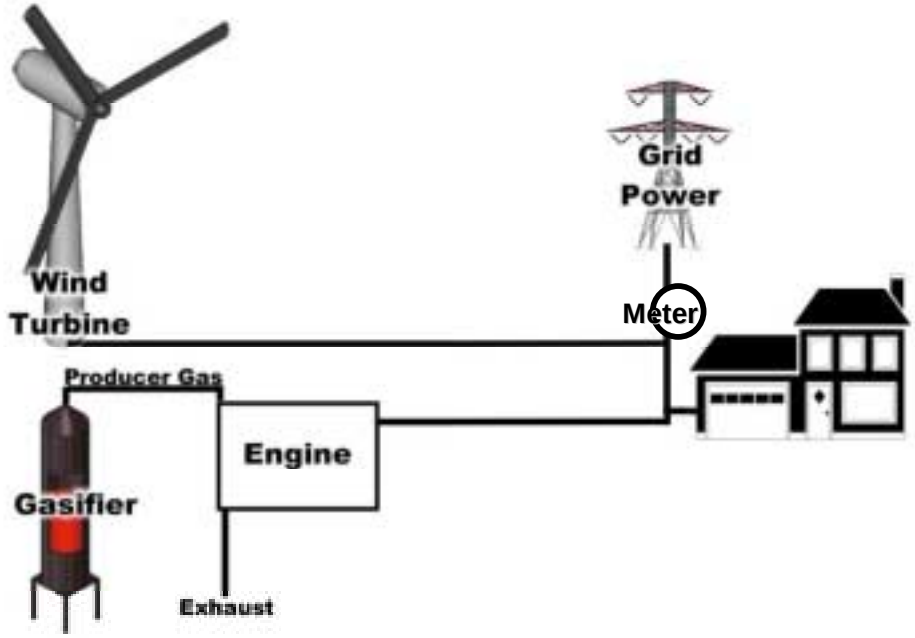
- Ag Environmental Products,
  Lenexa, KS
  800-599-9209
- Chemol Company,
  Greensboro, NC
  336-333-3071
- Columbus Foods,
  Chicago, IL
  773-265-6500
- CytoCulture,
  Point Richmond, CA
  510-233-0102
- Griffin Industries,
  Butler, KY
  703-256-4497
- High Performance Fuels and Additives,
  Houston, TX
  713-467-7084
- NOPEC Corporation,
  Lakeland, FL
  888-296-6732
- Pacific Biodiesel,
  Kahului, HI
  808-877-3144
- World Energy Alternatives,
  Cambridge, MA
  617-868-1988

The use of biodiesel to run gensets as part of hybrid wind-diesel engine systems is not widely practiced today since conventional diesel fuel is very inexpensive in comparison.

Producer Gas

Producer gas is made by the conversion of solid, carbonaceous fuels into flammable gas mixtures. Producer gas consists of carbon monoxide (CO), hydrogen (H_2), methane (CH_4), nitrogen (N_2), carbon dioxide (CO_2), and smaller quantities of higher hydrocarbons.[12] This gas can be burned directly in a furnace to generate process heat or it can fuel internal combustion engines, gas turbines, or fuel cells.

Figure 27: Hybrid Wind-Gasifier system



In a fluidized bed gasifier, a gas stream passes vertically upward through a bed of inert particulate material to form a turbulent mixture of gas and solid. Fuel is added at such a rate that it is only a few percent by weight of the bed material. The violent stirring action makes the bed uniform in temperature and composition with the result that "gasification" (liquid fuel becoming vaporized) occurs simultaneously at all locations in the bed. Fluidized beds are gaining favor as the reactor of choice for biomass gasification. The high thermal mass of the bed imparts a high degree of flexibility in the kinds of fuels that can be gasified, including those of high moisture content. Disadvantages include relatively high exit gas temperatures, which complicates efficient energy recovery, and relatively high amounts of impure particles in the gas due to the abrasive forces acting within the fluidized bed.

Although gasifier-engine systems have been demonstrated, they can be difficult to operate, are only moderately reliable, and have lifetimes of only 10 years. They also pose a potential threat of carbon monoxide poisoning.[13] Many gasification systems require constant adjustments during operation. Although automatic controls can be employed in their operation, hybrid wind-gasifier-engine systems are probably not practical at this time for homeowners or farmers because of their complexity.

Producer gas hybrids are better suited for industrial purposes where economies of scale and full-time personnel are available.

Producer gas hybrids are better suited for industrial purposes where economies of scale and full-time personnel are available. They would, however, be more suited for industrial or utility purposes where full-time personnel are available to attend them. Additionally, if a company generated biomass waste products the fuel costs would drastically decrease thus making gasification more economically viable. Larger scale systems also capture important economies of scale, which reduces the cost of electricity as the size of the system increases. *Figure 27* shows a typical hybrid wind-gasifier system.

According to David Walden of Bronzeoak Corporation, the cost of a downdraft gasifier sized at 2MW coupled with a "diesel" genset adapted to operate on 70% producer gas and 30% diesel would cost around $1300 per kW (gross). This is an unusual approach. More commonly, the spark ignition engine is used to burn 100% producer gas. For this approach, the total costs of the system could be around $2,000 per kW (gross)[14].

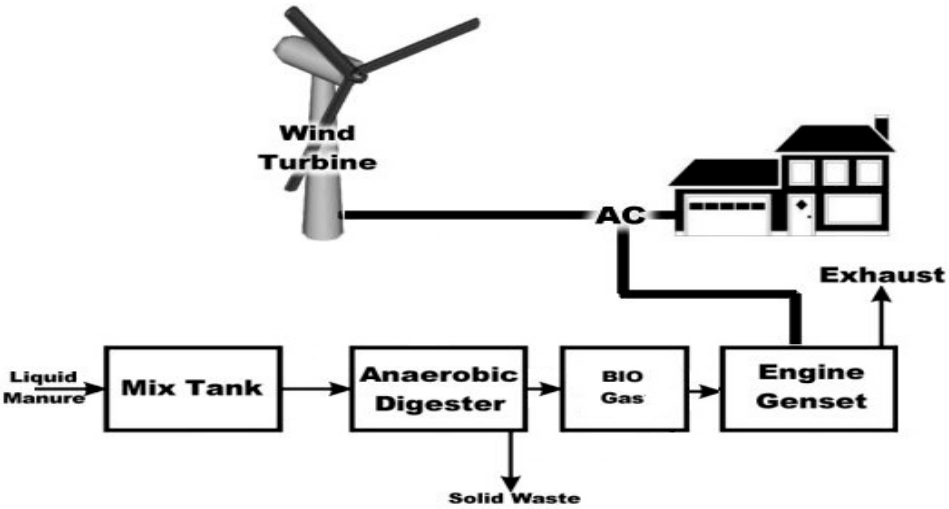
A resource for manufacturers of large and small-scale gasifiers can be found in "A Survey of Biomass Gasification 2000: Gasifier Projects and Manufacturers around the World."[15] This source is an international directory of gasifier manufacturers. It includes schematics, cost information, company history, current projects, and additional references with each manufacturer.

Biogas Hybrids

Biogas is distinguished from producer gas in that it is made through anaerobic (oxygen-free) digestion of organic waste to gaseous fuel by bacteria.[16] The process occurs in stages to successively break down the organic matter into simpler organic compounds. The product is a mixture of methane (CH_4), carbon dioxide (CO_2), and some trace gases. Most digestion systems produce biogas that is between 55% and 75% methane by volume. Biogas, once treated to remove sulfur compounds, can be used in many applications, including stationary power generation. Biogas is a suitable fuel for engine generator sets, small gas turbines, and some kinds of fuel cells.

The biological processes within an anaerobic digester that lead to biogas are relatively complicated. The process consists of three basic steps: hydrolysis and fermentation, transitional acetogenic dehydrogenation, and methanogenesis. Hydrolysis and fermentation involve hydrolytic and fermentative bacteria that break down proteins, carbohydrates, and fats into simpler acids, alcohols, and neutral compounds. Hydrogen and carbon dioxide are also produced. This step is followed by transitional digestion through the action of acid-forming bacteria. Products of fermentation that are too complex for methane-forming bacteria to consume are further degraded in this step to acetate, hydrogen, and carbon dioxide. Traces of oxygen in the feedstock are consumed in this step, which benefits oxygen-sensitive, methane-forming bacteria. The final step, methanogenesis, converts acetate to methane by the action of methane-forming bacteria.

Figure 28: Hybrid wind-anaerobic digester



Today anaerobic digesters are used to produce methane, which can be used to produce electricity by operating a genset adapted for methane. The AC output from the genset can be simply tied into an inverter and sent through a DC bus. An anaerobic digestion system can be combined with a wind turbine, as illustrated in *Figure 28*.

Basic anaerobic digestion systems are relatively simple. For some feedstocks, removal of scum may be desirable in advance of the anaerobic digester. Whether batch or steady flow processing, two effluent streams result: biogas and sludge. The biogas may have to be scrubbed in advance of combustion to remove hydrogen sulfide that would otherwise appear as the pollutant sulfur dioxide in the exhaust gas. Hydrogen sulfide increases concerns about wear to engine parts and bearings, which cause maintenance issues.

Examples of anaerobic reactor designs include the simple batch reactor, plug-flow reactors, continuously stirred tank reactors (CSTR), upflow reactors, and two-tank reactor systems. The batch reactor is a single vessel design in which waste is added and removed in batches and all steps of the digestion process take place in the same environment. More advanced reactor designs aim to improve waste contact with active bacteria and/or to separate and control the environments for acid-forming and methane-forming bacteria. Relatively new two-tank reactor technology (sometimes called a sequence-based reactor) physically separates the acid formation and methane formation phases of digestion so that each takes place under optimal conditions. Benefits of this technology are numerous: hydrolysis and acidification occur quicker than in conventional systems; the common problems of foaming in single-tank systems are reduced by the destruction of biochemical foaming agents before they reach the methane forming reactor; and the biogas produced is typically rich in methane.

The biological conversion process of anaerobic digestion can be used for a wide range of feedstocks of medium-to-high moisture content. Sewage sludge is most commonly used as feedstock for anaerobic digesters, but municipal solid waste (MSW), food processing wastes, agricultural wastes, Napier grass, kelp, bagasse, and water hyacinth can also be digested. Digesters are designed to maintain optimal conditions for a specific type of waste. Waste pretreatment, heating, mixing, nutrient addition, specialized bacteria addition, and pH adjustment can be manipulated to control digester performance.[17]

Typical thermodynamic efficiency in converting the chemical energy of dry matter to methane is about 60% with methane yields ranging between 8,000-9,000 cubic feet/ton of volatile solids added to the digester. However, thermodynamic efficiencies approaching 90% with methane yields of 11,000–13,000 cubic feet/ton volatile solids have been achieved in research programs.

When compared to the conventional aerobic digestion there are numerous advantages which include less solid waste, less odor, reductions in fly population, less space taken up by lagoons, and valuable byproducts in the form of fertilizer.[18] In addition, anaerobic digesters help reduce the amount of greenhouse gases (methane) that are released into the atmosphere with conventional aerobic digestion techniques. Some disadvantages are that anaerobic digesters require regular maintenance and in the past many digesters have failed due to bad designs. Design of anaerobic digesters is solely dependent upon the farmer's needs and costs accordingly. Typical payback can range up to 10 years. These digesters would be ideally suited economically for large scaled dairy, swine, and poultry operations where high wastes are available. A skilled operator would also be beneficial for daily maintenance and problems.

Biogas advantages include less solid waste, less odor,reduced greenhouse gas emissions and valuable by-products.

There are methane recovery projects in Nevada and Creston, Iowa.[19] One operation converts manure from a 4,800 animal farrow-to-wean operation into almost 912 thousand cubic feet of biogas per month. The biogas is burned in a genset that generates 67, 240 kWh per month. There are also three 250 kW wind turbines in Nevada one of the projects but they are not directly interconnected as a hybrid system such as proposed in *Figure 28*.

Solar Hybrids

Many wind hybrid systems incorporate solar energy. Solar energy can be harnessed through a number of means. Photovoltaic panels and materials convert sunlight directly to electricity through a photovoltaic chemical process. Solar thermal panels collect the sun's heat to heat water and thereby reduce the energy requirement of water heating in a residence. Double-pane windows also trap the sun's heat in the winter, reducing heating energy requirements in the home. Any method of conserving energy or reducing the energy load will improve the efficiency of a renewable system. For the purposes of generating electricity using a wind hybrid system, this section of the report will focus on the merits of incorporating photovoltaics (PV).

The photovoltaic technology that uses crystalline silicon is used in over 90% of current installed photovoltaic capacity. More efficient photovoltaic materials are available but at a much higher price. Photovoltaic technology is characterized by an increase in efficiency as the temperature falls (hence arrays may deliver more than their rated output in winter). Some photovoltaic systems can make use of all available solar energy (net of system losses), such as grid-connected systems or water pumping systems.

Grid-interconnected solar hybrids use all energy produced. Stand-alone systems are subject to 45% losses from battery storage.

Stand-alone residential systems with batteries are the most common type of solar installation. These systems and often integrate a wind turbine and back-up generators to create a complete hybrid energy system. Having a backup power supply or batteries with a PV system that is not grid-interconnected is essential to be able to provide energy to meet load requirements when the sun is not shining. However, the incorporation of batteries reduces the overall efficiency of the system compared to grid-interconnected systems or a system sized so that all the energy is directly used.

When estimating the output of a PV system, losses need to be included. Inverter losses are taken into account intrinsically by considering an AC rating for the PV system. Some PV systems included trackers that rotate the PV panels to continually face the sun as it moves. Many tracking systems rely on passive trackers that do not consume energy. Active trackers would use about 1% of the energy produced. Battery losses would be relevant only for systems that are not grid-connected. Small monitored systems connected to batteries have recorded 30% of the PV energy lost through: (1) round trip battery storage, and (2) overproduction at times with small loads and full batteries. This 30% would be in addition of inverter losses. Altogether the average

losses on a system connected to batteries with an inverter are on the order of 40-45%.[20]

Photovoltaics are usually incorporated into solar panels that can be mounted on a roof or stand. Some stands are designed to track the sun, increasing the efficiency of the solar panel as depicted in figure 29. Home-scale PV panels often use battery storage and a backup diesel or propane generator to provide power when sunlight is not available.

Figure 29: Tracker mount drawing for PV array

The solar energy calculator of the Iowa Energy Center shows outputs for different tracking systems in different Iowa locations.

By logging onto the web site of the Iowa Energy Center http://www.energy.iastate.edu/solarcalculator/index.htm, the reader can make use of a solar energy calculator specific for different types of solar systems and different locations in Iowa. The user can select various array geometries, including fixed and tracking arrays. Fixed arrays may be defined in terms of slope and orientation (azimuth). Four tracking arrays may also be selected: (1) 2-axis tracking arrays, designed to face the sun at all times; (2) one-axis tracking arrays with an horizontal north-south axis, and (3) one-axis tracking arrays with an horizontal east-west axis, and (4) one-axis tracking array with an axis tilted to the site's latitude. Newer photovoltaic options include roof tiles and windows that are coated with photovoltaic materials.

Solar energy is on average five times more expensive than wind energy per kilowatt, especially in Iowa, which has abundant wind but only moderate sunshine. However, solar energy can play a valuable role in providing energy

when the wind energy is not sufficient. *Figure 30* shows the annual average variations in available solar and wind energy in Iowa. Note that in the summer months when wind energy production is lower, the days are longer and there is more solar energy available.. Conversely, in the winter when the days are short and cloudy, the wind energy is more abundant. Since both wind and solar systems last a long time (at least 10-20 years), the economics will be based on the average production.

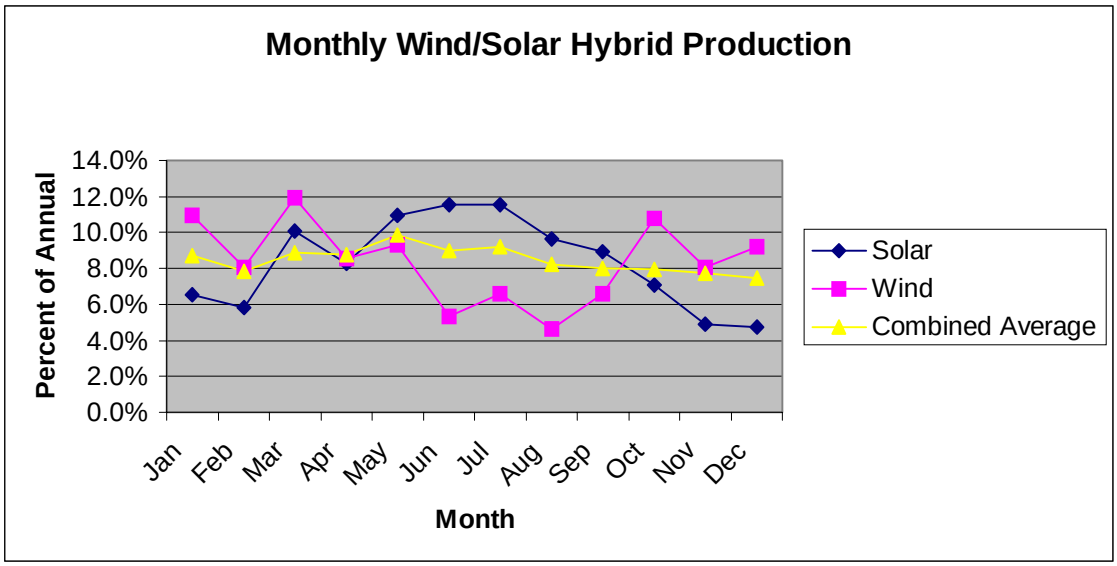


Figure 30: Comparison of percent of production for photovoltaic panels and small wind turbines

Figure 31 shows a typical daily wind and solar pattern for Iowa. Again, the bell curve for solar would be shorter in the winter and longer in the summer, and the wind capacity would be higher in winter than summer. Some days will be very windy and others will have no wind. This chart shows that on average, the wind is available around the clock, complementing the daily solar pattern.

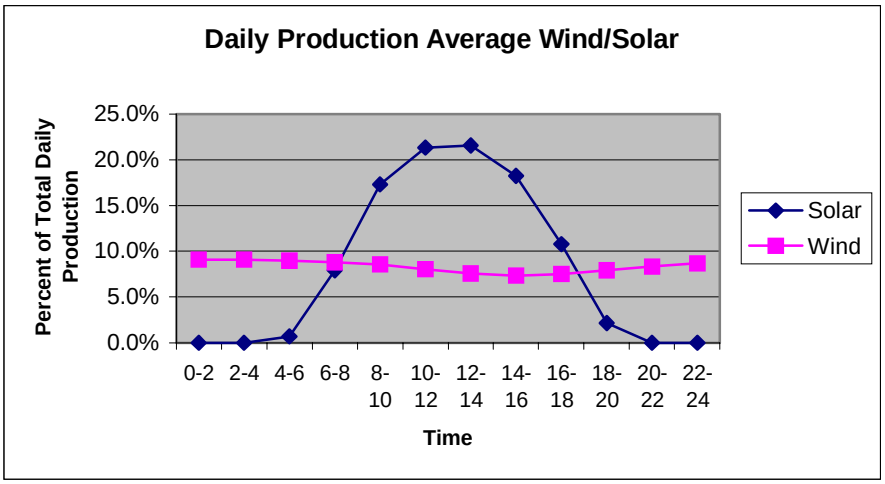


Figure 31: Comparison of Diurnal Patterns of Wind and Solar Energy

Using the information from these two charts to decide the proper sizing of the wind and solar components of a system requires an additional consideration: cost. The annual production chart indicates that the wind and solar components should be sized similarly, however this may vary in different locations.

Location will play an important role in any wind/solar hybrid system. The two maps of Iowa below show the regions of higher wind and higher solar energy. The best overlap is in west central Iowa.

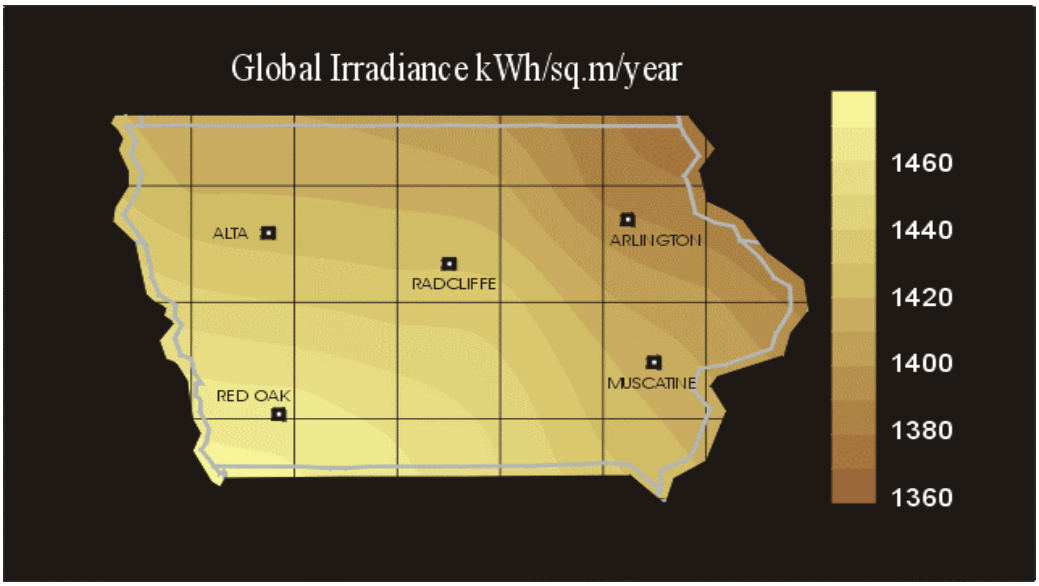


Figure 33: Annual Average Solar Resource Map of Iowa

For example, to design a system to serve an average 2,000-watt residential load, the goal would be to have the average output of the wind turbine and solar panel together to add up to 2,000 watts. Using the solar energy calculator from the Iowa Energy Center website referred to earlier in this chapter, it is possible to estimate the average output from a solar array at a particular location in Iowa. Using the wind energy calculator from the Iowa Energy Center website, the average output of a selected wind turbine at a specific location in Iowa can be determined. Since solar panels can cost up to five times more per kilowatt than a wind turbine, careful attention needs to be paid to the available wind and solar resource at the selected site to determine how best to size each component.

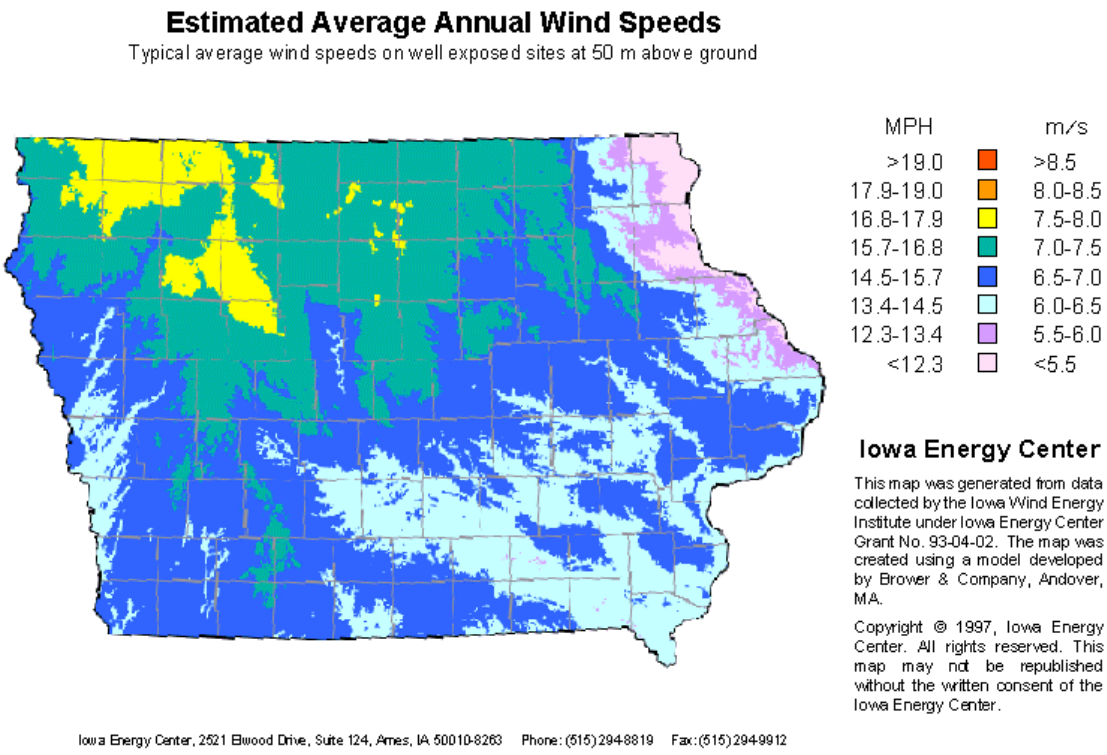


Figure 34: Annual Average Wind Resource Map of Iowa

Wind/Solar Hybrid Options:

1. A grid-interconnected system sized to meet the local load with net-metering would be the most economical way to install a wind-solar hybrid. However, net-metering contracts are difficult to achieve in Iowa as of this writing.

2. Another option is to size the wind-solar system so that the maximum output rarely exceeds the load requirement (2,000 watts in this example). In this instance, all the energy is used but a significant amount of energy will need to be purchased from the utility. For example, if the wind turbine was rated at a 1,000 watts and delivered a 20% capacity factor at the site (200 watts on average), and if the solar array was also rated at 1,000 watts operating at a 30% capacity factor (300 watts on average), then during full sunshine and a 28-mph wind, 100% of the power would be delivered from the wind turbine and solar panels but on average about 75% (1500 watts) of the electricity would need to be supplied from the utility. Of course, since the load requirement rises and falls at different times of the day and night as does the availability of wind and solar energy, the actual percentages of energy delivered from each component and the grid will vary.

3. A third option, for an off-grid system, is to size the components to meet the local load and back up the wind and solar generation with battery storage and a gas or diesel generator. The battery backup and generator will be required to ensure that electricity is always available. Batteries need to be protected from overcharging. They also need to be kept at a 50 percent charge level minimum to deliver power. This limitation of a battery bank accounts for significant losses of efficiency in the system. A hybrid system with these components will require a controller, inverter and other components. Its cost will be higher than grid-interconnected power. However the calculation tools available at the end of this report and the web-based wind and solar calculators from the Iowa Energy Center together should provide assistance in sizing the components appropriately for specific locations in Iowa with different wind and solar resources.

The total cost of a standalone home-scale system with PV panels (1,200 watt), battery bank, small wind turbine (3,000 watt), backup generator and controller could be about $30,000 with the homeowner responsible for installation and maintenance. The following chart gives some typical component costs.

Rated Capacity of Each Component	**1,000 watt**	**3,000 watt**
PV Array	$12,000	$36,000
Wind Turbine with Tower	$3,000	$9,000
Backup Generator	$750	$1,500
Battery Bank	$500	$1,500
Controller w/meter & inverter	$3,000	$6,000
System Cost	**$19,250**	**$54,000**

Since the size of each component and load requirements offer so many variables, a further analysis of costs is best gained by looking at the calculator included at the conclusion of this report and by contacting referenced companies that sell the components of hybrid systems.

Micro-Hydroelectric Hybrids

Where flowing water exists, it may be possible to generate electricity with a micro-hydroelectric turbine. Hydroelectric generation, where feasible, has a very high return over its lifetime. Many of these systems can provide a relatively constant power supply.

Most commonly used in "home" applications are impulse turbines.[21] This device uses either a Pelton wheel or a Turgo wheel to turn flowing water into alternating current (AC) electricity. The Turgo wheel is a rugged bronze turbine wheel that is applicable to a wide range of elevation heads as small as 2 meters.[22] The Pelton wheel is most useful for higher head, lower flow situations. Both types of turbines must be supported by a "penstock" that channels flowing water into a pipe, which then feeds into the turbine and turns the wheel. All small hydroelectric turbines have fairly high losses that limit energy conversion efficiencies to 25-50%. Losses arise within the turbine as well as from friction between the pipe and moving water. These losses must be accounted for when evaluating power requirements. A rectifier, which turns AC to direct current (DC), is often a standard on most turbines since battery storage is assumed. If the turbine is used for a home, an inverter is required to change the current back to AC.

A Pelton or Turbo wheel converts flowing water into AC electricity with a conversion efficiency of 25-50%.

Micro-hydroelectric refers to turbines that are able to operate under low elevation head or low volumetric flow rate conditions. Elevation head and volumetric flow rate determine the water pressure and amount of water flowing and are therefore important factors in determining the feasibility of micro-hydroelectric power for a particular location. It is these conditions that determine the size of the micro-hydroelectric turbine to be used since each turbine is dependent upon the flow and head. The U.S. Department of Energy maintains a Web site that is helpful in determining elevation head, volumetric flow rates, legal requirements, costs, and other considerations in constructing a successful micro-hydroelectric system for home application at http://www.eren.doe.gov/consumerinfo/refbriefs/ab2.html.

In the Midwest, where winters are very cold and summers are often dry, streams and some rivers usually freeze entirely in the winter or dry up in the summer. In these environments it may be necessary to couple a micro-hydroelectric turbine to a wind turbine or PV array to assure a constant power supply.[23] *Figure 35* schematically illustrates a hybrid wind/hydro/battery system.

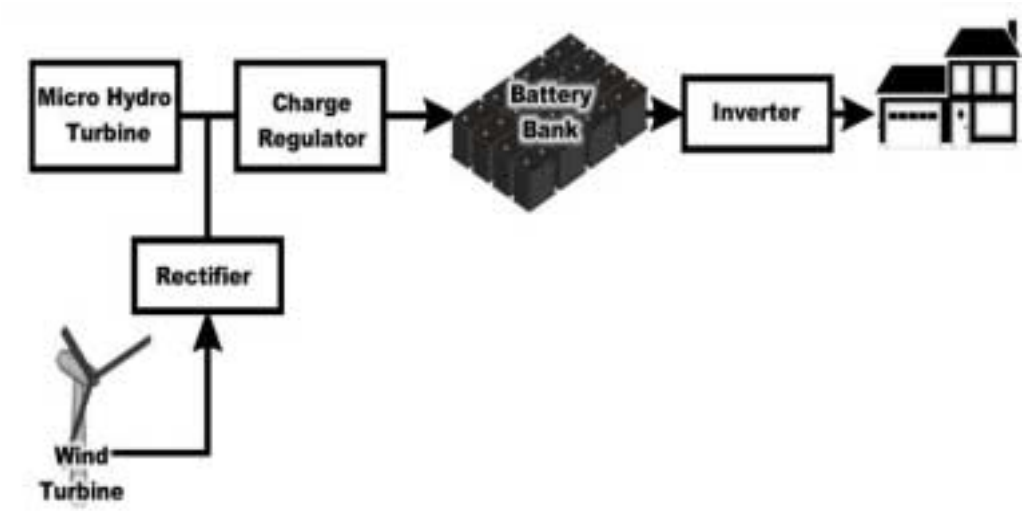


Figure 35: Hybrid Wind/Hydro/Battery System

On the other hand, if the water resource is plentiful year round, a hydroelectric turbine with a battery bank could provide an adequate supply of electricity without the addition of a wind turbine or PV array. Accordingly, a careful assessment of hydraulic resources should be performed before deciding to incorporate it into a hybrid energy system. Typical cost of a two nozzle Harris Pelton Turbine that produces 1400 watts at 24 Volts will cost about $1,000 without installation.[24] Installation is the major capital cost of a hydro system, costing between $5,000 and $10,000.[25] The cost per kilowatt-hour for these systems is analyzed in the calculator included at the end of this document.

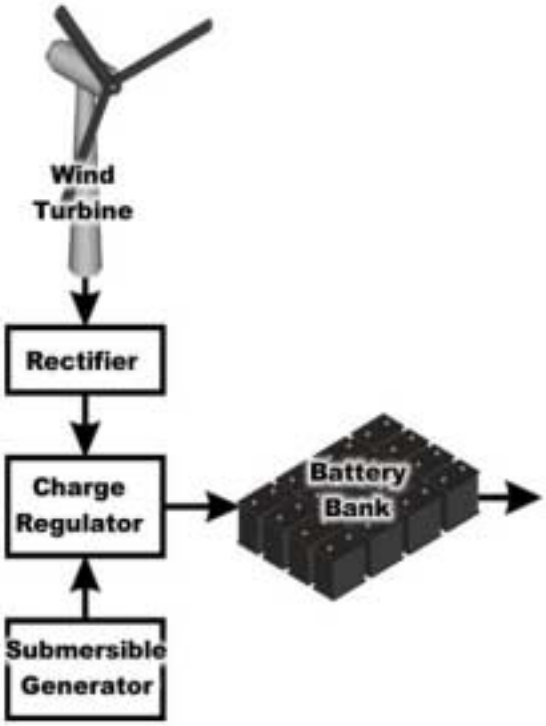
A submersible hydro generator consists of a propellor that turns an alternator sealed in a metal housing.

Another way to generate electricity from relatively fast-flowing rivers or streams is the use of submersible generators. The Aquair UW 100 Watt Submersible generator is one of several commercially available units. The generator consists of a simple propeller attached to a shaft that turns an alternator sealed in a metal housing filled with oil. The output is AC power that can be converted to DC power by a suitable rectifier for storage in electric batteries (12 or 24 volt). *Figure 36* illustrates a submersible generator coupled to a wind turbine and battery charging system.

This system is more benign to the environment than micro-hydroelectric turbines, because the submersible generator does not require any special pipelines or modifications to the stream. The submersible generator is simply lowered into a flowing stream. They can be mounted to bridges via a vertical support that allows adjustments to obtain suitable depths in a seasonal stream. Stream channeling can be employed to increase flow velocities with subsequent increases in electrical power, but is not necessary. The cost of a

submersible turbine is low but the output power is also low compared to micro-hydroelectric turbines. At water speeds between 2.5 m/s and 4.0 m/s the power output ranges between 60 watts and 100 watts.[26] The Aquair submersible generator requires only 0.33 meters (13 in.) water depth to operate. The cost of the Aquair submersible generator is about $1,300, which is an expensive $13,000 per kilowatt of capacity. Oasis Montana is one of many dealers that sell the Aquair 100 Watt submersible generator. As with the micro-hydroturbine systems, seasonal flow variations may cause problems. For costs per kilowatt-hour of these systems refer to the calculator at the end of this report.

Figure 36: Hybrid Wind/Submersible/Battery System



Energy Storage Methods

When using a wind turbine to generate electricity there are times when the wind is intermittent or non-existent. In these situations the use of a storage device will help smooth out the diurnal variations of wind. Most commonly used in renewable applications is the lead-acid battery. The common use of this chemical storage device is due to its relatively low costs and commercial availability. However, there are different methods of storing energy other than batteries that might be attractive in certain applications. This section compares some of the most promising alternatives to chemical batteries for energy storage: flywheels, pumped hydro, compressed air energy storage (CAES), and hydrogen created by electrolysis stored for use in fuel cells.

Electric Batteries for Energy Storage

Storage batteries are an essential part of any self-sufficient renewable energy system that is not connected to a utility grid. Battery banks act as a back up energy source when the wind is not blowing or when the sun is not shining. An integrated wind-battery storage system is shown in *Figure 37*.

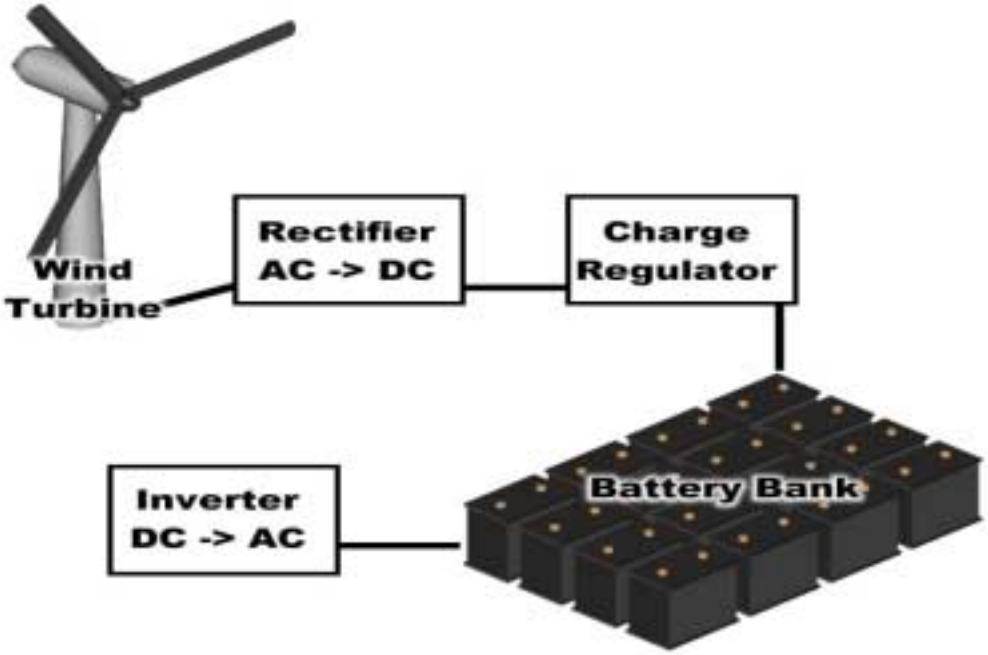


Figure 37: Hybrid Wind-Battery System

Battery storage systems require a charging regulator to extend the life of the batteries.

A battery storage system requires a charging regulator, which controls the flow of power from the source of electricity to the battery. Proper charging insures minimal battery damage and maximum life of the battery. Typically a wind turbine comes with a charge regulator specific to the wind turbine. An inverter is needed to convert DC power to AC power. Most consumers buy and assemble individual components when building a renewable system. Some, however, purchase an integrated system that includes all of the components of the storage system. In addition to having everything in one unit, a power panel may be helpful in meeting local building inspections and codes.

Secondary batteries are a type of battery that allows for repeated charging and discharging cycles. This is mainly why they are the battery of choice for hybrid systems. Secondary batteries (lead-acid) are commonly categorized accordingly to their discharge characteristics: shallow cycle or deep cycle. Shallow cycle batteries do not significantly deplete the stored charge; discharges rarely exceed 20% of the total charge. They are commonly used in tractors and cars. Deep cycle batteries are used for repeated deep cycle discharges of 50-80%. Lead-acid and alkaline batteries, both capable of deep cycle operation, are most commonly used in energy storage systems.

Lead-acid batteries have been a favorite for home and utility applications since their invention in the 1800's. They are composed of two electrodes made of lead and lead dioxide with sulfuric acid serving as electrolyte. Some advantages of lead-acid batteries include their relatively high efficiency, low cost, and temperature operation range of 0° - 100° F. Compared to other batteries, lead-acid batteries have excellent power-density.[27]

Despite the popularity of lead-acid batteries, they have a few drawbacks. These include high weight, relatively long charge times, and high maintenance costs.[28] It should be noted that the temperature at which the lead-acid battery operates will effect its performance and cycle life. These batteries are designed to operate near ambient temperatures (80° F). If operated at temperatures higher than the designed operating temperature the capacity will rise, but at the consequence of a shortened battery. Likewise, operating below the designed operating temperature may last longer, but at the expense of a lower capacity.

In recent years, low maintenance lead-acid batteries known as sealed batteries have been introduced to the market. Sealed batteries include Gel and Absorbed Glass Mat (AGM) systems. Gel batteries have a gel-like electrolyte in them.[29] Some advantages are that they are more mobile, are spill-proof, and do not require equalization charges. However, they cannot be charged quickly,

requiring low charging voltages. As a result, they are susceptible to damage during charging. The AGM batteries have similar advantages to the Gel battery, but do not require specific charging voltages.[30] However, AGM are significantly higher priced than lead-acid batteries. A good source of detailed information on AGM batteries is the Northern Arizona Wind and Sun's web site given below.

Alkaline batteries employ either nickel and cadmium or nickel and iron for electrodes in a potassium hydroxide (alkaline) electrolyte. Advantages over lead-acid batteries are longer life cycles and ability to withstand full discharges without compromising the battery life and efficiency. Disadvantages, however, are higher charging voltages, lower charge efficiencies, lower cell voltages, environmental disposal problems, and higher costs compared to lead-acid batteries. As a result, they are seldom used in renewable energy systems.

Battery capacity is measured in amp hours.

Before buying batteries one must determine the battery capacity (that is, the number of amp-hours required), minimum operating temperature, operating voltage (12, 24, or 48 VDC), maximum charging voltage, and the maximum number of days of use. Batteries come in 6 or 12 volt sizes. Use the following directions adapted from source[31] to calculate system load requirments and battery size needed.

AC loads

1. List all AC loads (Watts) and multiply it by the number of hours used per week (Watt-hours/week)

2. Divide total load calculated above by the DC inverter voltage (12 or 24 Volts) to get the total AC load (amp-hour/week)

DC Loads

3. List all DC loads (Watts) and multiply it by the number of hours used per week (Watt-hours/week)

4. Divide total load calculated above by the DC inverter voltage (12 or 24 Volts) to get the total DC load (amp-hour/week)

Total Load

5. Add both total loads for AC and DC (2 and 4) to gain total system load (amp-hour/week)

6. Divide the number above by 7 days to calculate the total average (amp-hours/day)

Battery Sizing

7. Multiply the total average load (line 7) by the expected number of days without sun or wind.

8. Divide line 7 by 0.8 to maintain a 20% reserve after deep discharge.

Battery temperature adjustment:

80 F (26.7 C) = 1.00
70 F (21.2 C) = 1.04
60 F (15.6 C) = 1.11
50 F (10.0 C) = 1.19
40 F (4.4 C) = 1.30
30 F (-1.1 C) = 1.40
20 F (-6.7 C) = 1.59

9. If using a lead-acid battery select an operating temperature and multiply line 8 by this correction factor. This is the optimum battery size in amp-hours.

10. Divide the optimum battery size figured above in line 9 by the amp-hour rating of selected battery to obtain the total number of parallel batteries needed.

11. Round up to next whole number to see number of batteries needed.

Deciding the appropriate battery voltage: 12, 24, or 48 VDC will depend upon system components (i.e. inverter) and storage requirements. Most commonly 12 or 24 VDC are chosen. Both have their advantages and disadvantages. For example, a 12-volt system is more common and simpler to manage, but for hybrid systems where there is a significant distance between the source of power (wind, solar, hydro) and the home, 24- or 48-volt systems are more efficient.

Using a 24 or 48 volt storage system with deep cycle lead-acid batteries is most cost effective today.

Higher voltage reduces the line losses with distance and can save money by reducing the conductor size of the wire used to connect the power source to the battery. Below is a simple methodology for estimating the number of batteries needed for a desired application:[32]

1. Total amp-hours per day (DC and AC)

2. Maximum number of days without sun or wind

3. Multiply line 1 by line 2

1. Divide line 3 by 0.8 to maintain a 20% reserve after deep discharge.
2. Battery temperature adjustment

80 F (26.7 C) = 1.00

70 F (21.2 C) = 1.04

60 F (15.6 C) = 1.11

50 F (10.0 C) = 1.19

40 F (4.4 C) = 1.30

30 F (-1.1 C) = 1.40

20 F (-6.7 C) = 1.59

6. Multiply line 4 by line 5. This is the optimum battery size in amp-hours.

7. Amp-hour rating of battery

8. Divide line 6 by line 7. This is total number of parallel batteries needed.

9. Round up to next whole number.

Warren Lauzon of Northern Arizona Wind & Sun notes that small golf cart batteries are commonly used in RV type systems and smaller applications, but are not recommended for larger applications.[33] Lead-acid deep cycle batteries can be obtained at retail stores in 75 amp-hour and 115 amp-hour sizes for about $40 and $55, respectively. These batteries can be wired in parallel to get the desired capacity. Cost breakdowns for battery banks and PV cells are available on Independent Power and Light's web site given below. They also give suggestion for proper charging of battery systems.

Flywheel Energy Storage

A flywheel has the potential to provide energy storage for a wind turbine. The flywheel is a highly efficient rotating mass that is accelerated when excess energy is available and then is used to spin a generator when energy is required. In technical terms, the energy stored is proportional to the moment of inertia and the square of the angular velocity of the flywheel. However, the maximum energy that can be stored is determined by the material properties of the flywheel as described by the equation:[34]

$$W_{MassMax} = \frac{K\sigma_{Max}}{\rho}$$

where K is the shape factor, σ_{max} is the allowable tensile stress, and ρ is the density of the material being used. Maximum energy storage is achieved with a material of low density and a high tensile strength.

In the past, flywheels were constructed of wood and mild steel, which made them inefficient due to their size and weight. Although flywheels were invented centuries ago, their use for energy storage has only started to become practical in recent years with advances in synthetic materials. . It is possible to store 10,000 kilowatts of energy for periods of up to one hour. Flywheels are best suited for high discharges, but can only provide power for a few seconds or minutes. Flywheels are best suited for high discharges, but only on the scale of seconds to minutes.[35] A flywheel coupled to a wind turbine would help smooth out variations in generated power. In hybrid wind-diesel applications this would help alleviate the need for frequent starting and stopping of the diesel genset when the wind is intermittent.

However, the utility of the flywheel is a function of cost. The composite material of a flywheel is the most expensive component of a flywheel. Therefore it is necessary to compare costs of various fibers. This was done for a hybrid wind-flywheel storage system in West Texas.[36] A 277 kWh flywheel was devised that cost $796 per kWh. Although this flywheel was intended for larger 300 kW wind turbines, it is clear that flywheels are a relatively expensive storage option. In analyzing the economics of flywheels, one must judge them on their life-cycle cost rather than simply their capital cost,[37] which is relatively high compared to lead-acid batteries. From an environmental perspective, the flywheel is completely benign since there are no air pollution emissions or hazardous wastes generated, which is the main impetus for considering them in stationary power applications.[38] Regenerative Power and Motion is developing a flywheel battery, but no systems are currently available from commercial suppliers.

Pumped Hydro Storage

Pumped hydro is capable of storing large amounts of energy.[39] Usually this technique is employed in electric utility-scale applications. Pumped hydro is based on moving water from a reservoir at low elevation to a reservoir at higher elevation. *Figure 38* is a schematic of a pumped hydro system.

The increase in elevation represents an increase in the gravitational potential energy, W (kilowatts per hour), of the water:

$$W = \frac{\rho V \Delta z}{3.6E^6}$$

where ρ is the density of water (1000 kg/m^3), V is the volume of water (cubic meters), *E* is the gravitational constant (9.8 m/s^2), and Δz is the change in elevation (meters). When power is required, the water runs though a hydroturbine to generate electricity. Pumped hydro, where applicable, is cost-effective, but it is usually limited to existing hydro plants, which are geologically selective. An important limiting factor to the use of pumped hydro is degradation of natural habitat. Schienbein adds that when pumped hydro is coupled with wind turbines the number of practical sites is greatly reduced.[40] Therefore, this type of energy storage is typically limited to electric utility operations, and then only under special circumstances.

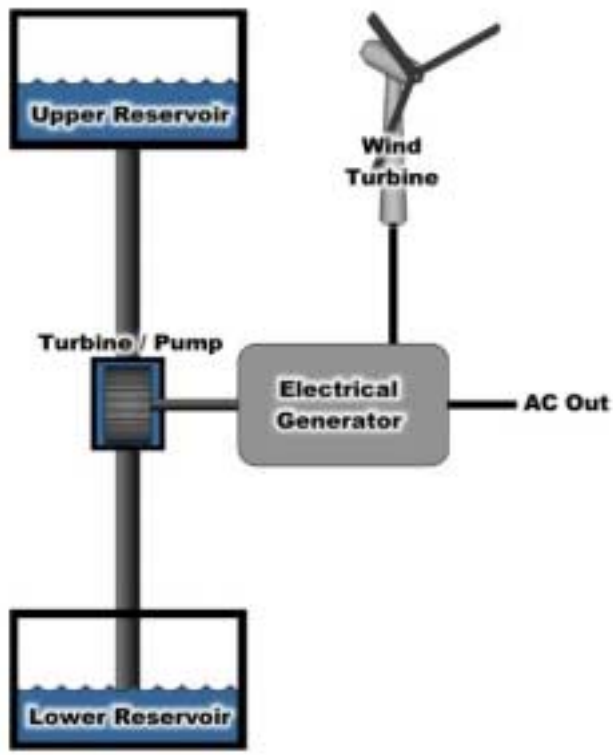


Figure 38: Pumped Hydro Energy Storage

A relatively new concept of pumped hydro employs a lower reservoir buried deep in the ground. Depending on specific site rock formations, the only limiting factor in these systems are the available head from the turbine pump. Often the lower reservoir is buried at depths of 1,000 meters or more.[41]

Currently there are no known examples of hybrid wind-pumped hydro systems. However, one could envision a system that utilized excess power from wind turbines to pump water to an upper reservoir, which can later be discharged when there is a lack of wind resources or an increased peak load.

Compressed Air Energy Storage

Compressed air energy storage (CAES) was originally developed as an energy storage system for combustion turbine systems. Although generally considered inefficient, it may have applications in specific settings. It could be adapted to wind turbines. Rather than directly driving an electric generator, the wind turbine would power an air compressor. During periods of electric demand, the compressed air would be expanded through an air turbine (as opposed to a combustion turbine) that drives an electric generator. During periods of low electric demand and high wind speeds, the compressed air would be diverted to a storage chamber. When the wind is intermittent, this compressed air would be expanded through the air turbine to produce electric power. *Figure 39* shows a schematic of a hybrid wind compressed air energy storage system.

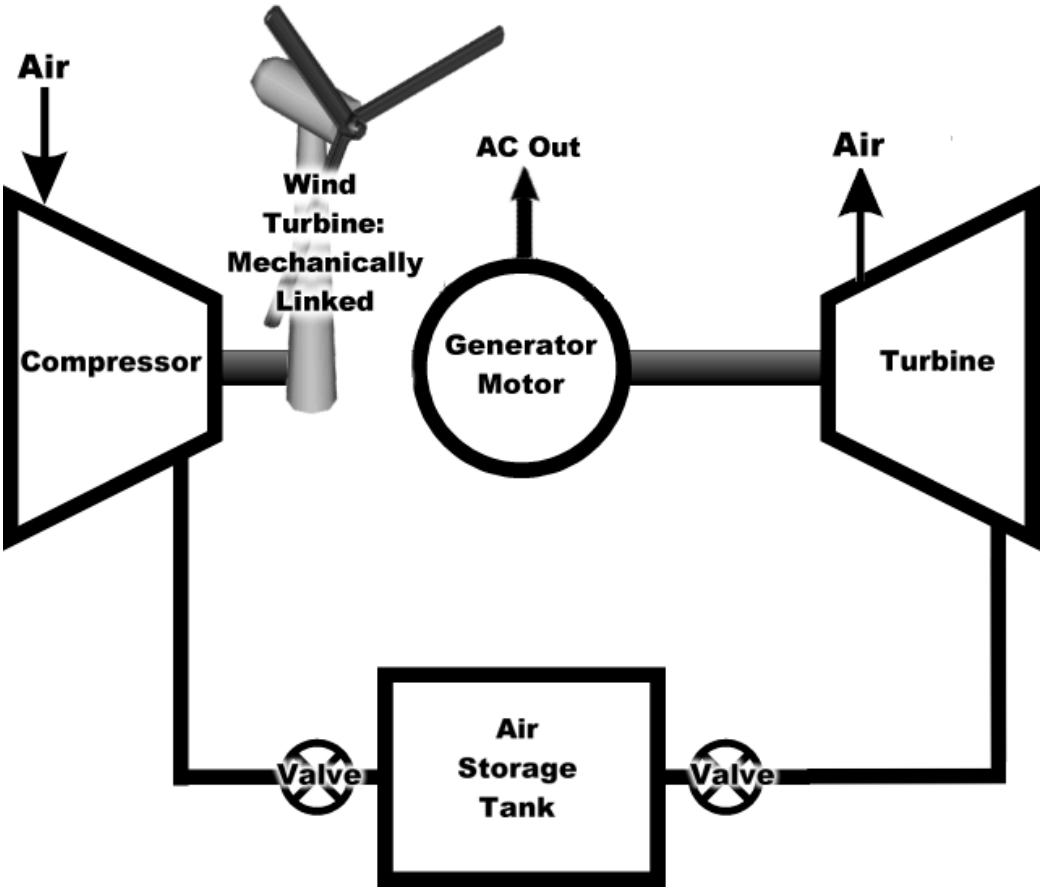


Figure 39: Compressed Air Energy Storage

A typical CAES system uses an underground cavern or chamber to store compressed air due to the large volume of air required. CAES systems using underground caverns are economical, but due to geological restrictions and site requirements CAES may be better suited for larger applications.[42] Some of these costs are associated with pre-feasibility tests and the cost of underground excavation. Detailed studies of underground storage caverns are essential before excavation and are very expensive.

Emerging Technologies: Fuel Cells

Emerging technologies are still undergoing extensive technological and production development. Interestingly, many of these technologies were first invented some time ago. Hydrogen-oxygen fuel cells were first invented by W.R Grove in 1839. However, most of the technological advances have been within the past few decades. Fuel cells convert chemical energy directly into electricity without combustion. They utilize the electrochemical reaction of hydrogen and oxygen atoms to release electrons with water as a by-product. They are similar to batteries except that they are continuously supplied with fuel so they never become discharged.[43] The operation of a fuel cell with fuel processor is illustrated schematically in *Figure 40*.

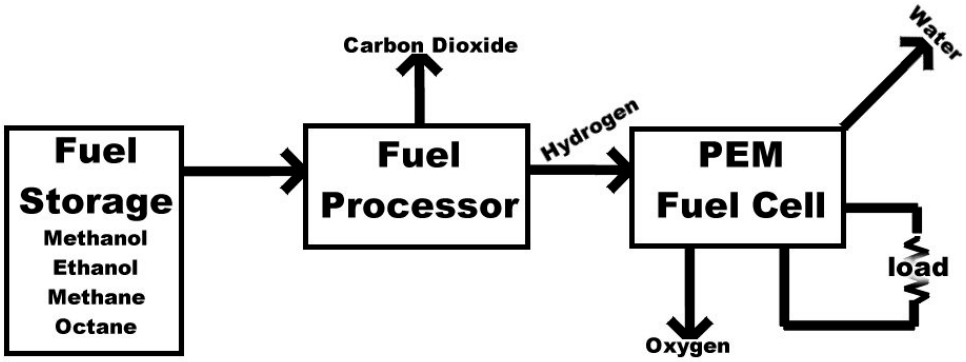


Figure 40: Fuel Cell with fuel processor

Hydrogen gas, the ultimate fuel in all current designs of fuel cells, is separated from the fuel gas by a fuel processor and then enters the fuel cell at the anode while oxygen is admitted at the cathode. The fuel cell consists of two gas-permeable electrodes separated by an electrolyte, which is a transport medium for electrically charged ions. Depending on the fuel cell design, either positively charged hydrogen ions form at the anode or negatively charged ions containing oxygen form at the cathode. The resulting ions migrate through the electrolyte to the opposite electrode from which they are formed. Hydrogen ions migrate to the cathode where they react with oxygen to form water. Oxygen-bearing ions migrate to the anode where they react with hydrogen to form water. Both ionic processes release chemical energy in the form of electrons at the anode, which flow to the cathode through an external electric circuit. The flow of electrons from anode to cathode represents the direct generation of electric power from flameless oxidation of the hydrogen fuel.[44]

Fuel cells are based on the electrochemical reaction of hydrogen and oxygen and the only by-products are water and heat.

Several types of fuel cells have been developed or are under development. These fuel cells are classified according to the kind of electrolyte employed: phosphoric acid, molten carbonate, solid oxide, alkaline, and proton exchange membrane. Despite differences in materials and operating conditions, all these fuel cells are based on the electrochemical reaction of hydrogen and oxygen and the only by-products are water and heat. The molten carbonate and solid oxide fuel cells operate in temperatures of 600-1200°C, which raises safety concerns for residential applications.[45] Alkaline fuel cells require pure oxygen and hydrogen as fuels. Therefore these fuel cells are not very practical for residential applications due to their inflexible conditions and current high costs.

Phosphoric acid fuel cells operate at more moderate temperatures of about 200°C. They do not require pure hydrogen, but operate via fuel processors that break down hydrocarbon fuels into hydrogen and carbon dioxide through chemical processes. The use of a fuel processor allows the fuel cell to burn a variety of hydrocarbons (e.g., methane, gasoline, natural gas, and ethanol). In addition, they are less sensitive to carbon dioxide and other impurities in the fuel stream. These fuel cells may have uses in commercial applications such as hotels or restaurants.[46]

A relatively new type of fuel cell is the Proton Exchange Membrane (PEM) fuel cell. They operate at lower temperatures around 80°C. According to the U.S. Department of Energy, “They are the primary candidates for light-duty vehicles, for buildings, and for much smaller applications such as replacements for rechargeable batteries in video cameras."

PEM Fuel Cells operate at 80 °C and are appropriate for vehicles, buildings, and consumer electronics.

Stationary PEM fuel cells are expected to become commercial somewhere after January 2001 and at least 5 companies claim to have commercial systems ready.[47] A fuel cell with a reformer which separates oxygen and hydrogen can be expected to cost as much as $25,000 for a 5 kW residential system as only prototypes and low volumes of production are available.[48]

However, increase in the cumulative production volume of fuel cells is expected to decrease prices to the target of $1,000 per kilowatt.[49] This will help put stationary fuel cells into many remote off-grid applications.

The following table gives the component cost break down.

Component cost breakdown

Component	Efficiency	Cost
Fuel Processor	79%	40%
Fuel cell sack	57%	27%
Power conditioning	95%	18%
Control	90%	15%
Overall	39%	100%

Being able to use the waste heat from a PEM fuel cell makes it desirable for residential applications.

The waste heat produced by the fuel cell can be harnessed to improve overall efficiency and make them more cost effective. The use of a heat exchanger allows heat to transfer from the fuel cell exhaust to a working fluid, which would most likely be water. Being able to use this waste heat directly from the source makes the PEM fuel cells desirable for residential applications, because it cuts back on heating costs. This would help decrease the pay back time for a fuel cell.

Advantages of fuel cells are that they are expected to be highly reliable because of the absence of moving parts. They also have low environmental impact: water is the only waste stream. If reformed hydrocarbons serve as fuel, carbon dioxide will be a waste product. In this case, fuel cells emit no more CO_2 per kilowatt than central power plants.[50] Use of renewable fuels such as biodiesel or ethanol would make fuel cells greenhouse gas neutral because carbon dioxide is removed from the atmosphere by the crop used to produce the biofuel.

Fuel cells are expected to be highly reliable and have a life of 15-20 years.

Expected life spans range from 15-20 years with minimal maintenance. Hydrogen safety is an issue, although hydrogen quickly disperses into the environment, making it less of a fire hazard than gasoline.[51] Disadvantages include the high cost of fuel cells, although costs are expected to decline as fuel cells are mass-produced.

Fuel cells should be sized to meet the average electrical demand of a residence. Occasional peaks are handled through the use of a battery bank. In addition, a fuel cell can be coupled with other renewable systems to make a system able to handle daily peaks. Excess energy from wind or solar could be coupled to an electrolyzer, which splits water into hydrogen and oxygen. The oxygen is released into the atmosphere and the hydrogen is stored in a compressed tank.

Excess energy from a wind turbine or solar panel could be used to electrolyze water to create hydrogen for a fuel cell.

Using an electrolyzer would eliminate the need for a reformer and therefore reduce greenhouse gas emissions. This type of system is referred to as a regenerative fuel cell, and a schematic can be seen in the *Figure 41* given below.

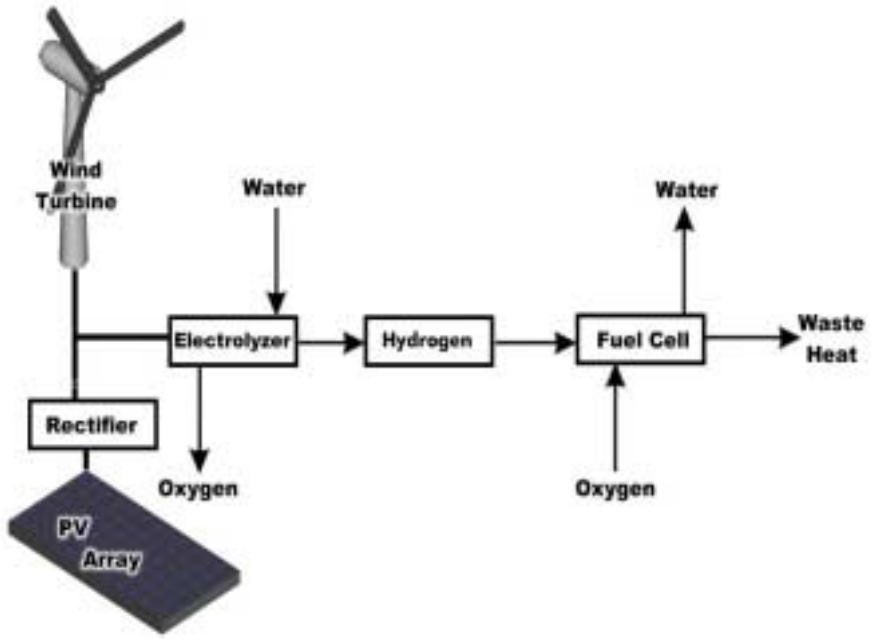


Figure 41: Regenerative Fuel Cell

The auto industry is investing over a billion dollars on fuel cell development. The auto industry needs to bring costs down to about $25 per kW for the fuel cell stack to be competitive with the internal combustion engine. The U.S. auto industry's goal is $25-$35 per kW for an 80 kW stack for a car by 2005. Fuel cell commercialization will likely occur sooner for the higher value market for residential and military markets.

The auto industry is investing over a billion dollars on fuel cell development.

In a November/December 1998 article in *Home Power*, two companies expect their residential fuel cells to cost $3,000 to $5,000 plus installation. The units will be about 3 kW in size. Total delivered cost will be 7¢ per kWh with gas at $3.25/MMBTU. One company combines a 3 kW fuel cell with batteries for providing peaking power up to 10 kW. The target price is $5,000 installed. As of this writing, none of these promises have come to market.

An important advantage of fuel cells is zero or close to zero pollution emissions. However, changing the energy infrastructure of the nation from fossil fuels to hydrogen would take at least a generation to accomplish.[52] The government of Iceland is currently supporting programs to convert the energy system of that nation to hydrogen. This will stimulate important technological development and showcase the technology to other nations.

The use of reformers to convert hydrocarbon fuels to hydrogen is an important stepping-stone to a hydrogen-based economy. Amory Lovins, a well-known energy forecaster and promoter of energy efficiency and renewable energy, suggests that residential production of hydrogen would alleviate the cost of converting the current energy infrastructure of the nation.[53] The main disadvantage of using this system to electrolyze water is relatively low energy conversion efficiency and currently high cost.[54]

Microturbine Hybrid

The microturbine is a miniature version of a jet engine which entered the market very recently. Air is compressed, fuel is injected and burned in a combustor, and the hot, high-pressure gas is expanded through a turbine to run the compressor and produce electric power. A microturbine usually integrates a compressor, turbine, and an electrical generator on a single shaft. This design limits the moving parts to only the shaft and increases reliability. Air exiting the compressor enters a recuperator that transfers waste heat from the turbine exhaust to the compressed air. Preheating decreases the amount of fuel that must be burned in the combustion temperature to raise the gas temperature to the desired turbine inlet temperature, an important efficiency feature. The hot gases from the combustion chamber drive the turbine blades, which turn the shaft and generate electricity. This process is illustrated in *Figure 42* below.

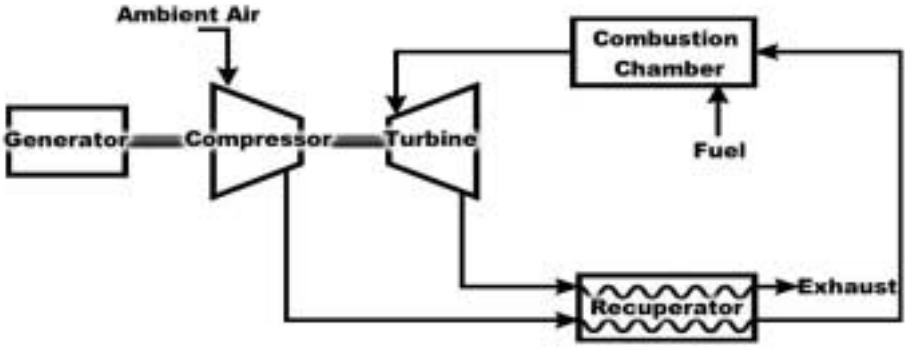


Figure 42: Microturbine schematic

All microturbines include electronics that rectify the high frequency alternating current from the generator to direct current. An inverter converts it back to alternating current at a frequency of 50 or 60 Hz frequency,[55] which is suitable for distribution. According to Rich Sanders of Elliott Inc, the electronics are more likely to fail than the microturbine or recuperator itself.[56] When compared to equally sized diesel gen-sets, microturbines have significantly lower nitrous oxide emissions, higher efficiencies, lower noise, lower maintenance requirements, lighter weight, and can use a variety of fuels.[57] The microturbine's ability to operate on various fuels makes it applicable to various situations and therefore more versatile. The range of fuels includes natural gas, gasoline, diesel fuel, propane, and kerosene.

When burning natural gas in a microturbine, nitrogen oxide emissions are only 0.1-0.5 lb per megawatt-hour compared to 4.0-10.0 lb per megawatt-hour for coal-fired power plants and 0.1-2.0 for a large combustion turbine.[58] Capstone, a leading manufacturer of microturbines, have a 30-kW Turbo-generator that is light weight and targets noise at less than 60 decibels at 10 meters distance from the turbine. Projected efficiencies for future machines range from 25-30%.[59] This is a reasonable efficiency for a small machine. By comparison, its efficiency is less than that of a fuel cell but better than a steam engine.

A 25kW microturbine would be able to supply continuous electricity to 10-12 homes.

Microturbines entered the market about 1998. Some of the major manufacturers are Honeywell, Elliott, and Capstone. Typical sizes of microturbines range from 25-300 kilowatts. Generally, microturbines are manufactured with commercial applications in mind, but a 25-kilowatt system would be able to supply continuous electricity to 10-12 homes, assuming 2-kilowatt consumption per house. This would be ideal for a small community that was isolated from a utility grid.

Typical installation costs of microturbine systems range from $450-700 per kilowatt.[60] This is currently an expensive alternative to diesel gen-sets. However, the benefits and anticipated rapid declines in price as mass production begins should be weighed in the consideration.

A microturbine could be run on a biofuel and provide renewable backup to a wind turbine.

Even though microturbines are designed to continuously supply power to homes and farms, they may merit consideration for hybrid wind energy systems as well. The microturbine can be run on biodiesel or ethanol as a completely renewable energy option for backup power. The cost of energy from the wind turbine would be much less than the microturbine and save on fuel and operating costs.

Significantly, the electric power industry frequently uses large gas turbines as part of emergency or peak power capacity. Typical start up times range from 20-120 seconds.[61] A simple battery bank may eliminate transients in power as a system switches from wind to microturbine; however, microturbines were not designed for repeated start and stop cycles.

Companies are trying to modify conventional microturbines to burn lower quality fuels such as biogas and producer gas from anaerobic digestion and gasification, respectively. These fuels cause problems in current microturbines, because microturbines require a very clean gas. Impurities in

the gas stream, which are commonly found in biogas and producer gas can damage turbine blade and reduce the life of the system.

Hydrogen obtained from electrolysis of water using wind turbine electricity could be envisioned as part of an energy storage and recovery system, although this application is probably several years away. The relatively high capital cost of microturbines reduces its attractiveness, though, in applications where it is on stand-by for long periods.

Stirling Engine Hybrid

Robert Stirling patented the first Stirling engine in 1816.[62] However, they have been subject to continual improvement since that time with the addition of modern materials and technology. Stirling engines qualify as 'external' combustion engines because combustion occurs outside the working fluid of the engine (away from the piston), in contrast to internal combustion engines where combustion occurs next to the piston.[63] A cool working fluid is compressed and then expands between a displacer and the piston as shown in *Figure 43*. The working fluid for Stirling engines is typically air, hydrogen, or helium. Stirling engines can employ either burn fuels or use solar, geothermal, or waste heat as its energy source.

One of the simplest versions of this engine is the displacement type Stirling engine, shown in *Figure 43*. This version consists of a displacer, power piston, cylinder, and a regenerator. The displacer and power piston are configured at 90 degrees apart on a crankshaft, which allows power to be delivered to the piston at the expansion stroke.[64] The driving force in Stirling engines is temperature gradient: one end of the cylinder is heated while the other end is cooled. The role of the displacer is to drive the working fluid back and forth between these cold and hot regions. In the process, a regenerator, which is a type of heat exchanger, absorbs heat from the hot gas as it moves from the hot to cold region. This absorbed heat is transferred to the cold gas as it moves from the cold to hot region.[65] This back and forth transport of the working fluid results in pressure differences within the cylinder, causing the power piston to move up and down delivering mechanical energy to a crankshaft. In this type of assembly, the crankshaft would be connected to an alternator that generated alternating current.

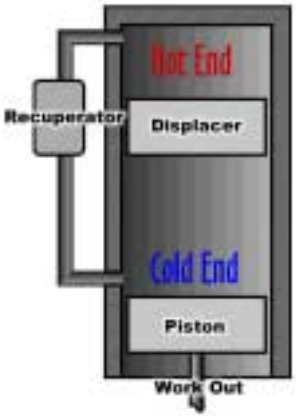


Figure 43: Displacement Stirling Engine

Another type of Stirling engine is the two-piston type. This type operates on the same basic principle as the displacement Stirling engine, but uses a second piston instead of a displacer to move the working fluid from one region to another.

Stirling engines, at 20% efficiency, are slightly more efficient than small internal combustion engines, which rarely exceed 18% efficiency.[66]

Occasionally Stirling engines can achieve 50% of the theoretical efficiency predicted by the Carnot efficiency equation:[67,68]

$$\eta_{Max} = 1 - \frac{T_{Cold}}{T_{Hot}}$$

In principle, Stirling engines have lower pollution emissions than internal combustion engines because external combustion can be more easily controlled. Soot, carbon monoxide, and nitrogen oxides should all be lower than internal combustion engines, although exact performance depends on the details of engine operation.

The reference section on Web Sites lists current manufacturer's of Stirling engines. One burns natural gas and is rated at 25 kilowatts. The cost of this system is $50,000, which represents an expensive option at $2,000 per kilowatt. The company projects that this cost would be drastically reduced if mass production were implemented.

Another manufacturer offers a pair of engines with electrical outputs of 750 watts as either AC or DC power. The DC system is geared towards marine applications, such as battery charging, and is only available in Western Europe. The AC system is designed for remote applications and is only available for trial applications. Refer to their web site below for further details.

A third manufacturer has designed a 1 kW biomass-fueled free-piston Stirling engine. The free-piston engine operates under the same principles as the displacement type engine, but has a linear alternator connected to the rod of the piston instead of a crankshaft. The free-piston engine uses the working fluid as a lubricant, reducing maintenance.[69] The engine has a burner that is suitable for a variety of biomass-derived fuels. The fuel is burned at the heater head of the engine; exhaust gas is routed through an external regenerator that is used to heat incoming combustion air.[70] This 1 kW system is still a prototype and is not available commercially at this time.

In the future, the Stirling engine will undoubtedly be an attractive alternative to diesel engines as a back up power source for a wind turbine. Although Stirling engines are more efficient and less polluting than internal combustion engines, their high capital cost has been a barrier to market entry.

Government Policy and Incentive Support Programs

There are several different programs at the federal and state level that serve as incentives for renewable energy. Some programs give tax incentives. Others help defray utility bills for residential customers and yet others encourage the use of renewable energy sources.

The Million Solar Roofs Initiative to reduce emissions, create high tech jobs and keep the U.S. solar Industry competitive.

On June 26, 1997, in a speech before the United Nations Session on Environment and Development, President Clinton announced the *Million Solar Roofs* initiative to install photovoltaic panels on one million roofs in the United States by the year 2010. Two types of technology are included in the initiative - photovoltaics that produce electricity directly from sunlight, and solar thermal panels that produce heat for domestic hot water, swimming pools and space heaters.

This Million Solar Roofs initiative does not directly pay home or business owners to install the solar systems, but helps to partner the U.S. Department of Energy with the building industry, utilities, energy service providers, the solar energy industry, state and local governments, financial institutions, non-governmental organizations and other federal agencies to meet the program goals. The initiative brings these institutions together with the hopes of developing a strong market for solar energy applications. There are three goals of the Million Solar Roofs Initiative. One, reduce greenhouse gas and other emissions; two, create high tech jobs; and three, keep the U.S. solar energy industry competitive. To reach these goals there is an action plan that includes the following activities: help to establish local markets, enhance financial tools and resources available for solar energy, increase consumer awareness and understanding of solar energy benefits, support research and development, and encourage builders and developers to include solar energy systems in new housing developments.

The Wind Powering America Initiative to have at least 5% of U.S. electricity generation from wind by 2020.

Wind Powering America is another initiative by the federal government to increase the use of renewable energy in the U.S. Wind Powering America sets specific, measurable goals as to the amount of wind energy to be online in the next several years. These goals include: at least 5% of the nation's electricity from wind by 2020, install more that 5000 megawatts by 2005, have more than 10,000 megawatts online by 2010, double the number of states that have more than 20 megawatts of wind capacity to 16 by 2005, and triple the number to 24 by 2010, and increase wind's contribution to federal electricity use to 5% by 2010. These goals are simple and straightforward and will help

the rural economy, as well as reduce air pollution and increase energy security.

Wind energy has many benefits that will be felt here in Iowa. There are enormous wind energy resources in the northwest and north central regions of the state that will be crucial in the development of enough wind energy to meet the goals set forth in the program. Farmers and rural landowners stand to be major winners when wind energy is developed in Iowa. The leases being signed for land to place the turbines on bring in a significant income for the landowner.

A Renewable Porfolio Standard mandates the percentage of electric generation that must come from renewable sources.

A renewable portfolio standard, or RPS, means that the state or federal government requires electric utilities to contain a certain percentage of renewable energy in their fuel mix. The RPS must lay out the percentage as well as what fuel types are considered renewable.

In 1983 Iowa passed the Alternate Energy Production (or AEP) law. This law required the state's investor-owned utilities to purchase 105 megawatts of renewable energy. This is in effect a RPS of about 2%. The utilities' contracts for this renewable power are mainly from wind and biomass sources.

A Systems Benefits Charge allows states to fund energy efficiency, renewable energy, and low-income programs.

A System Benefits Charge (SBC) is a way of funding programs considered to be "benefits" to the "system." This is an item that has been included with deregulation legislation across the country, but can also stand-alone. The programs that have most commonly been included are energy efficiency, renewable energy, and low-income programs. Under the renewables genre programs states have set up funds for research and development, monetary incentives for the use of renewables and subsidies to renewables to make them more cost competitive with fossil fuel plants. Funding is secured through a charge on electric customers' monthly bills through either a per kWh charge or a flat monthly charge, which in most cases is remitted to the states for distribution to the appropriate program. A System Benefits Charge is a widely accepted means to secure funding for these important programs.

The Production Tax Credit provides federal funding to utilities and independent power producers for renewable energy.

The Energy Policy Act of 1982 enacted the Production Tax Credit (PTC) as part of the Internal Revenue Code. Its purpose is to support wind energy development and production and to promote competition between renewable energy and conventional energy sources. A 1.72-cent per kilowatt-hour tax credit is available for all commercial generation by new renewable sources that is sold to a utility. This tax credit enables the industry to compete with traditional generating sources

being sold at lower prices. The PTC has been pivotal in the development and use of renewable energy throughout the U.S. The PTC has been extended by Congress to all projects in commercial operation by December 31, 2001. These projects will be eligible for the tax credit for 10 years. Efforts are underway to extend the deadline for installation of new renewable generation facilities for a few years. Since renewable energy still represents less than one percent of the nation's energy, it has not yet had a chance to achieve the true economies of scale that will allow it to compete on a level playing field with conventional energy sources. This type of federal subsidy has been essential in the development of every new form of energy. Large subsidies have been extended to the fossil fuel industry, for hydroelectric development, and for nuclear power.

Net-metering is a way for small businesses and residences to gain full economic benefit from a renewable installation.

Net-metering is a way of billing residents or businesses that have installed their own renewable energy systems. The customer has one meter, just like any other customer. This meter can run in both directions. If the renewable energy system is producing more power than the customer is using, the meter runs backwards. If the customer is pulling power from the grid, the meter runs forward. At the end of each month the customer pays the difference. If at the end of the month there is a credit there are several options. The utility may pay the customer for the excess power, they may carry the credit to the next month, or the customer may simply give the power to the utility.

Iowa has a very broad net-metering rule, but achieving utility contracts has been difficult. Iowa's net-metering is a policy is currently being considered by the Federal Energy Regulatory Commission as well as the Iowa Supreme Court.

Net-metering is a very important incentive for renewable energy. It gives economic value to intermittent renewable energy no matter when the energy is generated. This usually makes the difference in whether a small-scale installation is economical. School districts, hospitals, farmers, small businesses, and homeowners have taken advantage of this law, and it is a valuable incentive for the future of small-scale intermittent renewable energy.

Iowa Alternative Energy Revolving Loan Program provides low-interest loans for renewable energy systems.

The *Iowa Alternative Energy Revolving Loan Program*, managed by the Iowa Energy Center, provides low-interest loans to Iowans interested in installing a renewable energy system. The program in open to individuals and organizations, with a requirement that the facility must be in the state.

Interested parties submit an application to the Iowa Energy Center, which then reviews and ranks the applications. After the Center qualifies the project, the

lending institution the applicant has chosen financially qualifies the project. After the application is given final approval, a single, low-interest loan consisting of AERLP funds and lender-provided funds is disbursed. The AERLP provides 50% of the total loan up to $250,000.

This is a program which helps people who have an interest in renewable energy, but do not have the funds to invest. It is a great way to promote renewable energy and help the people of Iowa at the same time.

The Iowa Energy Bank finances energy efficiency and wind energy programs for public and non-profit facilities.

The Iowa Energy Bank program targets public and non-profit facilities to finance energy efficiency and wind energy programs. After the initial audit and engineering analysis, full-term, municipal lease-purchase agreements or capital loan notes from private lending institutions are available at interest rates negotiated by the Department of Natural Resources. Many organizations have realized major bottom-line savings. The program is expected to facilitate more than $250 million in improvements using private funds in combination with minimal state and federal support.

Rebuild Iowa assists communities to implement and finance energy efficiency and renewable energy projects.

Rebuild Iowa is for communities in Iowa to identify, implement, and finance energy efficiency and renewable energy improvements. Communities submit proposals to become a Rebuild Iowa Leader. The following support and services are available to participating communities from the Iowa DNR, the U.S. Department of Energy and Rebuild Iowa Partners: training for leaders, staff and volunteers; training for contractors and builders; coordination of financing; management of implementation projects; tracking and monitoring of energy savings; as well as other aspects of the program. The number of Rebuild Iowa communities has been growing each year of the program and it continues to be a great success.

All of these policies will have a dramatic impact on the future of renewable energy in Iowa. Some of these programs are in place and working quite well, while others would need to be added to the Iowa Code by the General Assembly. Iowa's elected officials in the past have been very supportive of renewable power, but time will tell if the policies needed to truly advance the cause of renewable energy are enacted.

Technology Cost Comparison

The purpose of this section is to show the relative cost per kilowatt-hour of the different technologies described in this report. This report focuses on the home and commercial scale units available on the market today. A full hybrid system may also contain a controller that switches between the various generators and storage according to the load requirement. An example of a hybrid system with batteries, generator, wind generator and controller was given at the end of the chapter on solar energy hybrid options.

For combustion generators, the following are the assumptions on fuel costs:

Natural Gas			***Kerosene***	#1 diesel	
Density	0.79	kg/m^3	Density	840	kg/m^3
Heating Value	45000	kJ/kg	Heating Value	43200	kJ/m^3
Cost per energy	**0.0038**	**$/MJ**	**Cost per energy**	**0.0117**	**$/MJ**
Fuel Cost	$0.13	/m^3	Fuel Cost	$425.31	/m^3
Propane (Liquid)			***Diesel***	#2 diesel	
Density	500	kg/m^3	Density	880	kg/m^3
Heating Value	46357	kJ/kg	Heating Value	42800	kJ/kg
Cost per energy	**0.0193**	**$/MJ**	**Cost per energy**	**0.0119**	**$/MJ**
Fuel Cost	$446.45	/m^3	Fuel Cost	$446.45	/m^3
Gasoline			***Biodiesel***		
Density	720	kg/m^3	Density	875	kg/m^3
Heating Value	44000	kJ/kg	Heating Value	37200	J/kg
Cost per energy	**0.0108**	**$/MJ**	**Cost per energy**	**0.0203**	**$/MJ**
Fuel Cost	$343.42	/m^3	Fuel Cost	$660.43	/m^3
Switchgrass			***Corn Stover***		
Yield	3628.74	kg/acre	Yield	1817.36	kg/acre
Bulk density	130	kg/m^3	Bulk density	130	kg/m^3
Heating Value	18004.61	kJ/kg	Heating Value	17444.00	kJ/kg
Cost per energy	**0.0031**	**$/MJ**	**Cost per energy**	**0.0047**	**$/MJ**
Fuel Cost	$201.94	/acre	Fuel Cost	$150.00	/acre

When considering the wind turbine for the system, the price per kilowatt drops considerably as the size of the turbine increases. In today's market, small turbines are available in sizes such as 500 watts, 1,000 watts, 3,000 watts, 10 kilowatts, 20 kilowatts and 50 kilowatts. The price per kilowatt of these turbines with the necessary tower and transformation is at least $1,500 per kilowatt. Large turbines range in size from 600 kilowatts to 2.5 megawatts. When installed in a wind farm, they achieve economies of scale bringing the price down to $850 to $1,250 per kilowatt. Large turbines are usually more efficient as well.

Below are five steps to evaluating the cost benefit of a wind hybrid system and its components. These steps may be followed sequentially or the reader may wish to skip to the information of interest.

Step One - Determine Energy Needs and Current Costs.

Here, the reader should detemine the amount of energy that is typically used or desired from the wind hybrid system. By looking at utility bills, the cost being currently paid for electricity should be recorded. This information will be carried forward to the subsequent steps for comparative analysis.

a. Average Annual Electric Usage in kilowatt-hours
b. Average Annual Cost of Electricty
c. Average Cost per kWh (divide b by a)

Step Two - Determine Wind Resources Output.

The Iowa Energy Center website: www.energy.iastate.edu/wind/calc.cfm provides the ability to look up the location of the proposed wind turbine site and then to select a turbine size and tower height appropriate for the site and energy requirement. The result is a calculation of the proposed turbine's monthly and annual energy output along with the average wind speeds and turbine capacity factor (a measure of the turbine's efficiency).

Step Three - Cost Comparison of Wind/Hybrid Components.

The third step is to integrate the information in the first two steps and add hybrid components (other energy sources or energy storage) to the system. Using the chart below or logging onto the hybrid cost comparison calculator website of the Iowa Department of Natural Resources: http://www.wuebdesign.com/energy/pubs/whea/analysis/index.htm. This web site allows the user to compare kilowatt-hour price for different hybrid componentsr. The Capacity Factor and Wind Turbine size determined from step two are entered here. An opportunity is provided to adjust the default fuel costs if using a generator or biomass with fuel locally available. The result is a cost per kWh for each component and the system as a whole. These costs are for comparison sake only. They only include equipment purchase and fuel costs.They do not include installation, operation, maintenance, warranty or "life-cycle" costs.

If the hybrid system includes solar photovoltaics, refer to the following web site for more information on the energy output characteristics of photovoltaics at a chosen site in Iowa. http://www.energy.iastate.edu/solarcalculator/index.

Large Wind Turbine	
Fuel Cost	
Average Capacity Factor	30.00%
Rated Power Output	900 kW
Fuel Conversion Efficiency	na
Fuel Consumption	0 MJ/kW
Fuel Cost per Energy	$0.00000 /MJ
Annual Fuel cost	***$0 /year***
Cost of Capital	
Rated Capacity	900 kW
Est. price per kW	$1,000 /kW
Period of Loan	15 Years
Amount of Loan	$900,000
Interest Rate of Loan (Annual)	10.00%
Amt. paid over life of loan	$1,774,896
Payments per year	***$118,326 /year***
TOTAL	**$118,326 /year**
Cost per kilowatt-hour	***$0.050 $/kWh***
kWh produced annually	***2,365,200 kWh***

Small Wind Turbine	
Fuel Cost	
Average Capacity Factor	25.00%
Power Output	20 kW
Efficiency	na
Fuel Consumption	0 MJ/kW
Fuel Cost per Energy	$0.00000 /MJ
Annual Fuel cost	***$0 /year***
Cost of Capital	
# of kilowatts (nameplate)	20 kW
Est. price per kW	$1,500 /kW
Period of Loan	8 Years
Amount of Loan	$30,000
Interest Rate of Loan (Annual)	10.00%
Amt. paid over life of loan	$44,987
Payments per year	***$5,623 /year***
TOTAL	**$5,623 /year**
Cost per kilowatt-hour	***$0.128 $/kWh***
kWh produced annually	***43,800 kWh***

Wind "Capacity Factor" refers to the average percentage of the turbine's rated capacity that the turbine achieves in Iowa winds. A definition of the terms used in the analysis of the different generators follows.

	Definitions
Fuel Cost	
Percent of Time in Operation	*Capacity required to offset wind capacity factor*
Rated Power Output	*Maximum output available on typical sized unit.*
Fuel Conversion Efficiency	*Efficiency of converting fuel to energy*
Fuel Consumption	*Fuel consumed to produce one kilowatt*
Fuel Cost per Energy	*Fuel cost of type of fuel required*
Annual Fuel cost	*Total fuel cost for the period*
Cost of Capital	
Average Capacity Factor	*Average percent of rated capacity delivered (net)*
Rated Capacity	*Rated maximum power output of unit*
Est. price per kW	*Cost to produce one kilowatt*
Period of Loan	*Length of loan financing*
Amount of Loan	*Average purchase cost of unit*
Interest Rate of Loan (Annual)	*Loan interest rate*
Amt. paid over life of loan	*Cumulative payment at loan completion*
Payments per year	*Payment for the period*
TOTAL	*Total for the period*
Cost per kilowatt-hour	*Cost per kilowatt hour*
Total kWh/year	*Total kilowatt hours delivered per year*

Diesel Engine

Fuel Cost	
Percent of Time in Operation	75%
Rated Power Output	25 kW
Fuel Conversion Efficiency	25%
Fuel Consumption	100 MJ/kW
Fuel Cost per Energy	$0.01185 /MJ
Annual Fuel cost	***$28,036 /year***

Cost of Capital	
Rated Capacity	25 kW
Est. price per kW	$500 /kW
Period of Loan	8 Years
Amount of Loan	$12,500
Interest Rate of Loan (Annual)	10.00%
Amt. paid over life of loan	$18,744
Payments per year	***$2,343 /year***
TOTAL	**$30,379 /year**
Cost per kilowatt-hour	***$0.185 $/kWh***
kWh produced annually	***164,250 kWh***

Microturbine

Fuel Cost	
Percent of Time in Operation	75.00%
Rated Power Output	25 kW
Fuel Conversion Efficiency	25.00%
Fuel Consumption	100 MJ/kW
Fuel Cost per Energy	$0.00379 /MJ
Annual Fuel cost	***$8,962 /year***

Cost of Capital	
Rated Capacity	25 kW
Est. price per kW	$700 /kW
Period of Loan	8 Years
Amount of Loan	$17,500
Interest Rate of Loan (Annual)	10.00%
Amt. paid over life of loan	$26,242
Payments per year	***$3,280 /year***
TOTAL	**$12,242 /year**
Cost per kilowatt-hour	***$0.075 $/kWh***
kWh produced annually	***164,250 kWh***

Submersible Generator

Fuel Cost	
Percent of Time in Operation	75.00%
Power Output	0.5 kW
Efficiency	na
Fuel Consumption	0 MJ/kW
Fuel Cost per Energy	$0.00 /MJ
Annual Fuel cost	***$0.00 /year***

Cost of Capital	
Rated Capacity	0.5 kW
Est. price per kW	$13,000 /kW
Period of Loan	8 Years
Amount of Loan	$6,500
Interest Rate of Loan (Annual)	10.00%
Amt. paid over life of loan	$9,747
Payments per year	***$1,218 /year***
TOTAL	**$1,218 /year**
Cost per kilowatt-hour	***$0.371 $/kWh***
kWh produced annually	***3,285 kWh***

Hydroturbine (micro)

Fuel Cost	
Percent of Time in Operation	75.00%
Rated Power Output	1.4 kW
Fuel Conversion Efficiency	na
Fuel Consumption	0 MJ/kW
Fuel Cost per Energy	$0.00 /MJ
Annual Fuel cost	***$0.00 /year***

Cost of Capital	
Rated Capacity	1.4 kW
Est. price per kW	$6,071 /kW
Period of Loan	8 Years
Amount of Loan	$8,499
Interest Rate of Loan (Annual)	10.00%
Amt. paid over life of loan	$12,745
Payments per year	***$1,593 /year***
TOTAL	**$1,593 /year**
Cost per kilowatt-hour	***$0.173 $/kWh***
kWh produced annually	***9,198 kWh***

Stirling Engine

Fuel Cost	
Percent of Time in Operation	75.00%
Rated Power Output	1 kW
Fuel Conversion Efficiency	25.00%
Fuel Consumption	4 MJ/kW
Fuel Cost per Energy	$0.00379 /MJ
Annual Fuel cost	***$358 /year***

Cost of Capital	
Rated Capacity	1 kW
Est. price per kW	$6,000 /kW
Period of Loan	8 Years
Amount of Loan	$6,000
Interest Rate of Loan (Annual)	10.00%
Amt. paid over life of loan	$8,997
Payments per year	***$1,125 /year***
TOTAL	**$1,483 /year**
Cost per kilowatt-hour	***$0.226 $/kW-h***
kWh produced annually	***6,570 kWh***

Fuel Cell

Fuel Cost	
Percent of Time in Operation	75.00%
Power Output	5 kW
Efficiency	35.00%
Fuel Consumption	14.28571 MJ/kW
Fuel Cost per Energy	$0.05451 /MJ
Annual Fuel cost	***$18,418 /year***

Cost of Capital	
Rated Capacity	5 kW
Est. price per kW	$5,000 /kW
Period of Loan	8 Years
Amount of Loan	$25,000
Interest Rate of Loan (Annual)	10.00%
Amt. paid over life of loan	$37,489
Payments per year	***$4,686 /year***
***TOTAL**	**$23,104 /year**
Cost per kilowatt-hour	***$0.703 $/kW-h***
kWh produced annually	***32,850 kWh***

Solar Panel

Fuel Cost	
Average Capacity Factor	35.00%
Power Output	1 kW
Efficiency	60.00%
Fuel Consumption	0 MJ/kW
Fuel Cost per Energy	$0.00000 /MJ
Annual Fuel cost	***$0 /year***

Cost of Capital	
Rated Capacity	1 kW
Est. price per kW	$6,000 /kW
Period of Loan	8 Years
Amount of Loan	$6,000
Interest Rate of Loan (Annual)	10.00%
Amt. paid over life of loan	$8,997
Payments per year	***$1,125 /year***
TOTAL	**$1,125 /year**
Cost per kilowatt-hour	***$0.367 $/kWh***
kWh produced annually	***3,066 kWh***

Gasifier

Fuel Cost	
Percent of Time in Operation	75.00%
Rated Power Output	80 kW
Fuel Conversion Efficiency	25.00%
Fuel Consumption	320 MJ/kW
Fuel Cost per Energy	$0.00473 /MJ
Annual Fuel cost	***$35,811 /year***

Cost of Capital	
Rated Capacity	20 kW
Est. price per kW	$1,300 /kW
Period of Loan	8 Years
Amount of Loan	$26,000
Interest Rate of Loan (Annual)	10.00%
Amt. paid over life of loan	$38,988
Payments per year	***$4,874 /year***
TOTAL	**$40,685 /year**
Cost per kilowatt-hour	***$0.077 $/kWh***
kWh produced annually	***525,600 kWh***

Step Four - Design a Wind Hybrid System.

There are two programs that in give greater detail the cost analysis of a wind hybrid system. Both programs were funded through the National Renewable Energy Laboratories.

The first is the http://www.clean-power.com/iec/. This program was developed specifically for Iowa and incorporates most Iowa utility rates into the calculation. It allows for selection of a number of components and delivers the payment schedule and cost per kilowatt-hour.

The second is http://www.ecs.umass.edu/mie/labs/rerl/hy2/intro.htm. This is a very good and in-depth program for analyzing wind hybrid systems with multiple components. A demo version of the program can be downloaded from the web site information provided.

An excellent example of a wind hybrid demonstration project in the Buffalo Ridge area of northwest Iowa was funded by Alternative Energy Revolving Loan Program. The installation uses a Bergey 10-kilowatt wind turbine on a 100-foot tower, about 2,000 watts of solar panels, a steam biomass engine, 48 deep-cycle batteries and necessary system controllers. The entire system cost about $72,000 and is designed to generate the 25,700 kilowatt hours per year used by this farm residence and office. The costs of the components are consistent with the costs detailed above. The loan will be paid down in 8 years, but the entire system is not planned to pay for itself for 30 years. It is not strictly economical compared to buying energy from the utility, but it demonstrates the functionality of the hybrid approach. More information on this and other hybrid demonstration projects in Iowa is available through the Iowa Energy Center.

Conclusion

This report identifies many wind hybrid technologies and analyzes their relative cost per kilowatt-hour. Markets for wind hybrid applications are related to these costs. The following conclusions are based on the findings in the previous section and mentioned in the chapters of this report.

When considering wind energy, a utility will compare it to the cost of energy from other generation sources. Energy from the best existing large hydroelectric facilities costs Iowa utilities under one cent per kilowatt-hour. From the most efficient coal-fired generators, utilities' avoided fuel costs are under two cents per kilowatt-hour. These prices are below the best price that wind energy can achieve today in Iowa. However, there are no untapped resources for building new, large, low-cost hydroelectric facilities. Also, strict emissions standards have increased the risk and cost of building new coal-fired facilities. Similarly, no new nuclear facilities are planned, and existing facilities are scheduled for decommissioning.

Most new power generation is planned using natural gas generators and diesel peaking units. But natural gas prices have been very unstable and high. With the production tax credit, wind energy is less expensive than the avoided fuel costs for natural gas and diesel generators today. On this basis, there is increasing demand for wind energy even though it is intermittent (non-dispatchable) and has a lower reliability (capacity credit) than a combustion or hydro power plant. There are companies today which are able to forecast the hourly average energy output of a wind farm up to 48-hours in advance with an accuracy of plus or minus 40 percent. These forecasts may improve the capacity credit for a wind farm.

Wind hybrid solutions have system benefits of providing a higher percentage of power on-demand and therefore have a higher capacity credit, but are much more expensive than wind alone.

The viability of residential-scale wind hybrid systems is dependent on the location of the facility being near good wind resources. Wind energy is more abundant in the northwest portion of the state. Solar energy is higher in the southwest and central part of the state. The opportunity for hydro is better in the central and eastern parts of the state.

On the residential scale, if storage is required, a deep cycle lead-acid battery bank is still the most cost effective solution. Introducing batteries usually significantly increases average system losses because of the need to maintain a 50% charge and not overcharge the batteries. At times when the load is enough to absorb all energy being produced, the only losses are inverter and line losses. When using a backup generator, the cost at the current time is

much lower using gasoline or diesel fuel rather than a biofuel. However, farms with the opportunity to capture methane from manure may find biogas an important alternative.

There is also promise from lowering solar cell costs, more efficient conversion systems for biofuels, and emerging fuel cell technology. Emerging technologies have the greatest promise but, at this time, the highest cost and the least field-testing.

Solar energy, biofuels, and hydrogen fuel cells are all complementary to wind energy. Biofuels provide the ability to generate power on demand when the wind energy is not available. Hydrogen fuel cells have the potential to utilize hydrogen formed by electrolysis from a wind turbine when it is producing power in excess of demand. Solar panels can produce power during hot peak energy days in the summer when the winds are low.

Wind turbines together with fuel cells or biofueled engines and battery banks can provide renewable energy on demand. The technology exists for efficient fully renewable energy systems. The only question then is of cost compared to grid-interconnected conventional energy. Economies of scale will reduce manufacturing costs of renewable technologies significantly. At the same time, escalation in fuel costs will raise the cost of energy for conventional technologies. At some point it is anticipated that the costs will intersect and we will see large growth in renewable implementation.

For the vast majority of residential or commercial energy users today, grid interconnected power will be less expensive and far easier than a renewable energy system. But with increased demand, government incentives, and technological advances, this may soon change. For utility-scale generation, wind energy is already very competitive with natural gas and diesel generators. With the Production Tax Credit, wind electricity is being offered to utilities in Iowa at less than three cents per kilowatt-hour on a fixed price basis for 20 years.

Environmental and economic demands provide good reason for government support of the developmental stage of renewable energy. Government incentives such as the Production Tax Credit, Million Solar Roofs Initiative, Wind Powering America, and the Energy Bank Program form important support for ushering in the new technologies. With that support, economies of scale in manufacturing, and technological development, many of the wind and wind hybrid options discussed in this paper will become increasingly financially competitive. The U.S. Department of Energy, the Iowa Department of Natural Resources, the Iowa Energy Center, the Iowa Renewable Energy Association, Iowa Citizen Action Network and other advocacy groups are actively pursuing bringing about greater reliance on clean renewable energy. Our renewable energy future is only a matter of public commitment and time.

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Web Links and Technology Information Sources

Wind Turbine Manufacturers:

Atlantic Orient Corporation

Farrell Farm Road, RTE 5N
P.O. Box 1097
Norwich, Vermont 05055
(802) 649-5446 Fax: (802) 649-5404
E-mail: aoc@vermontel.net
Web: www.aocwind.net

Bergey Windpower Company, Inc.

2001 Priestley Avenue
Norman, Oklahoma 73069
(405) 364-4212 Fax: (405) 364-2078
E-mail: sales@bergey.com
Web: www.bergey.com

Dutch Pacific, L.L.C.

3835 R. East Thousand Oaks Blvd. #346
Westlake Village, California 91362
(805) 495-3309 Fax (805) 371-5772
Web: www.dutchpacific.com

Enron Wind Corporation

13000 Jameson Road
P.O. Box 1910
Tehachapi, California 93581
(661) 823-6700 Fax: (661) 822-7880
E-mail: wind@enron.com
Web: www.wind.enron.com

Mitsubishi Heavy Industries America

660 Newport Center Drive
Suite 1000
Newport Beach, California 92660-8028
(714) 640-4664 Fax: (714) 640-6945

NEG Micon USA, Inc.

West Coast Office
19020 North Indian Avenue, Suite 2F
P.O. Box 1160
North Palm Springs, California 92258-1160
(760) 251-5461 Fax: (760) 251-5460

Midwest Office and Manufacturing Facility
301 E. Mercury Drive
Champaign, IL 61822
(217) 363-2366 Fax: (217) 363-2361
Contact: Mark Eilers

Nordex USA, Inc.

BORSIG ENERGY
Sales/Management Office
Carrier/ 360 Office Building
2080 N. Highway 360, Suite 140
Grand Prairie, TX 75050
(972) 660-8888 Fax: (972) 660-2220
Web: www.nordexusa.com

Northern Power Systems

PO Box 999
One North Wind Road
Waitsfield, VT 05673-0999
(802) 496-2955 Fax (802) 496-2953

Southwest Windpower

P.O. Box 2190
2131 N. First Street
Flagstaff, Arizona 86003-2190
(520) 779-9463 Fax (520) 779-1485
E-mail: info@windenergy.com
Web: http://www.windenergy.com

Vestas-American Wind Technology, Inc.

P.O. Box 278
19020 N. Indian Avenue, Suite 4C
North Palm Springs, California 92258-0278
(760) 329-5400 Fax: (760) 329-5558

The Wind Turbine Company

515 116th Avenue, NE, Suite 263
Bellevue, Washington 98004
(425) 637-1470 Fax: (425) 637-1483
Web: www.windturbinecompany.com

Wind Turbine Industries Corporation

16801 Industrial Circle, S.E.
Prior Lake, MN 55372
(612) 447-6064 Fax: (612) 447-6050
E-mail: wtic@windturbine.net
Web: www.windturbine.net

Government, Industry, and Renewable Energy Web Sites:

Government and Non-Profit Organizations

National Renewable Energy Laboratories: www.nrel.gov

National Wind Technology Center: www.nrel.gov/wind/index.html

U.S. Department of Energy: www.eren.doe.gov

Iowa Energy Center: www.energy.iastate.edu

Iowa Department of Natural Resources: www.state.ia.us/government/dnr/

Renewable Energy Policy Project: www.repp.org

Izaak Walton League of America: www.iwla.org/

Sandia National Laboratories: www.sandia.gov/

Wind Energy

American Wind Energy Association: www.awea.org

Solar Energy

Solar Energy Laboratory: http://sel.me.wisc.edu

Solar Energy Industries Association: www.seia.org

Biodiesel

National Biodiesel Board: http://www.biodiesel.org

Biodiesel Information Centre: http://www.greenfuels.org/bioindex.html

U.S. Department of Energy's National Biofuels Program: http://www.biofuels.doe.gov

Western Biomass: http://www.westbioenergy.org/March1999/index.htm

Biofuels Information Center: http://www.afdc.nrel.gov

Web Sites on Gasification

Gasification Technologies Council:

http://www.gasification.org/story/story.html

Caddet Renewable Energy: http://www.caddet-re.org/

Web Sites on Anaerobic Digestion

American Bioenergy Association: http://www.biomass.org/sites-andig.htm

AgSTAR: http://www.epa.gov/agstar/

Micro-Hydroelectric

U.S. Department of Energy Study:

http://www.eren.doe.gov/consumerinfo/refbriefs/ab2.html

Energy Systems and Design (Low Head Micro-Turbines):

http://www.microhydropower.com

Oasis Montana Inc. (Aquair Submersible hydro generator):

http://www.oasismontana.com/AQUAIR.html

Canyon Industries Inc. (Measuring Head and Flows):

http://www.geocities.com/~canyon5

Independent Power & Light (cost break down micro-hydro):

http://www.independent-power.com/small_hydro1.html

http://www.independent-power.com/Harris1-6.htm

http://www.independent-power.com/microhydro1.html

Battery Storage Systems

Northern Arizona Wind & Sun, Inc:

http://windsun.com/Batteries/Deep_Cycle.htm

Backwoods Solar Electric Systems: http://www.backwoodssolar.com

Independent Power & Light : http://www.independent-power.com/medium_system.htm

Go Solar Company (Battery distributor):

http://www.solarexpert.com/Catbattery.html

Pumped Hydro:

Integrative Science: Renewable Energy:
http://community.hei.com/altenergy/hydro.pshydro.html
Pumped Storage Hydro Station:
http://193.86.119.10/elektrarny_en/vodni/dlouhe_strane/html/ke_dlouhe_strane.htm

Web sites on Flywheels

Regenerative Power and Motion: http://rpm2.8k.com/homepage.htm

Fuel Cells

Fuel Cells 2000: http://216.51.18.233/index_e.html
U.S. Department of Energy, Fuel Cells and Transportation:
http://www.ott.doe.gov/oaat/fuelcell.html
Department of Defense Fuel Cell Web Links:
http://dodfuelcell.com/helpfulsites.html
Mother Earth News:
http://www.motherearthnews.com/altenergy/altenergy176.cells.middle.html
Hydrogen Fuel Cell Program: http://www.dri.edu/Projects/Energy/
Energy Partners: http://www.energypartners.org/product.htm

Microturbines

Gas Research Institute: http://www.gri.org/cgi-bin/re?url=http%3A//www.gri.org/pub/content/jan/20000117/143950/micro_4.html
Modern Power Systems:
http://www.capstoneturbine.com/press/Power899.htm
Global Gas Turbine News: http://asme.org/igti/ggtn/archives.html
Electrical Generating System Association:
http://www.egsa.org/powrline/nd98/98nd_micro.htm

Stirling Engines

Sunpower Inc.: http://www.sunpower.com/

American Stirling Company: http://www.stirlingengine.com/

Whisper Tech Ltd.: http://www.whispertech.co.nz/

Stirling Engine Web Site:

http://www.bekkoame.ne.jp/~khirata/english/howwork.htm

Stirling Thermal Motors: http://www.stmcorporation.com/

Government Incentives

U.S. Department of Energy Million Solar Roofs Program:

www.eren.doe.gov/millionroofs

Wind Powering America Initiative:

www.eren.doe.gov/windpoweringamerica

Iowa Alternative Energy Revolving Loan Program:

www.energy.iastate.edu/about/grantloan/AERLP

http://www.energy.iastate.edu/renewable/AssistDev.html

Iowa Energy Bank: www.state.ia.us/dnr/energy/programs

Rebuild Iowa: www.state.ia.us/dnr/energy/programs

References

[1], Izaak Walton League of America, *Landowner's Guide to Wind Energy in the Upper Midwest* (1995).

[2] Christopher Flavin and Nicholas Lenssen, *Power Surge, Guide to the Coming Energy Revolution* (World Watch Institute, 1994).

[3] Union of Concerned Scientists, *Powering the Midwest* (1993).

[4] E. Ian Baring-Gould, *Handbook on Hybrid Power Systems* (National Renewable Energy Laboratories, March, 1998).

[5] Hubert Stassen, *Small-Scale Biomass Gasifiers for Heat and Power: A Global Review* (World Bank Technical Paper, No. 296, Energy Series, 1995).

[6] Charles Ross, *Handbook of Biogas Utilization, 2nd Edition*, (U.S. Department of Energy, July, 1996).

[7] Associated Consultants Engineers, Inc., *Report on the Feasibility of a Biomass Burning Plant for Waverly Light and Power* (Project no. 93765., 1994).

[8] Ibid.

[9] Joshua Tickell, *How to Make Biodiesel Fuel from Vegetable Oil* (Midwest Renewable Energy Fair 2000 Workshop).

[10] Ibid.

[11] West Bioenergy, *Biodiesel Sources* (http://www.westbioenergy.org/March1999/index.htm).

[12] Robert Brown, *The Potential for Biomass and Conversion in Iowa* (Iowa Energy Center Report, 1994), pp. 220-241.

[13] P. Quaak, H. Knoef, and H. Stassen, *Energy from Biomass:A Review of Combustion and Gasification Technologies* (1999).

[14] David Walden, Personal communication (May 2000).

[15] T.B. Reed and S. Gaur, *A Survey of Biomass Gasification 2000: Gasifier Projects and Manufacturers Around the World* (NREL, 1999).

[16] Brown, pp. 236.

[17] J.K. Cliburn and Associates, *Biogas Energy Systems: A Great Lakes Casebook*. (Great Lakes Regional Biomass Energy Program, Council of Great Lakes Governors, 1993).

[18] Wisconsin Energy Bureau, *Turning Manure to Energy on Farms: Renewable Energy Fact Sheet*.

[19] Alison Kovac, *2000 Methane Recovery Project Summary Sheet* (Iowa Department of Natural Resources).

[20] Richard Perez, Bruce Baily, Kurt Eischolz, and Art Peterson, Jr., *Energy Flow and Reliability Analysis of a Residential PV Hybrid System* (2000).

[21] J. Cowdrey, "Hydro Basics," *Home Power* (Aug/Sept 1994), pp. 34-36.

[22] *Energy Systems and Design: Specifications Sheet* (http://www.microhydropower.com).

[23] Paul Cunningham, Personal communication (July 2000).

[24] Lake Michigan Wind and Sun, *Alternative Energy: 1999 Design Guide and Catalog*, pp. 22.

[25] Paul Cunningham, Personal communication (July 2000).

[26] *Aquair Submersible Generator Specifications Sheet*.

[27] J. O'M. Bockris, *Energy Options: Real Economics and the Solar-Hydrogen System* (1980), pp. 236.
[28] A. Ter-Gazarian, *Energy Storage for Power Systems* (1994), pp. 131-138.
[29] "Batteries and Chargers," *Backwoods Solar Electric Systems 2000*, pp. 90-93.
[30] Northern Arizona Wind and Sun, *All About Deep Cycle Batteries* (http://windsun.com/Batteries/Battery_FAQ.htm).
[31] *Alternative Energy: 1999 Design Guide and Catalog*. Lake Michigan Wind and Sun.
[32] Lake Michigan Wind and Sun, *Alternative Energy: 1999 Design Guide and Catalog*.
[33] Warren Lauzon, Personal communication (July 2000).
[34] Ter-Gazarian
[35] L.A. Schienbein, "Energy Storage and Wind Energy Conversion Systems," *International Journal of Global Energy Issues*, IX (No. 3, 1997), pp. 128-149.
[36] R.N. Headifen, "Flywheel Energy Storage for Wind Turbines," *Proceedings of the 1994 29th International Society of Energy Conversion Engineering Conference*, IV (1994) pp. 1374-1379.
[37] Ter-Gazarian
[38] Schienbein, pp. 128-149.
[39] Ter-Gazarian
[40] Schienbein, pp. 128-149.
[41] Ter-Gazarian
[42] Ibid.
[43] Brown, pp. 251-254.
[44] Robert Brown, Personal communication (May 2000).
[45] "Understanding Fuel Cells," *Home Power*, XXXV (June/ July 1993), pp. 37-40.
[46] "Types of Fuel Cells," *Fuel Cells 2000* (http://216.51.18.233/fctypes.htm).
[47] "Power to the People," *Mother Earth News: Online*, CLXXVI (Oct./Nov. 1999, http://www.motherearthnews.com/altenergy/altenergy176.cells.middle.html).
[48] R. Barlow, "Residential Fuel Cells: Hope or Hype," *Home Power*, LXXII (Aug./Sept. 1999), pp. 20-29.
[49] A. Lovins and B. Williams, *A Vision of a Hydrogen Future* (http://www.unh.edu/ipssr/Balaton/Bulletins/spr99page11.html).
[50] "Power to the People," *Mother Earth News: Online*.
[51] Robert Wills, "Hydrogen Fuel Cells: The Power Source of the '90's," *Home Power*, XXIII (June/July 1991), pp. 16-18.
[52] "Power to the People." *Mother Earth News: Online*.
[53] Lovins and Williams
[54] *Solar Hydrogen Energy Conversion* (http://www.solar-h.com).
[55] Richard Sanders, "What is So Attractive About Microturbines?" *The Electrical Generating Systems Association Powerline Magazine Online (*Nov/Dec 1998, http://www.egsa.org/powrline/nd98/98nd_micro.htm).
[56] Rich Sanders of Elliott, Inc., Personal communication (July 2000).
[57] James Watts, "Microturbines: A New Class of Gas Turbine Engines," *American Society of Mechanical Engineers*, XXXIX (No. 1. 1999, http://asme.org/igti/ggtn/archives.html).

[58] Laurence Zuckerman, "Tiny Turbine: The Next Generator?" *The New York Times*, December 2, 1997.

[59] Gas Research Institute, *Microturbines: Powerful Potential* (October 1999, http://www.gri.org/cgi-bin/re?url=http%3A//www.gri.org/pub/content/jan/20000117/143950/micro_4.html).

[60] Zuckerman

[61] Rich Sanders of Elliott, Inc., Personal communication (July 2000).

[62] *Encarta Encyclopedia Online* (http://encarta.msn.com/index/conciseindex/5B/05BB5000.htm?z=1&pg=2&br=1).

[63] Howard Shapiro, *Fundamentals of Engineering Thermodynamics, 4th Edition* (2000).

[64] American Stirling Company (http://www.stirlingengine.com/disp_a.htm).

[65] Stirling Technology Company (http://www.stirlingtech.com/basics.html).

[66] Neill Lane, "Micro-Biomass Electric Power Generation," *Sunpower, Inc.* (http://www.sunpower.com/tech_papers/pub72/72.html).

[67] Shapiro

[68] American Stirling Company (http://www.stirlingengine.com/disp_a.htm).

[69] Neill Lane, "Stirling Engines for Gas Fired Micro-Cogen and Cooling." *Sunpower, Inc.* (http://www.sunpower.com/tech_papers/pub67/ucogen.html).

[70] Neill Lane, "A Biomass-Fired 1 kW Stirling Engine Generator and Its Applications in South Africa," *Sunpower, Inc.* (http://www.sunpower.com/tech_papers/pub76/isec99.html).