2004 INDIANA RENEWABLE ENERGY RESOURCES STUDY

State Utility Forecasting Group
Purdue University
West Lafayette, Indiana

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Indianapolis, Indiana

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Foreword

This report represents the second annual study of renewable resources in Indiana performed by the State Utility Forecasting Group (SUFG). It was prepared to fulfill SUFG's obligation under Indiana Code 8-1-8.8 (added in 2002) to "conduct an annual study on the use, availability, and economics of using renewable energy resources in Indiana."

The major portion of the report consists of seven sections, each devoted to a specific renewable resource: energy from wind, dedicated crops grown for energy production, organic waste biomass, solar energy, photovoltaic cells, fuel cells, and hydropower from existing dams. The sections are organized according to the following general format:

- Introduction: This section gives an overview of the technology and briefly explains how the technology works.
- Economics of the renewable resource technology: This section covers the capital and operating costs of the technology.
- State of the renewable resource technology nationally: This section reviews the general level of usage of the technology throughout the country and the potential for increased usage.
- Renewable resource technology in Indiana: This section examines the existing and potential future usage for the technology in Indiana in terms of economics and availability of the resource. It also contains incentives currently in place to promote the development of the technology and recommendations that have been made in regards to how to encourage the use of the renewable resource.
- References: This section contains references that can be used for a more detailed examination of the particular renewable resource.

For the most part, there has been little change in the various technologies from last year's report. Usage levels, cost and efficiency data, and incentives available have been updated where new information is available. Any new developments, particularly those within Indiana, have been included.

A more in-depth coverage of the solar and photovoltaics technologies is included in this report as an appendix. This section compares the state of the solar energy conversion industry in the U.S. and Indiana compared to the rest of the world. In addition the section presents some typical performance characteristics of solar energy conversion technologies using a real time online solar laboratory operated by the Department of Mechanical Engineering Technology at Purdue University.

SUFG would like to thank everybody that assisted in the preparation of this document. Special thanks go out to Prof. William Hutzel of Purdue University for sharing his time and expertise on solar energy and photovoltaics.

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1. Energy from Wind

1.1 Introduction

Wind energy, defined by the United States Department of Energy (DOE) as the "process by which the wind is used to generate mechanical power or electricity," is a small but rapidly growing source of electricity. Wind energy is captured with the aid of wind turbines. Modern wind turbines can be classified into one of two different categories [1], illustrated in Figure 1-1:

- Horizontal axis type (traditional windmills)
- Vertical axis type (the "eggbeater" style Darrieus model)

Of the two, the horizontal axis type model is the more popular.

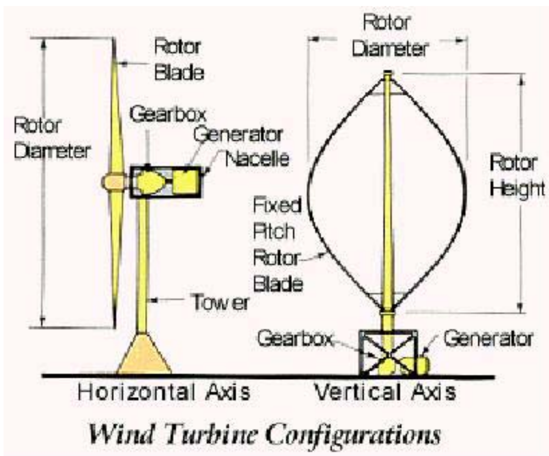
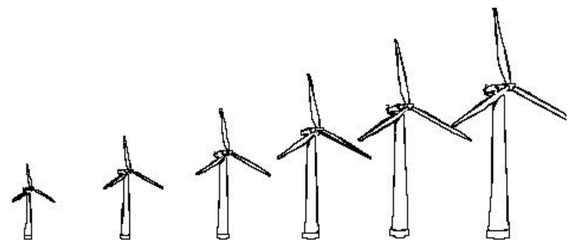


Figure 1-1: Types of wind turbines (Source: American Wind Energy Association)

The physical size and power output of wind turbines has increased dramatically over the past two decades [1], as shown in Figure 1-2. Although the power output of wind turbines has increased over the years, they are still small in comparison with generating units using conventional fuels. Capacity of coal and nuclear generating units can be more than 1000 MW. Wind turbines are usually grouped together to form a single wind power plant or "wind farm" when bulk electricity production is required. Electric power lines are then used to connect the wind farm to the high voltage power grid.



	1981	1985	1990	1996	1999	2000
Rotor (meters)	10	17	27	40	50	71
KW	25	100	225	550	750	1,650
MWh	45	220	550	1,480	2,200	5,600

Figure 1-2: Sizes of wind turbines (Source: American Wind Energy Association)

Wind speeds are important in determining a turbine's performance. Generally, annual average wind speeds of greater than 4 meters per second (m/s) or 9 miles per hour (mph) are required for small electric wind turbines whereas utility-scale wind power plants require a minimum wind speed at an elevation of 50 meters of between 6 to 7 m/s (13-15.7 mph) [2]. The power available in the wind is proportional to the cube of its speed. This implies that a doubling in the wind speed leads to an eight-fold increase in the power output. Wind power density indicates the amount of energy available for conversion by the wind turbine. Sites are classified based on their average annual wind speed and wind power densities. Table 1-1 lists the class distinctions currently used.

The major advantages of wind energy are:

- It is a free and inexhaustible resource;
- It helps diversify the portfolio of resources, thus reducing the potential impacts of events affecting other fuel sources, such as price increases;
- It reduces the reliance on imported fuels;
- It is a modular and scalable technology; and
- It is a source of clean, non-polluting electricity (no emissions or chemical waste).

However, there are some disadvantages of wind energy, namely:

- Wind is an intermittent source of energy (i.e., wind is not always blowing when the energy is needed);
- Good wind sites are usually located far away from load centers which may require additional transmission system construction;
- Wind tower/turbines are subject to high winds and lightning;
- Noise pollution due to blade rotation; and
- Concerns have been raised regarding the death of birds from flying into the turbine blades.

<table>
<tr><th rowspan="2">Wind Power Class</th><th colspan="2">10 m (33 ft) Elevation</th><th colspan="2">50 m (164 ft) Elevation</th></tr>
<tr><th>Wind Power Density (W/m^2)</th><th>Speed m/s (mph)</th><th>Wind Power Density (W/m^2)</th><th>Speed m/s (mph)</th></tr>
<tr><td rowspan="2">1</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td rowspan="2">100</td><td rowspan="2">4.4 (9.8)</td><td rowspan="2">200</td><td rowspan="2">5.6 (12.5)</td></tr>
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<tr><td rowspan="2">150</td><td rowspan="2">5.1 (11.5)</td><td rowspan="2">300</td><td rowspan="2">6.4 (14.3)</td></tr>
<tr><td rowspan="2">3</td></tr>
<tr><td rowspan="2">200</td><td rowspan="2">5.6 (12.5)</td><td rowspan="2">400</td><td rowspan="2">7.0 (15.7)</td></tr>
<tr><td rowspan="2">4</td></tr>
<tr><td rowspan="2">250</td><td rowspan="2">6.0 (13.4)</td><td rowspan="2">500</td><td rowspan="2">7.5 (16.8)</td></tr>
<tr><td rowspan="2">5</td></tr>
<tr><td rowspan="2">300</td><td rowspan="2">6.4 (14.3)</td><td rowspan="2">600</td><td rowspan="2">8.0 (17.9)</td></tr>
<tr><td rowspan="2">6</td></tr>
<tr><td rowspan="2">400</td><td rowspan="2">7.0 (15.7)</td><td rowspan="2">800</td><td rowspan="2">8.8 (19.7)</td></tr>
<tr><td rowspan="2">7</td></tr>
<tr><td>1000</td><td>9.4 (21.1)</td><td>2000</td><td>11.9 (26.6)</td></tr>
</table>

Table 1-1: Wind resource classification (Source: DOE)

1.2 Economics of wind energy

The levelized[1] cost of wind energy has been decreasing over the past twenty years, as shown in Figure 1-3. Currently, state-of-the-art wind farms in high wind areas can generate electricity for between 3 and 4.5 cents/kilowatthour (kWh) [3]. This is comparable to the cost of conventional energy technologies. Furthermore, a production tax credit (PTC) of 1.8 cents/kWh during the first ten years of operation was available until recently. The tax credit program expired in 2003 and may be reinstated in the future. Wind energy is also the lowest cost of the emerging renewable energy sources.

[1] Levelized costs represent the average capital, maintenance and fuel costs over the lifetime of the equipment.

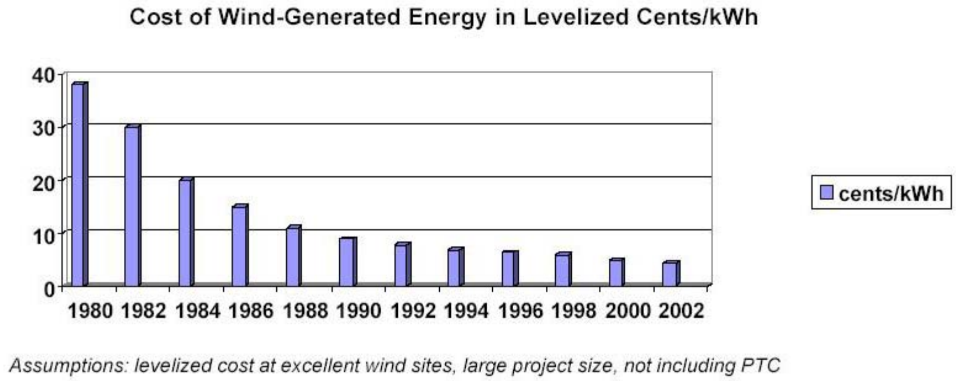

Figure 1-3: Cost of wind energy at excellent wind sites not including production tax credits[2] (Source: American Wind Energy Association)

While the cost of wind energy is still high for lower wind speeds (below class 4), DOE is working with three small turbine manufacturers to improve their turbines [4]. The goal of this initiative is to develop tested systems of up to 40 kilowatts (kW) in size with a cost/performance ratio of 60 cents/kWh at sites with an annual average wind speed of 5.4m/s (12.1 mph)[3]. The cost of energy (COE) from wind as projected by DOE's National Renewable Energy Laboratory (NREL) is shown in Figure 1-4 [3].

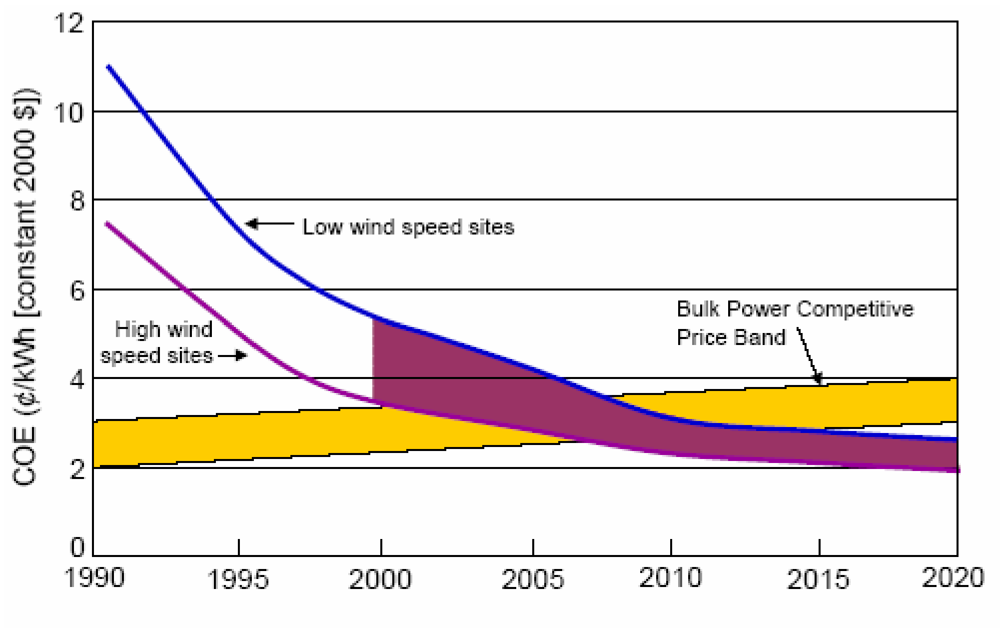

Figure 1-4: Projected cost for wind energy (Source: NREL)

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[2] Also called Renewable Electricity Production Credit.

[3] The cost/performance ratio is defined as follows: $\text{Cost/Performance} = \dfrac{\text{Initial Capital Cost}}{\text{Annual Energy Production}}$

1.3 State of wind energy nationally

Wind resources are prevalent throughout the United States with class 4 or higher winds concentrated in the Northwest, North Central and Northeast regions, as shown in the national wind resource map [5] in Figure 1-5. This map shows annual average wind power; for many locations, there can be a large seasonal variation. In the Midwest, average wind power is highest in the winter and spring, while it is lowest in the summer. This indicates that wind energy may be more suitable for meeting Midwest winter heating demand than for meeting summer cooling needs.

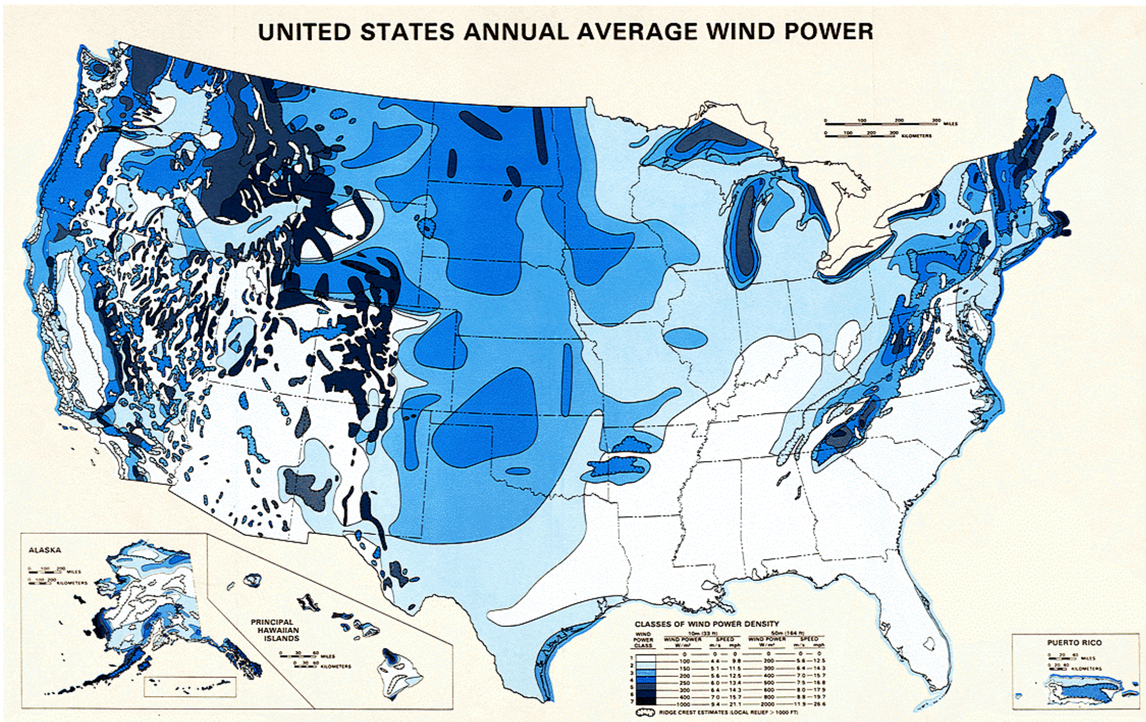

Figure 1-5: National wind energy resource map (Source: NREL)

California currently leads the nation in available wind generation capacity as well as annual energy produced from wind sources, as shown in Figure 1-6. This is due to the availability of high wind sites on the west coast and state government incentives for renewables that, when combined with improved wind turbine technology, make the cost of wind energy comparable with the cost of electricity from other sources.

According to DOE [2] as of 2001, electricity from wind energy sources constituted 4.2 percent of the total national renewable capacity and about one percent of the renewable energy consumed by users in the U.S. came from wind energy. Also, with wind energy being the lowest cost source of the emerging renewable energy sources, wind energy accounted for 93 percent of the renewable energy expansion from 2000 to 2001.

Wind capacity has been expanding rapidly, with the 6,374 MW as of the end of 2003 shown in Figure 1-6 representing an increase of over 36 percent from the previous year [5]. In the Midwest, 241 MW of new wind capacity was added in Minnesota in 2003 and 50 MW and 48 MW were added in Illinois and Iowa, respectively.

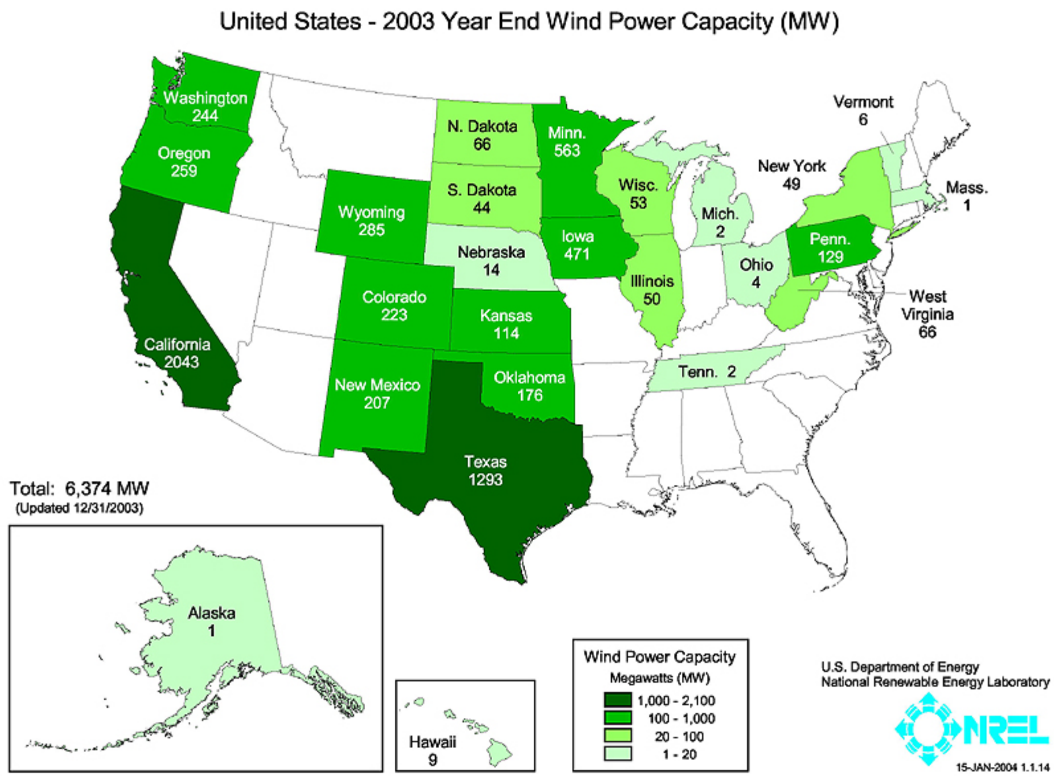

Figure 1-6: Wind energy installed generation capacity (Source: NREL)

Figure 1-7 shows the states that the American Wind Association has identified as the states with the most potential for wind energy production [1]. Of the states in the Midwest, Minnesota and Iowa have moved to the front of the pack in terms of installed wind energy capacity and wind energy production. Again this is due in the most part to their favorable positions in terms of high wind sites.

THE TOP TWENTY STATES for wind energy potential, as measured by annual potential in billions of kWhs, factoring in environmental and land use exclusions for wind class of 3 and higher:

1	North Dakota	1,210	11	Colorado	481
2	Texas	1,190	12	New Mexico	435
3	Kansas	1,070	13	Idaho	73
4	South Dakota	1,030	14	Michigan	65
5	Montana	1,020	15	New York	62
6	Nebraska	868	16	Illinois	61
7	Wyoming	747	17	California	59
8	Oklahoma	725	18	Wisconsin	58
9	Minnesota	657	19	Maine	56
10	Iowa	551	20	Missouri	52

Source: An Assessment of the Available Windy Land Area and Wind Energy Potential in the Contiguous United States, Pacific Northwest Laboratory, 1991.

Figure 1-7: Top twenty states for wind energy production potential (Source: American Wind Association)

1.4 Wind energy in Indiana

To date, there is almost no electricity capacity in Indiana that is driven by wind, as seen in Figure 1-6. According to NREL's Renewable Electric Plant Information System (REPiS), as of 2002 Indiana had only 22 kW of wind generation [5].

The national wind resource map shown in Figure 1-5 indicates that Indiana does not have sufficient wind resources to utilize large-scale wind turbines, as used in large-scale electricity production applications. With the exception of the Lake Michigan shore, Indiana is shown to have class 2 wind resources in the northern portion of the state and class 1 resources in the south. For the winter and spring maps (not included here), northern Indiana is shown to have class 3 resources and southern Indiana to have class 2 resources. In the summer, almost the entire state is shown to have only class 1 resources. For Indiana, the autumn map is similar to the annual average in Figure 1-5.

However, these maps are nearly twenty years old and may miss localized windy areas. A new wind resource map was released by NREL in July 2004 and is shown as Figure 1-8 [6]. This map shows the wind power density and corresponding wind speeds at a height of 50 meters. This map indicates that localized areas of class 3 wind resources exist in the state, primarily in Benton, Boone, and Clinton counties. Table 1-2 lists the average wind speeds and wind power densities as measured by the National Climatic Data Center in various cities within Indiana. These wind speeds were most likely collected at lower elevations than those at which a wind turbine would operate, so they may understate the potential for wind power somewhat.

In the spring of 2003, enXco, a developer of wind capacity, proposed construction of a wind farm at one of two sites near Fowler in Benton County. The initial proposal called for up to 100 MW of wind powered capacity to be operational in late 2004. According to a January 2004 press release [7], enXco now plans to build the "Indiana Winds" project in the summer of 2005. The project will consist of 67 wind turbines, each rated at 1.5 MW.

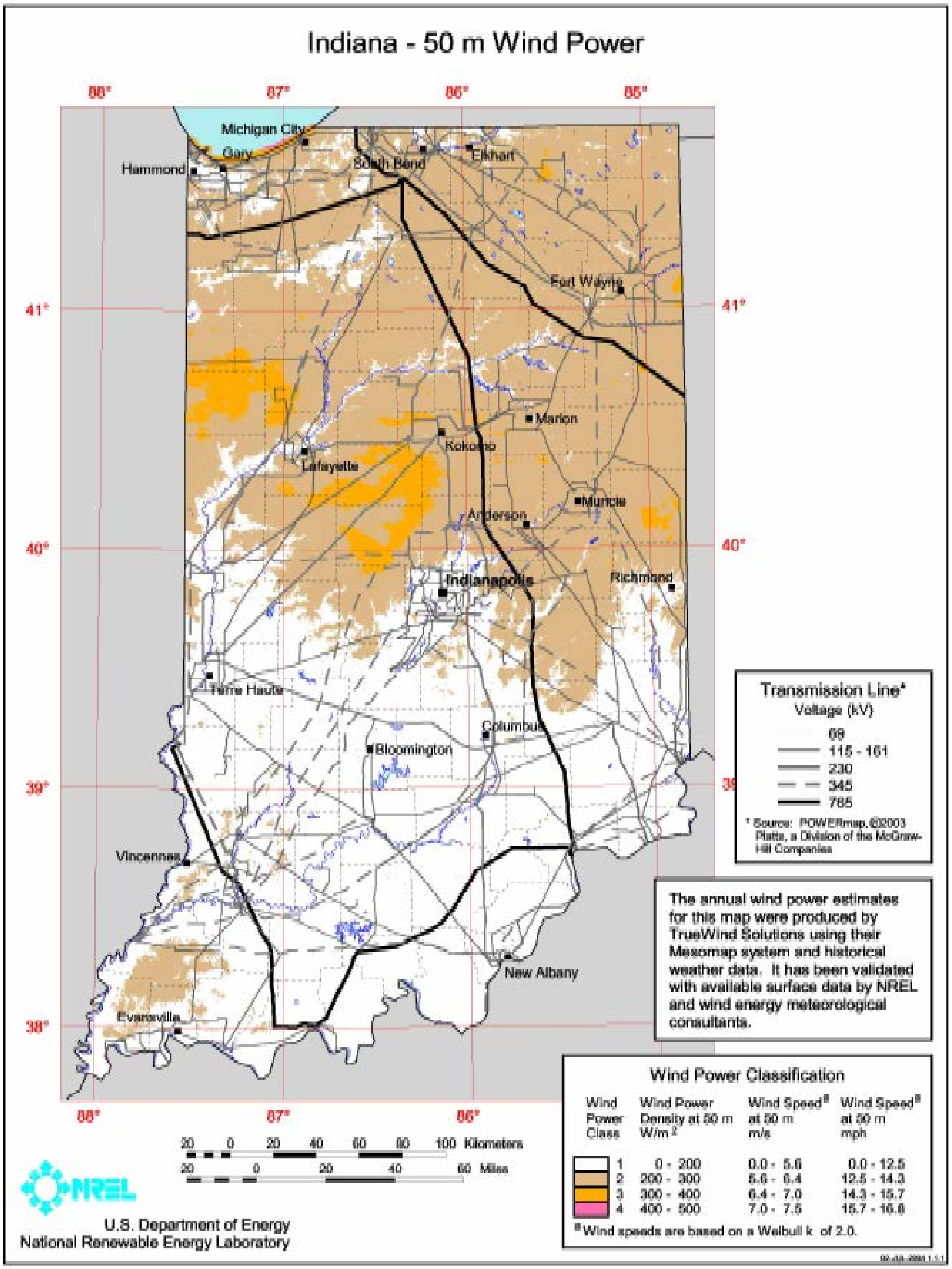

Figure 1-8: Indiana wind energy resource map (2004) (Source: NREL)

Station Name	Annual		Winter		Spring		Summer		Autumn	
	Speed (m/s)	**PD (w/m^2)**	**Speed (m/s)**	**PD (w/m^2)**	**Speed (m/s)**	**PD (w/m^2)**	**Speed (m/s)**	**PD (w/m^2)**	**Speed (m/s)**	**PD (w/m^2)**
BUNKER HILL	3.6	72#	4.3	102#	4.3	104#	2.5	29#	3.3	58#
COLUMBUS	3.7	77	4.3	101	4.3	109	2.8	38	3.4	64
COLUMBUS	3.3	58%	3.8	73%	4	83%	2.6	30%	3	47%
EVANSVILLE	4.1	95	4.8	126	4.7	133	3.2	46	3.7	77
EVANSVILLE	3.4	58	4	80	4	79	2.7	29	3.1	46
FT. WAYNE	3.8	78	4.3	106	4.2	93	2.9	34	3.6	71
FT. WAYNE	5.2	158	5.6	186	5.9	225	4.2	81	5	145
FT. WAYNE	4.6	117	5.3	168	5.1	146	3.8	62	4.2	90
GOSHEN	4.5	126	5.4	176	5.2	167	3.6	65	4.3	116
INDIANAPOLIS	5	146	5.6	189	5.7	205	3.9	68	4.7	127
INDIANAPOLIS	4	76	4.6	105	4.5	98	3.3	40	3.8	59
SOUTH BEND	4.9	132	5.3	160	5.5	175	4	69	4.8	122
SOUTH BEND	4.6	110	5.3	158	5.1	142	3.8	62	4.2	85
TERRE HAUTE	4	94	4.7	132	4.7	138	2.9	36	3.6	74
TERRE HAUTE	4.3	106	5	138	5.4	167	3.1	44	3.9	72
W. LAFAYETTE	5.1	166#	6	235#	5.7	209#	3.9	73#	4.8	144#

Annual or seasonal mean wind power with the # (or %) symbol may be as much as 20 percent in error because climatic mean air temperatures were used to calculate the hourly (or 3-hourly) wind power values that went into the calculation of the mean value.

Table 1-2: Wind measurements within Indiana (Source: National Climatic Data Center)

On a much smaller scale, Cinergy is installing a single 10 kW wind turbine at an interstate rest stop in White County. The energy output of the turbine will be used to displace some of the electrical requirements of the rest stop. The expected operation date for the installation is August 2004.

Small-scale wind turbines that require lower wind speeds could be used within the state for remote power applications[4], but their high production costs in comparison with the low electricity costs available within Indiana do not make them economically attractive. In order to improve the cost effectiveness of wind energy the federal and state governments have implemented several incentives for wind power development within Indiana [8]. These are:

- Renewable Electricity Production Credit which credited wind energy producers 1.8 cents/kWh during the first ten years of operation. This federal program expired at the end of 2003. A renewal of the program was included in the comprehensive energy legislation that did not make it out of Congress in 2003. It may be considered in upcoming sessions.
- Renewable Energy Systems Exemption provides property tax exemptions for the entire renewable energy device and affiliated equipment.
- Distributed Generation Grant Program offers awards of up to $30,000 to commercial, industrial, and government entities to “install and study alternatives to central generation” (wind energy falls under one of these alternatives).
- Alternative Power and Energy Grant Program offers grants of up to $30,000 to enable businesses and institutions to “install and study alternative and renewable energy system applications (wind energy is an acceptable technology).
- Green Pricing Program is an initiative offered by some utilities that gives consumers the option to purchase power produced from renewable energy sources at some premium.
- Net Energy Credit: Facilities generating less than 1000 kWh per month from renewable sources are eligible to sell the excess electricity to the utility. Facilities generating more than 1000 kWh per month need to request permission to sell the excess electricity to the utility.
- Emissions Credits: Electricity generators that do not emit nitrogen oxides (NO_x) and that displace utility generation are eligible to receive NO_x emissions credits under the Indiana Clean Energy Credit Program [9]. These credits can be sold on the national market.

Figure 1-9 shows the importance of incentives[5], wind speed, and electricity prices in the economic viability of small-scale wind systems [3]. As incentives are added, wind speed increases, or electric rates increase, the time needed to recover the cost of installation decreases. Figure 1-10 shows the locations that have incentives for small residential wind installations.

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[4] As in the 10kW installation in Fort Wayne owned by the American Electric Power Co. Inc. [10]
[5] A buy-down is a subsidy or grant that covers a portion of the purchase cost.

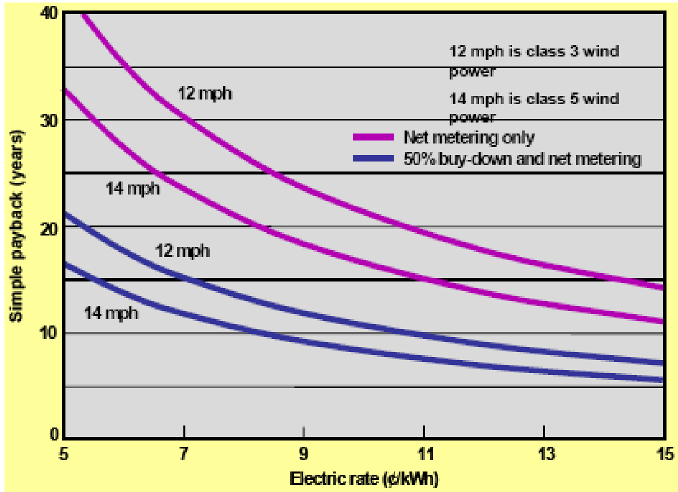


Figure 1-9: Economic payback for small wind systems (Source: DOE Wind Powering America)

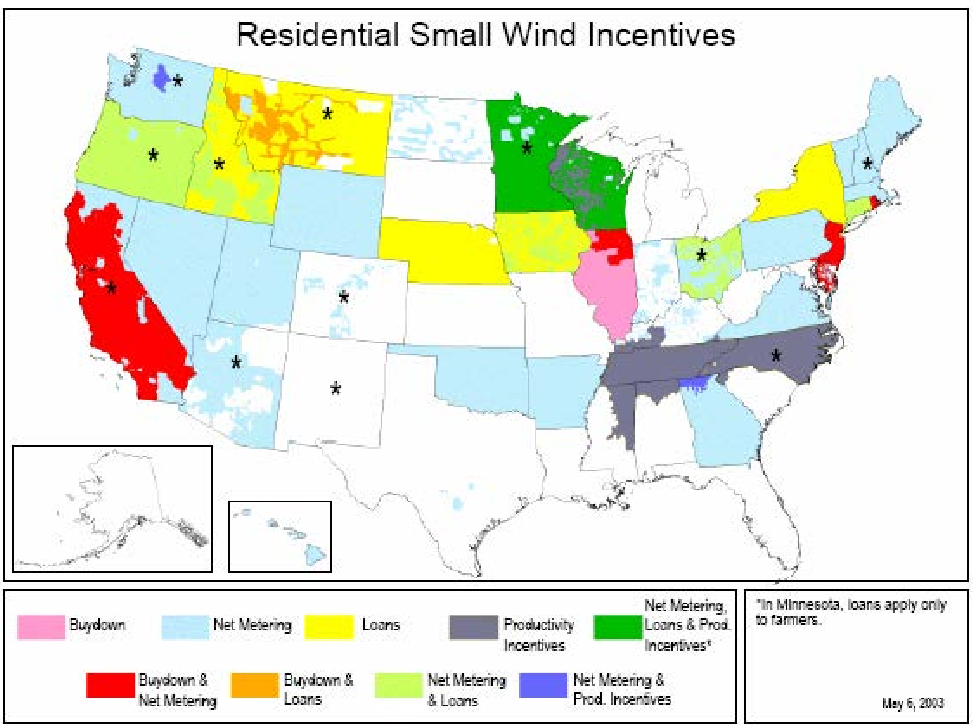


Figure 1-10: Residential small wind incentives (Source: DOE Wind Powering America)

The current low cost of electricity generated from coal and the relatively low average wind speeds tend to limit the future role of wind energy in Indiana. However, the following factors could affect this outcome [10]:

- Technological advancements in low-speed wind turbine technology: The successful construction and testing of lower cost, low power, and low wind speed turbine technology could help make wind energy more competitive for remote power applications.

- Green power pricing programs: These programs allow consumers wishing to utilize renewable and environmentally friendly resources to pay higher premiums, providing a subsidy to cover the higher cost of wind power.
- The cost of electricity from conventional sources: Anything that increases the cost of electricity from conventional sources, such as additional environmental restrictions, could help wind power be more competitive in Indiana.
- Governmental incentives for renewable energy: There are currently several federal and state government incentives aimed at increasing the economic viability of wind energy. Increased incentives, including reinstatement of the renewable electricity production credit, could further assist the cause of wind energy within Indiana.
- The national energy policy: Wind Powering America is a DOE initiative aimed at increasing the use of wind energy within the nation. One of the goals is to supply 5 percent of the nation's energy by 2020 [11]. These national initiatives could assist in the introduction of wind energy within the rural areas of Indiana.

1.5 References

1. http://www.awea.org/windinfo.html
2. EIA, United States Department of Energy, "Renewable Energy Trends 2000: Issues and Trends," Feb 2000.
3. http://www.eere.energy.gov/windpoweringamerica/pdfs/wpa/wpa_update.pdf
4. http://www.eia.doe.gov/
5. http://www.nrel.gov/
6. http://www.eere.energy.gov/windpoweringamerica/pdfs/wind_maps/in_50m.pdf
7. http://www.enxco.com/press_012204.php
8. http://www.dsireusa.org
9. http://www.in.gov/idem/energycredit/ecreditfct.pdf
10. K. Althoff, "Review of Prospects for Alternative Energy as Assessed in the Past," Purdue University, Jan 2003.
11. L.T. Flowers, P.J. Dougherty, "Wind Powering America: Goals, Approach, Perspectives and Prospects," 2002 Global Wind Power Conference, Paris, France.

2. Dedicated Crops Grown for Energy Production (Energy Crops)

2.1 Introduction

The Oak Ridge National Laboratory (ORNL) defines energy crops as "perennial grasses and trees produced with traditional agricultural practices and used to produce electricity, liquid fuels, and chemicals" [1].

Energy crops are just one of the possible forms of biomass. DOE [2] defines biomass as "any organic matter available on a renewable basis, including dedicated energy crops and trees, agricultural food and feed crops, agricultural crop wastes and residues, wood wastes and residues, aquatic plants, animal wastes, municipal wastes, and other waste materials."

Energy derived from biomass supplies or "bioenergy" can occur in several possible ways.

- <u>Biomass direct combustion</u>**:** This is the simplest conversion process when the biomass energy is converted into heat energy. The heat can be used to produce steam which in turn can be used in the electricity generation industry. This direct combustion, however, leads to large levels of ash production.
- <u>Biomass cofiring</u>**:** This conversion process involves mixing the biomass source with existing fossil fuels (typically coal or oil) prior to combustion. The mix could either take place outside or inside the boiler. This is the most popular method utilized in the electricity generation industries that utilize biomass. This is because the biomass supply reduces the nitrogen oxide, sulfur dioxide and carbon dioxide emissions without significant losses in energy efficiency. Typically five to ten percent of the input fuel is biomass with the rest being the fossil fuel [3].
- <u>Chemical conversion</u>**:** Biomass can be used to produce liquid fuels (biofuels) such as ethanol and biodiesel. While they can each be used as alternative fuels, both are more frequently used as additives to conventional fuels to reduce toxic air emissions and improve performance.
- <u>Biomass gasification</u>**:** This involves a two-step thermo-chemical process of converting biomass or coal into either a gaseous or liquid fuel in high temperature reactors. Thermal gasification converts approximately 65-70 percent of available energy from the biomass into gases that could be used in gas turbines to generate electricity.

Bioenergy constituted 4 percent of the total energy consumed in the U.S. and 47 percent of the total renewable energy consumed in the U.S. in 2003 [4]. Of the 2.663 quadrillion British thermal units (Btu) supplied by biomass in 2001, 1.678 quadrillion Btu was consumed in the industrial sector, 0.466 quadrillion Btu was consumed in the electricity sector and 0.407 quadrillion Btu was consumed in the residential sector [5]. A total of 0.133 quadrillion Btu was consumed in the transportation sector in the form of ethanol. The majority of the consumption in the industrial sector is the cogeneration that takes place at the pulp and paper plants. Here the wood residues from the manufacturing process are combusted to produce steam and electricity [6]. Residential consumption occurs primarily in the form of wood burning fireplaces and stoves.

The primary sources of biomass for electricity generation are landfill gas and municipal solid waste. Together, they account for over 70 percent of biomass electricity generation [5]. A complete overview of organic waste biomass is presented in Section 3 of this report.

Agricultural, forest, and municipal solid wastes are valuable short-term bioenergy resources, but do not provide the same long term advantages as energy crops [7]. Energy crops are not being commercially grown in the United States at present although a few demonstration projects are underway with DOE funding in Iowa and New York [6]. These are both discussed below. The Bioenergy Feedstock Development Program at ORNL has identified hybrid poplars, hybrid willows, and switchgrass as having the greatest potential for dedicated energy use over a wide geographic range [7].

Switchgrass falls under the category of herbaceous energy crops. These energy crops are perennials that are harvested annually after taking two to three years to reach full productivity. The hybrid poplar and hybrid willow are short rotation, fast growing hardwood trees. They are harvested within five to eight years after planting [2]. The comparative chemical characteristics between the relevant energy crops and the conventional fossil fuels are shown in Table 2-1 [8].

Fuel Source	**Heating Value (Gigajoule/ton)**	**Ash (percent)**	**Sulfur (percent)**
Switchgrass	18.3	4.5-5.8	0.12
Hybrid Poplar/Willow	19	0.5-1.5	0.03
Coal (Low Rank)	15-19	5-20	1-3
Coal (High Rank)	27-30	1-10	0.5-1.5
Oil	42-45	0.5-1.5	0.2-1.2

Table 2-1: Comparative chemical characteristics of energy crops and fossil fuels (Source: ORNL)

In today's direct-fired biomass power plants, generation costs are about 9 cents/kWh. In the future, advanced technologies such as gasification-based systems could generate power for as little as 5 cents/kWh. In cofiring applications, modifications to the coal plant can have payback periods of 2-3 years [9].

2.2 Economics of energy crops

The economic feasibility of energy crops is a function of many factors. First, the price of the energy crop is crucial. If the price is too high, the energy crop will not be able to compete with other energy sources, such as fossil fuels. On the other hand, if the price is too low, the producer will use the land for other, more profitable uses, such as planting corn or soybeans. A second factor is the set of environmental regulations that fuel users operate under, which may make energy crops more attractive. A third factor is the cost of transporting the energy crop to the consumer. Unlike other renewable resources, energy crops must be harvested and transported instead of used locally. A final factor is the existence of government subsidies, such as those used in the ethanol industry. These factors are discussed in more detail in the following sections.

2.3 State of energy crops nationally

Energy crops can be grown on most of the more than 400 million acres classified as cropland in the nation, as shown in Figure 2-1 from the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) [7]. They offer many environmental advantages when produced on erosive lands or lands that are otherwise limited for conventional crop production.

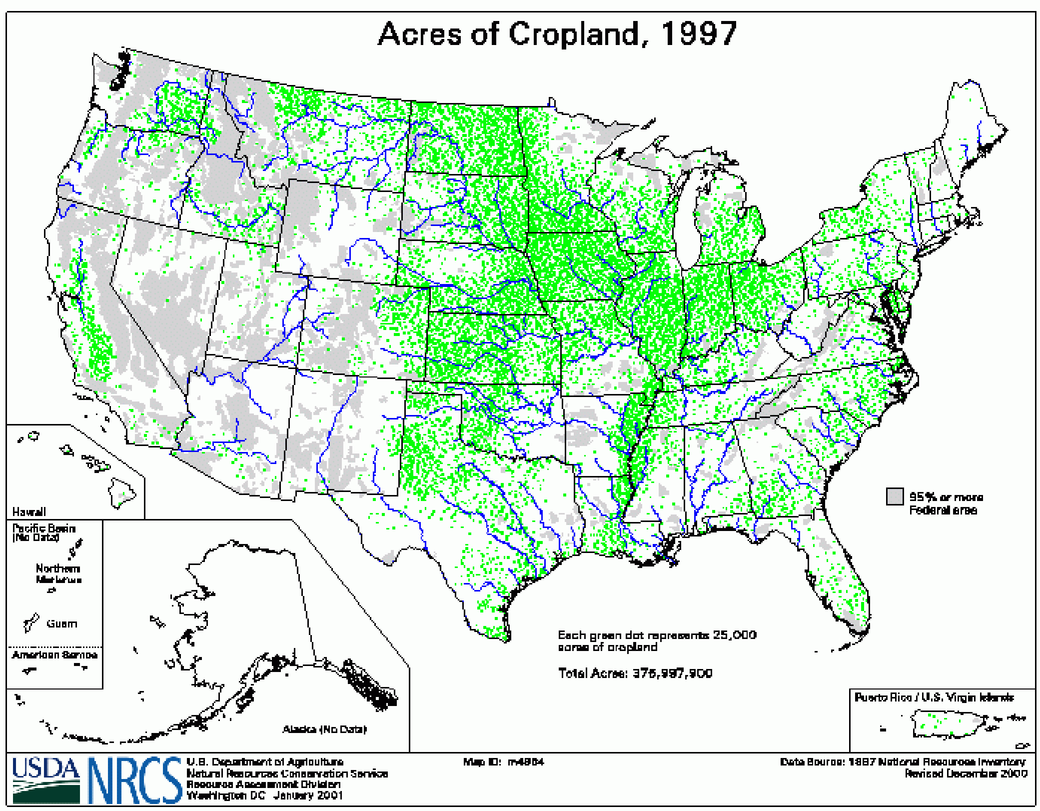
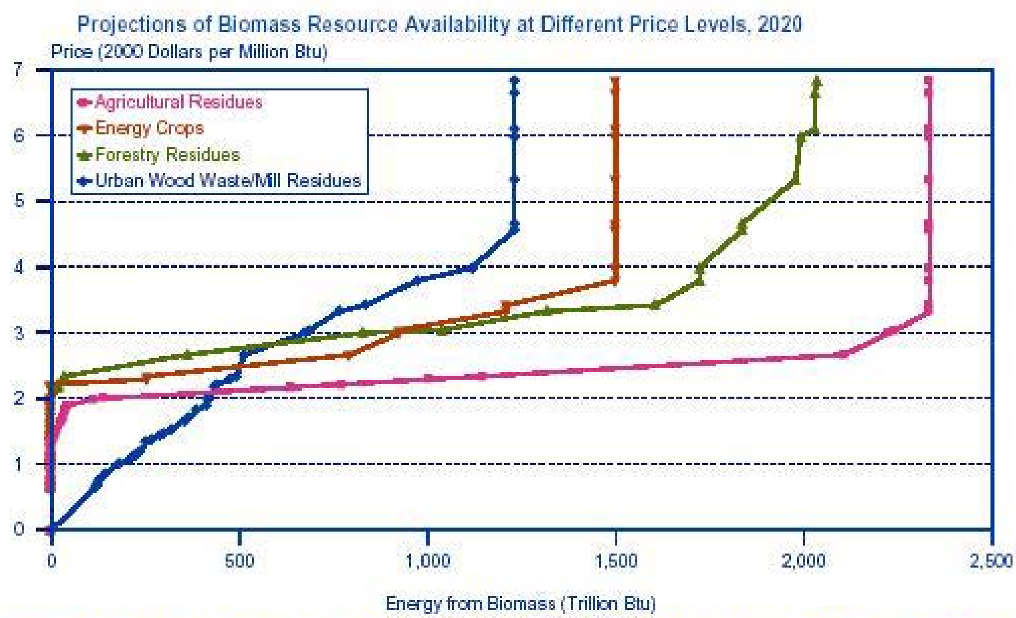


Figure 2-1: Cropland distribution in the United States (Source: NRCS)

In 1979, Purdue University published a comprehensive report titled, "The Potential of Producing Energy from Agriculture," for the Office of Technology Assessment within the U.S. Congress [10]. This report analyzed the technological, resource and environmental constraints to producing energy from agricultural crops and residues. The report concluded that there would likely be government incentives or mandates required to stimulate widespread production and conversion of biomass to energy.

The primary barrier to the commercial development of energy crops is the high cost of the feedstock relative to the cost of fossil fuels. The high feedstock costs are driven by competition with other crops that could be produced on the land. The price of the energy crop needs to be high enough to entice producers to grow the energy crop rather than other crops, including those whose prices are federally subsidized. Also, some have argued that the true environmental costs of burning fossil fuels are not charged to the entity using the fuel [3].

The Energy Information Administration (EIA), a division of DOE, published a report titled," Biomass for Energy Generation," by Zia Haq [6]. This report focused on the expected biomass energy supply (including energy crop supply) in 2020. It utilized an agricultural sector model called POLYSYS (Policy Analysis System), which was developed by ORNL to estimate the possible future supplies. The estimated national supply curve for biomass and energy crops produced by POLYSYS for the year 2020 is shown in Figure 2-2.



Sources: A.F. Turhollow and S.M. Cohn, *Data and Sources of Biomass Supply*, unpublished report (Oak Ridge, TN: Oak Ridge National Laboratory, January 1994); M. Walsh et al., *Biomass Feedstock Availability in the United States: 1999 State Level Analysis* (Oak Ridge, TN: Oak Ridge National Laboratory, April 1999, updated January 2000), web site http://bioenergy.ornl.gov/resourcedata; M. Walsh et al., "The Economic Impacts of Bioenergy Crop Production on U.S. Agriculture" (Oak Ridge, TN: Oak Ridge National Laboratory, May 2000), web site http://bioenergy.ornl.gov/papers/wagin/index.html; and Antares Group, Inc., *Biomass Residue Supply Curves for the United States (Update)*, Report for the U.S. Department of Energy and the National Renewable Energy Laboratory (June 1999).

Figure 2-2: POLYSYS estimated biomass supply curve for year 2020 (Source: EIA)

ORNL uses POLYSYS to estimate the quantities of energy crops that could be produced at various prices in the future. The POLYSYS model assumes that irrigation of energy crops would be a huge economic penalty and thus due to the natural rain gradient in the U.S., excludes the Western Plains. Also the Rocky Mountain region is excluded as it is assumed to be an unsuitable climate in which to produce energy crops. The assumed yields of energy crops were lowest in the Northern Plains and highest in the heart of the cornbelt. The hybrid poplar production was assumed to occur in the Pacific Northwest, Southern and Northern regions, while willow production was assumed to only occur in the Northern region due to limited research being conducted for the potential growth outside that area. The production assumptions used by ORNL are shown in Figure 2-3. The final panel in Figure 2-3 shows the acreage in the Conservation Reserve Program (CRP) that is assumed potentially available for bioenergy. These and further assumptions ORNL used with the POLYSYS model are discussed in ORNL's The Economic Impacts of Bioenergy Crop Production on U.S. Agriculture [11].

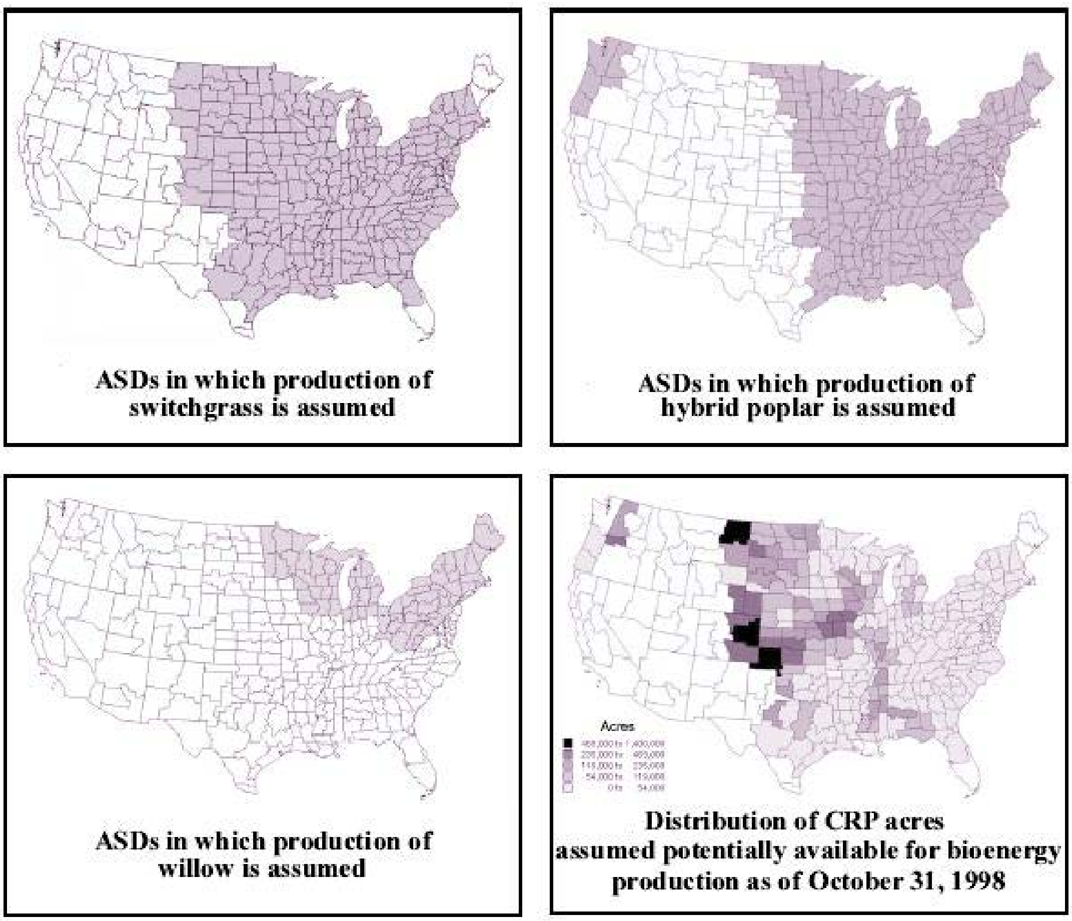


Figure 2-3: POLYSYS assumed Agricultural Statistical Districts (ASDs) for energy crop production (Source: ORNL)

Figure 2-2 indicates that energy crops will be supplied into the market when the average price (in 2000 dollars) exceeds about $2.10/million Btu. In comparison, the average price of coal to electric utilities in 2001 was $1.23/million Btu [12]. Therefore, the use of energy crops could represent an increased cost to the electric utilities. Table 2-2 shows the estimated amounts of biomass, including energy crops that would be available in 2020 in the various North American Reliability Council (NERC) regions when the price is $5/million Btu. The various NERC regions are shown in Figure 2-4.

Biomass Resources by NERC Region: Quantities Assumed To Be Available in 2020 at $5 per Million Btu
(Trillion Btu)

NERC Region[a]	Agricultural Residues	Energy Crops	Forestry Residues	Urban Wood Waste/ Mill Residues	Total
ECAR	407	183	363	156	1,109
ERCOT.	57	78	29	45	209
MAAC.	28	19	44	50	141
MAIN	439	112	125	36	712
MAPP.	946	398	191	39	1,574
NPCC/NY.	3	59	40	63	165
NPCC/NE.	0	38	81	50	169
SERC/FL	0	4	32	42	78
SERC.	61	217	342	307	927
SPP	264	387	225	138	1,014
NWP.	53	0	414	180	647
WRA.	54	6	105	30	195
CNV	23	0	43	94	160
Total.	2,335	1,501	2,034	1,230	7,100

[a]North American Electric Reliability Council (NERC) regions: ECAR, East Central Area Reliability Coordination Agreement; ERCOT, Electric Reliability Council of Texas; MAAC, Mid-Atlantic Area Council; MAIN, Mid-America Interconnected Network; MAPP, Mid-Continent Area Power Pool; NPCC/NY, Northeast Power Coordinating Council/New York; NPCC/NE, Northeast Power Coordinating Council/New England; SERC/FL, Southeastern Electric Reliability Council/Florida; SERC, Southeastern Electric Reliability Council (Excluding Florida); SPP, Southwest Power Pool; NWP, Northwest Power Pool; WRA, Rocky Mountain Power Area; CNV, California-Southern Nevada Power.

Source: Personal communication with Marie Walsh, Oak Ridge National Laboratory, and Kevin Comer, Antares Group, Inc.

Table 2-2: <u>POLYSYS estimated biomass supply for year 2020 for NERC regions</u> (Source: EIA)

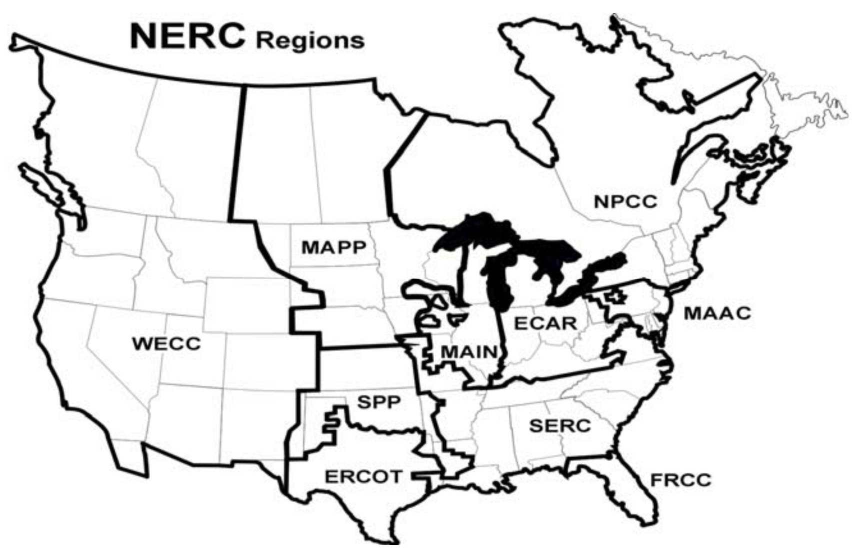


Figure 2-4: <u>NERC defined regions</u> (Source: www.nerc.com)

The United States Department of Agriculture (USDA) and DOE conducted a joint study, using the POLYSYS model, to determine the potential of producing biomass energy crops [13]. The results indicated that an estimated 188 million dry tons (2.9 quadrillion Btu) of biomass could be available annually at delivered prices of less than $50/dry ton ($2.88/million Btu) by the year 2008. The analysis includes all cropland suitable for the production of energy crops that is currently planted to traditional crops, idled, in pasture, or in the CRP. It is estimated that 42 million acres of cropland (about 10 percent of all cropland acres) could be converted to energy crop production including 13 million CRP acres. Harvest of CRP acres will require a significant change in the current laws and should be structured in a way that maintains the environmental benefits of the program. The estimated quantities represent the maximum that could be produced at a profit greater than that which could be earned through existing uses. Farmer adoption of new crops is based on several factors. Greater profitability will encourage, but not necessarily ensure, the adoption of a new crop.

Energy crop yields will increase over time, but so will traditional crop yields. The interplay of demand for food, feed, and fiber with traditional crop yields, and crop production costs will determine the number of acres allocated to traditional crop production. International demand for food, feed, and fiber is expected to increase in the future.

Another factor that will impact the amount of land available for energy crops is the conversion of cropland to other uses, especially to developed land. Figure 2-5 shows the distribution of land in the lower 48 states in millions of acres in 1982, 1992, and 2002 according to the National Resources Inventory by NRCS [14]. Note that the CRP did not exist until 1985.

Biotechnology is expected to substantially increase crop yields in the future, although studies (such as those by the Office of Technology Assessment and by the Resource Conservation Act assessments) indicate that the largest increases in yields will likely occur after 2020 rather than before this time. Potential quantities of energy crops could increase in the near future, but increases may be more due to increasing yields per acre than from increasing acres. Opportunities to tailor biomass energy crops to serve multiple purposes have not been considered in this analysis.

Two demonstration projects are currently underway in Iowa and New York.

- IES Utilities, Ottumwa Station (Iowa): This project involves the cofiring of switchgrass with coal at a rate of 5 percent. It is estimated that 200,000 tons of switchgrass is required and thus 40,000 to 50,000 acres of land would need to be harvested annually. The USDA has approved the use of 4,000 acres of CRP and other marginal lands [6, 10].
- NRG Dunkirk Station (New York): For this project, willow from 400 acres of farmland will be cofired with coal.

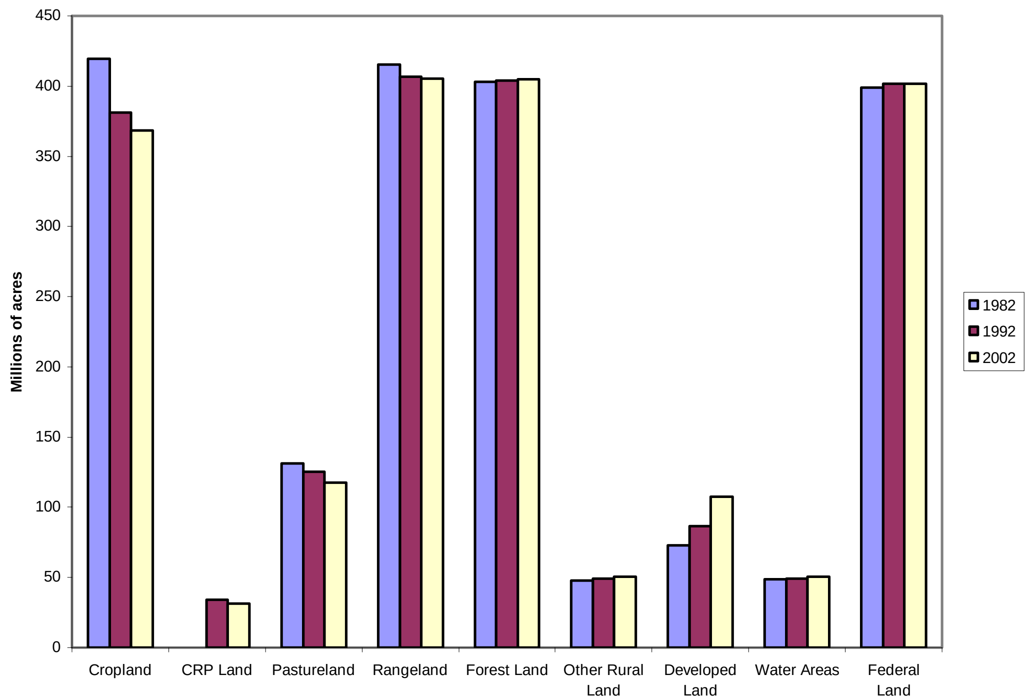


Figure 2-5: Land use in the contiguous United States (Source: NRCS)

2.4 Energy crops in Indiana

Currently, Indiana depends heavily on carbon-based fuels for electricity production. EIA has estimated that 94 percent of electricity production in Indiana comes from coal. The average cost of coal to Indiana electric utilities in 2002 was $1.16/million Btu. Furthermore, in February 2003, 2,708,000 tons of coal containing 2 percent sulfur and 8.5 percent ash and 1,181,000 tons of coal containing 0.2 percent sulfur and 4.7 percent ash was used for electricity generation within Indiana [12]. Despite the low sulfur content of energy crops, the only biomass resource utilized to produce electricity in 2000 was municipal solid waste and landfill gas.

It has been estimated that 27.1 billion kWh of electricity could be generated using renewable biomass fuels in Indiana [15]. This represents about 27 percent of total Indiana utility electric energy requirements [16]. These biomass resource supply figures are based on estimates for five general categories of biomass: urban residues, mill residues, forest residues, agricultural residues, and energy crops. Of these potential biomass supplies, most forest residues, agricultural residues, and energy crops are not presently economic for energy use. New tax credits or incentives, increased monetary valuation of environmental benefits, or sustained high prices for fossil fuels could make these fuel sources more economic in the future [15].

While Indiana has a huge potential for energy crops, it is unlikely that farmers will utilize prime farmland for an uncertain return on energy crops. It is more likely that marginal lands[6] will be used [3]. Switchgrass has been identified as the most effective energy crop for most of the Midwest including Indiana [3, 17]. The following reasons were used to justify this claim [3]:

- It is native to most of the Midwest;
- It does not require much input after planting, therefore less soil disturbance;
- With less soil disturbance there is less chance of soil erosion;
- Harvest usually occurs from September to October prior to the harvest of corn and soybeans; and
- Machinery required for switchgrass is similar to that used for hay or silage harvest.

According to GIS-based estimates, the total switchgrass yield for Indiana using all agricultural land would be 90 million tons/year, giving an energy production potential of 1.54 quadrillion Btu/year [3]. Obviously, not all land would be used for switchgrass production but this does illustrate the huge potential available within Indiana. The central region of the state has the highest potential for switchgrass production because of favorable soils and a high percentage of agricultural lands. The southern region has the least potential and the northern region has a fairly high potential, as shown in Figure 2-6.

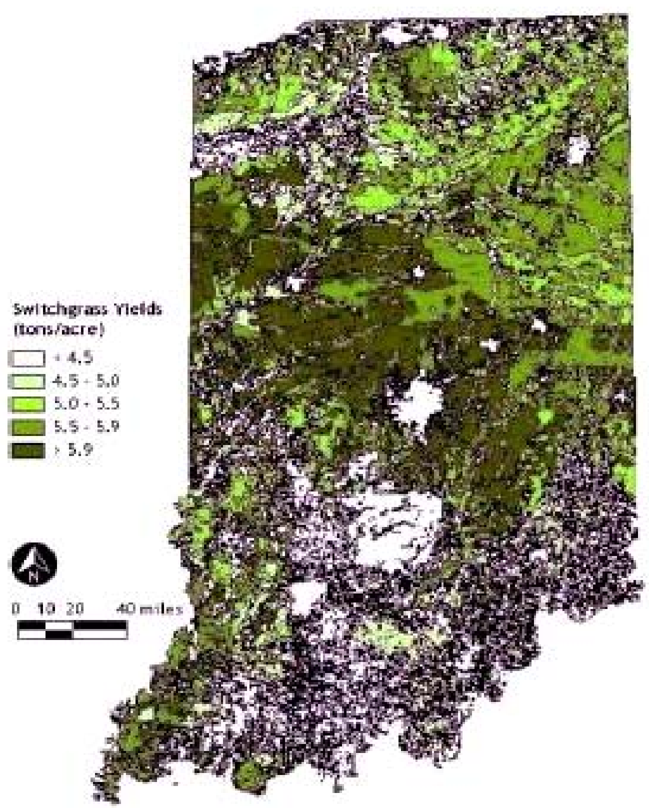


Figure 2-6: Switchgrass potential in Indiana (Source: Brown, et al.)

[6] Marginal lands include highly erodable land, CRP land and reclaimed surface mined lands.

The joint USDA and DOE study [13] estimated that the annual cumulative production level of energy crops in Indiana would be as shown in Table 2-3.

State	< $30/dry ton ($1.73/million Btu) delivered	< $40/dry ton ($2.31/million Btu) delivered	< $50/dry ton ($2.88/million Btu) delivered
Indiana	0	418042	5026234

Table 2-3: Estimated annual cumulative energy crop quantities (dry tons), by delivered price (1997 dollars) for Indiana (Source: ORNL)

Government support is seen as crucial for the development of energy crops as a viable energy source within Indiana [10]. First, if CRP lands are to be utilized to grow energy crops, some government approval would be required as these lands were set aside for conservation purposes. Second, since farmers would only utilize farmland to grow energy crops if they yield profits at least as great as the traditional crops that they replaced, high feedstock prices for electric utilities could be expected. Furthermore, Indiana is a source of low cost coal that is the dominant fuel for electricity production in the state. Thus, the government would need to provide incentives for farmers or electricity generators that use energy crops in order to help make them more competitive. The following incentives have been available to assist in the use of energy crops [18].

- Renewable Electricity Production Credit which credited biomass energy producers 1.8 cents/kWh during the first ten years of operation. This federal program expired at the end of 2003. A renewal of the program was included in the comprehensive energy legislation that did not make it out of Congress in 2003. It may be considered in upcoming sessions.
- Distributed Generation Grant Program offers awards of up to $30,000 to commercial, industrial, and government entities to “install and study alternatives to central generation” (biomass falls under one of these alternatives).
- Alternative Power and Energy Grant Program offers grants of up to $30,000 to enable businesses and institutions to “install and study alternative and renewable energy system applications” (biomass is an acceptable technology).
- Net Energy Credit: Facilities generating less than 1000 kWh per month from renewable sources are eligible to sell the excess electricity to the utility. Facilities generating more than 1000 kWh per month need to request permission to sell the excess electricity to the utility.
- Emissions Credits: Electricity generators that do not emit nitrogen oxides (NO_x) and that displace utility generation are eligible to receive NO_x emissions credits under the Indiana Clean Energy Credit Program [19]. These credits can be sold on the national market.

Government aid could also assist in offsetting the renovation costs of conventional fossil-fueled stations wanting to include some energy crops as an input. It has been stated that converting a coal-fired station to cofire with biomass will result in an incremental cost of approximately 1 to 2 cents/kWh and if the biomass was gasified then the resulting incremental cost would be approximately 7 cents/kWh [20]. Further biotechnology developments in energy crops and improvements in energy conversion technology would also assist in the development of energy crops within Indiana.

2.5 References

1. http://bioenergy.ornl.gov/pubs/resource_data.html
2. http://www.eere.energy.gov/RE/bio_resources.html
3. H. Brown, J. Elfin, D. Fergusin and J. Vann, “Connecting Biomass Producers with Users: Biomass Production on Marginal Lands,” Nov 2002.
4. http://www.eere.energy.gov/biomass/biomass_today.html
5. http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/table7.html
6. Zia Haq, “Biomass for Electricity Generation,” Energy Information Administration, US Department of Energy.
7. http://bioenergy.ornl.gov/papers/misc/biocost.html
8. http://bioenergy.ornl.gov/papers/misc/biochar_factsheet.html
9. http://www.eere.energy.gov/biopower/basics/index.htm
10. W. Tyner, et al., “The Potential of Producing Energy from Agriculture,” Purdue University, 1979.
11. ftp://bioenergy.ornl.gov/pub/pdfs/eco-impact.pdf
12. http://www.eia.doe.gov/cneaf/electricity/epm/chap4.pdf
13. http://bioenergy.ornl.gov/resourcedata/index.html
14. http://www.nrcs.usda.gov/technical/land/
15. http://www.eere.energy.gov/state_energy/tech_biomass.cfm?state=IN
16. State Utility Forecasting Group, “Indiana Electricity Projections: The 2003 Forecast,” Purdue University, 2003.
17. Environmental Law and Policy Center, “Repowering the Midwest: The Clean Energy Development plan for the Heartland,” 2001.
18. www.ies.ncsu.edu/dsire/library/includes/map2.cfm?CurrentPageID=1&State=IN
19. http://www.in.gov/idem/energycredit/ecreditfct.pdf
20. http://www.energyfoundation.org/documents/Bioenergy.pdf

3. Organic Waste Biomass

3.1 Introduction

Organic waste biomass can be divided into five subcategories [1]:

- Agriculture crop residues: Crop residues include biomass, primarily stalks and leaves, not harvested or removed from the fields in commercial use. Examples include corn stover (stalks, leaves, husks and cobs), wheat straw, and rice straw. With approximately 80 million acres of corn planted annually, corn stover is expected to become a major biomass resource for bioenergy applications.
- Forestry residues: Forestry residues include biomass not harvested or removed from logging sites in commercial hardwood and softwood stands as well as material resulting from forest management operations, such as pre-commercial thinnings and removal of dead and dying trees.
- Municipal waste: Residential, commercial, and institutional post-consumer wastes contain a significant proportion of plant derived organic material that constitutes a renewable energy resource. Waste paper, cardboard, wood waste and yard wastes are examples of biomass resources in municipal wastes.
- Biomass processing residues: All processing of biomass yields byproducts and waste streams collectively called residues, which have significant energy potential. Residues are simple to use because they have already been collected. For example, processing of wood for products or pulp produces sawdust and collection of bark, branches and leaves/needles.
- Animal wastes: Farms and animal processing operations create animal wastes that constitute a complex source of organic materials with environmental consequences. These wastes can be used to make many products, including energy.

As discussed in Section 2, biomass can be converted to energy in one of several ways[7]:

- Biomass direct combustion
- Biomass cofiring
- Chemical conversion
- Biomass gasification

There are varying levels of efficiency for plants using each of the above-mentioned biomass conversion technologies. Typical efficiency ranges are from 20 to 24 percent for direct combustion, 33 to 35 percent for biomass cofiring and 35 to 45 percent for gasification [2].

According to EIA [3], bioenergy constituted 4 percent of the total energy consumed in the U.S. and 47 percent of the total renewable energy consumed in the U.S. in 2003. A large portion of the bioenergy usage is for cogeneration that takes place at the pulp and

[7] These terms are explained fully in Section 2.

paper plants. See the previous section for a more detailed coverage of energy from wood and other crops.

The primary sources of biomass for non-cogeneration electricity are landfill gas and municipal solid waste (MSW). Together, they account for over 70 percent of biomass electricity generation by electric utilities and independent power producers [3].

The energy content in the various organic waste biomass fuels vary as shown in Table 3-1 [4].

Fuel Type	Heat Content	Units
Agricultural Byproducts	8.248	Million Btu/Short Ton
Digester Gas	0.619	Million Btu/Thousand Cubic Feet
Landfill Gas	0.490	Million Btu/Thousand Cubic Feet
Municipal Solid Waste	9.945	Million Btu/Short Ton
Paper Pellets	13.029	Million Btu/Short Ton
Peat	8.000	Million Btu/Short Ton
Railroad Ties	12.618	Million Btu/Short Ton
Sludge Waste	7.512	Million Btu/Short Ton
Sludge Wood	10.071	Million Btu/Short Ton
Solid Byproducts	25.830	Million Btu/Short Ton
Spent Sulfite Liquor	12.720	Million Btu/Short Ton
Tires	26.865	Million Btu/Short Ton
Utility Poles	12.500	Million Btu/Short Ton
Waste Alcohol	3.800	Million Btu/Barrel
Wood/Wood Waste	9.961	Million Btu/Short Ton
Source: Energy Information Administration, Form EIA-860B (1999), "Annual Electric Generator Report - Nonutility 1999."		

Table 3-1: Average heat content of selected biomass fuels (Source: EIA)

3.2 Economics of organic waste biomass-fired generation

Cofiring of existing fossil fuels with biomass is seen as a way to reduce harmful emissions. Typical cofiring applications utilize 5 to 10 percent biomass as the input fuel mix. To allow for cofiring, some conversion of the existing fuel supply system in the station is required. It has been stated that the payback period of this capital investment could be as low as two years if low cost biomass is used [5].

The following excerpt was extracted from DOE's website[5]:

> *"A typical existing coal fueled power plant produces power for about 2.3 cents/kWh. Cofiring inexpensive biomass fuels can reduce this cost to 2.1 cents/kWh. In today's direct-fired biomass power plants, generation costs are about 9 cents/kWh. In the future, advanced technologies such as gasification-*

based systems could generate power for as little as 5 cents/kWh. For comparison, a new combined-cycle power plant using natural gas can generate electricity for about 4 to 5 cents/kWh at today's gas prices.

For biomass to be economical as a power plant fuel, transportation distances from the resource supply to the power generation point must be minimized, with the maximum economically feasible distance being less than 100 miles. The most economical conditions exist when the energy use is located at the site where the biomass residue is generated (i.e., at a paper mill, sawmill, or sugar mill). Modular biopower generation technologies under development by the U.S. Department of Energy (DOE) and industry partners will minimize fuel transportation distances by locating small-scale power plants at biomass supply sites."

3.3 State of organic waste biomass-fired generation nationally

In 2001, the total biomass-based generation capacity in the U.S. was 9,709 MW [6]. Of this installed capacity 5,882 MW was dedicated to generation from wood and wood wastes (mostly by pulp and paper mills), 3,292 MW was attributed to generation capacity from MSW and landfill gas supplies, and the remainder used various other sources such as agricultural byproducts. There are currently about 39 million tons of unused economically viable annual biomass supplies available in the nation [5]. This translates to about 7,500 MW of additional generation capacity.

There are several generation projects throughout the U.S. that have implemented biomass gasification or are in the process of researching its use with the aid of DOE funding [7]:

- McNiel Generation Station, Burlington, Vermont: This station which has a generating capacity of 50 MW, utilizes waste wood from nearby forestry operations as its feedstock. It operated traditionally as a wood combustion facility but recently added a low pressure wood gasifier where the gas produced is fed directly into the boiler. This addition has led to an increase in capacity of 12 MW.
- Emery Recycling, Salt Lake City, Utah: Integrated gasification and fuel cells that use segregated municipal solid waste, animal waste and agricultural residues are being tested.
- Sebesta Bloomberg, Roseville, Minnesota: It has begun a project on an atmospheric gasifier with gas turbine at a malting factory which uses barley residues and corn stover as the feedstock.
- Alliant Energy, Lansing, Iowa: Corn stover is used as the feedstock in a new combined-cycle concept being developed that involves a fluidized-bed-pyrolyzer.
- United Technologies Research Center, East Hartford, Connecticut: Project testing has begun using clean wood residues and natural gas as feedstocks.
- Carolina Power and Light, Raleigh, North Carolina: Biomass gasification process to supply utility boilers using clean wood residues is being developed.

There are currently several commercially operational stations throughout the U.S. that cofire biomass with traditional fossil fuels to generate electricity. These are shown in Table 3-2 [7].

U.S. Power Plants Currently Co-firing with Biomass

Facility Name	Company Name	City/County	State	Capacity (Megawatts)	Heat Input from Biomass (Percent of Total)
6th Street	Alliant Energy	Cedar Rapids	IA	85	7.7
Bay Front	Xcel Energy, Inc.	Ashland	WI	76	40.3
Colbert	TVA	Tuscumbia	AL	190	1.5
Gadsden 2	Alabama Power Co.	Gadsden	AL	70	<1.0
Greenridge	AES	Dresden	NY	161	6.8
C. D. McIntosh, Jr.	City of Lakeland	Polk	FL	350	<1.0
Tacoma Steam Plant	Tacoma Public Utilities	Tacoma	WA	35	44.0
Willow Island 2	Allegheny Power	Pleasants	WV	188	1.2
Yates 6 and 7	Georgia Power	Newnan	GA	150	<1.0

Sources: Personal communication with Evan Hughes, Electric Power Research Institute, Kevin Comer, Antares Group, Inc., Douglas Boylan, Southern Company Services, Inc., and Hugh Messer, City of Tacoma; Energy Information Administration, 2000 data from Form EIA-759 and Form EIA-767; corporate web sites; and G. Wiltsee, *Lessons Learned from Existing Biomass Power Plants*, NREL/SR-570-26946 (Golden, CO: National Renewable Energy Laboratory, February 2000), web site www.nrel.gov/docs/fy00osti/26946.pdf.

Table 3-2: List of current biomass projects in the United States (Source: Haq)

In most of the cofiring operations listed above the input mix of biomass is less that 10 percent except for the Bay Front station and the Tacoma Steam Plant. The Bay Front station can generate electricity using coal, wood, rubber and natural gas [7]. It was found that cofiring caused excessive ash and slag and therefore over time it was found that it was better to operate the two units on coal during heavy loads and on biomass during light loads thus the high average biomass input. The Tacoma Steam Plant can cofire wood, refuse-derived fuel and coal. The plant runs only as many hours as necessary to burn the refuse-derived fuels that it receives [7]. A listing of other pilot projects can be found on DOE's website [8].

3.4 Organic waste biomass in Indiana

In 2000, the total energy generated by renewable sources in Indiana comprised 0.6 percent of the total energy generated in the state. Of this, 0.1 percent was from biomass sources (mainly MSW/landfill gas) [9]. The reason for this low contribution is mainly because of the availability of low-cost fossil fuels (coal) in the state, thus leading to generation predominantly from fossil-fueled stations [10]. According to REPiS, as of 2002 Indiana had only 18.67 MW of organic waste biomass generation [11].

The most active user of organic waste biomass for electricity generation is Wabash Valley Power Association (WVPA). WVPA owns two landfill gas units in Hendricks and Cass counties and purchases the output of three other units in Indiana. Furthermore, WVPA is constructing two additional units in Jay and White counties, with completion expected in early 2005. Each of these units consists of four 800 kW engines for a total output capacity of 3.2 MW per unit. This gives WVPA 16 MW of capacity from organic waste biomass at present with that number increasing to 22.4 MW in 2005.

Indiana has a large agricultural residue biomass resource potential, as shown in Figures 3-1 and 3-2 [12]. It is estimated that over 11 million dry tons of agricultural residues (corn stover and wheat straw) are available each year within Indiana. The other organic waste biomass resource estimates for Indiana are as follows [13]:

- Forest residues: 470,000 dry tons per year
- Biomass Processing Residues: 1,227,000 dry tons per year

Although there are considerable agricultural residue resources available within Indiana, the cost of collecting and transporting these residues to energy production facilities makes these biomass resources expensive in comparison to the low cost coal resources. Furthermore, farmers are unlikely to undertake the collection and transportation of the agricultural residues if there is no stable market for it [14].

The Northern Indiana Public Service Company (NIPSCO) in Hammond conducted biomass cofiring tests at two of its coal-fired power plants (Michigan City Station (425 MW) in Michigan City and Bailey Station (160 MW) in Chesterton). The biomass fuel tested was urban wood waste. The tests were conducted with biomass input fuel mix for the Michigan City station at 6.5 percent and 5 percent for Bailey Station. Both of these cofiring tests revealed reductions in the levels of nitrogen oxides, sulfur dioxide and carbon dioxide emissions. DOE assisted NIPSCO in sharing the costs [15].

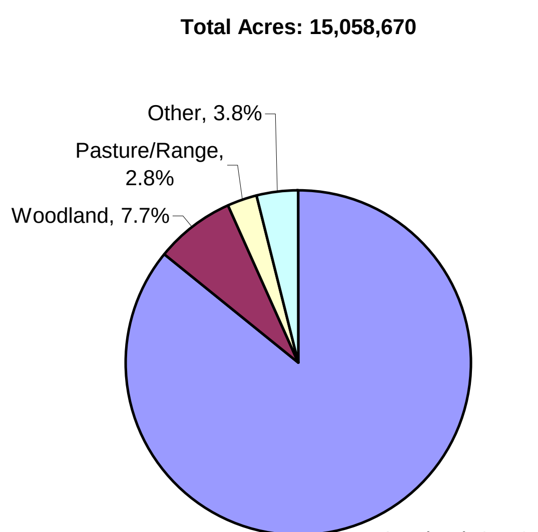


Figure 3-1: Indiana land use in 2002 (Source: USDA)

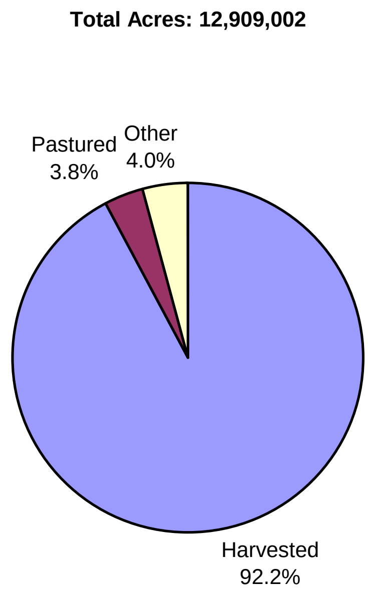


Figure 3-2: Indiana cropland use in 2002 (Source: USDA)

Construction has been completed at the Fair Oaks Dairy in northwest Indiana whereby biogas from animal manure is going to be used to generate electricity. The generation capacity for the facility is 700 kW and the electricity generated will be used for the dairy operations [16].

The major current source of non-hydro, renewable energy in Indiana is biomass. Of this, the majority is from MSW/landfill gas. The use of MSW has two purposes: the generation of electricity and the reduction of MSW levels. The abundant croplands in Indiana are a source of large quantities of agricultural residues, as shown in Figure 3-3 [17]. However, there are potential problems associated with residue removal [18]. First, the removal of agricultural residues will increase the likelihood of soil erosion and thus the removal will depend on the soil type and slope of the land. Second, farmers would incur costs when removing and transporting the residues. The farmers would only be willing to incur these costs if there were a stable market for the residues. The transportation distance is seen as a crucial factor in the cost of residues for generating plants. The estimated feasible transportation distance for these residues is stated as 100 miles [5]. However, the low cost of coal within Indiana will further tighten this bound.

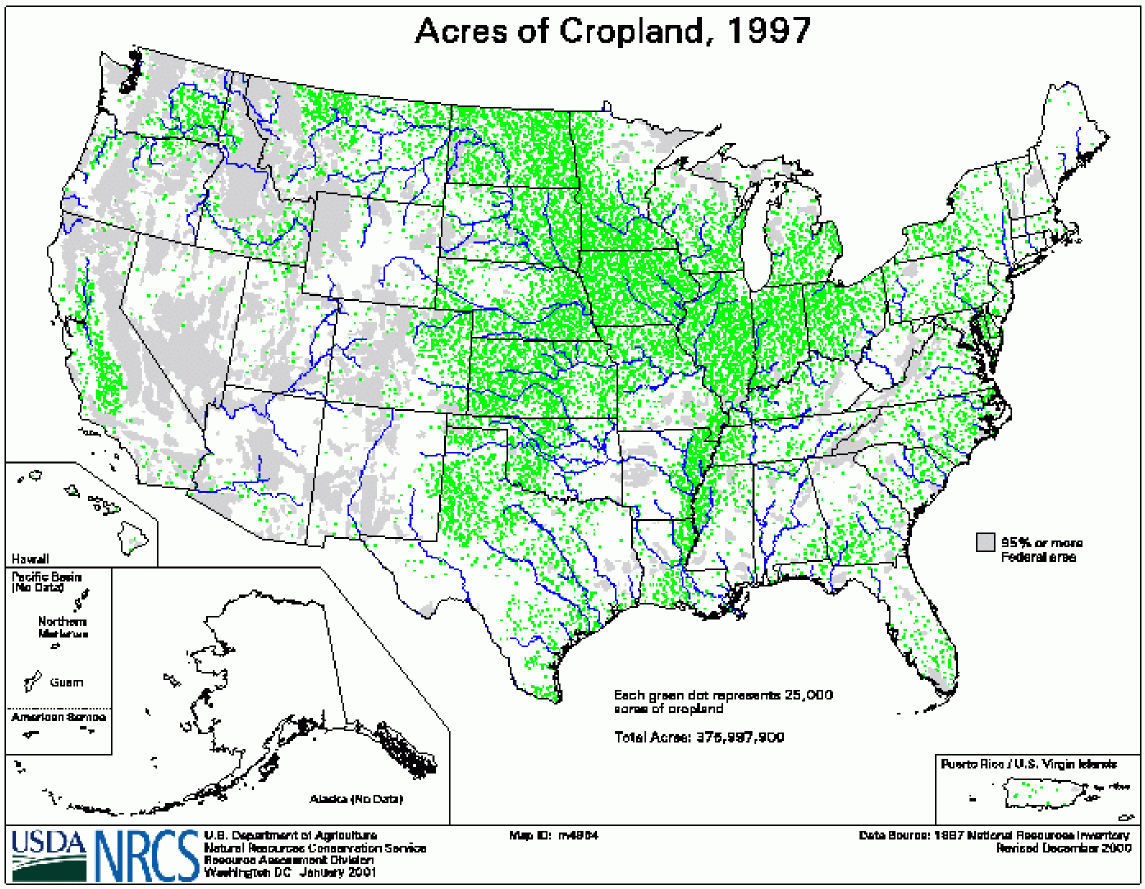


Figure 3-3: Cropland distribution in the United States (Source: NRCS)

Since most of the generating units in Indiana are coal-fired, it is likely that if any agricultural residues are going to be used, they will involve cofiring with coal. Thus modifications to the existing stations would be required. The costs incurred in these modifications could also hamper the introduction of biopower.

Several factors are seen as crucial in determining whether organic waste biomass will have a major role in the electricity generation sector. These include:

- Government support for biomass**:** Government support is needed to help make biomass resources more competitive with coal. This support could be in the form of grants for converting plants or tax credits for energy production from cofiring plants. The government might also need to provide tax incentives to farmers for the supplying of the agricultural residues. This would help reduce the cost of the input biomass fuels. All of these incentives are consistent with the government's energy policy of cleaner and more diversified energy sources. Several incentives are offered by both the federal and state governments as explained in Section 2.
- Stable growing market**:** This is important from both the supply and demand side. In Indiana, where the predominant organic waste biomass supply would be from

agricultural residues, the farmers who would be responsible for this supply will incur costs in the removal and transportation of the residues. This process might only be feasible if the farmer has some certainty of receiving a profit. A stable, growing demand market is required for this. From the demand side, the electricity generators would need to ensure stable supply prices in order to minimize risk. Since the residue supply will likely be from many suppliers (unlike the coal supply), the input price stability is important for generator operations.

- <u>Improved conversion technology</u>**:** Research is being conducted on the various conversion processes for organic waste biomass. The improved efficiency of the conversion process along with the benefits of reduced emissions would greatly help the cause of organic waste biomass as a fuel for electricity generation.

3.5 References

1. http://www.eere.energy.gov/RE/bio_resources.html
2. http://www.eere.energy.gov/state_energy/technology_overview.cfm?techid=3
3. http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/table7.html
4. http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/tableb6.html
5. http://www.eere.energy.gov/biopower/basics/ba_econ.htm
6. http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/table5.html
7. Zia Haq, "Biomass for Electricity Generation," Energy Information Administration, US Department of Energy.
8. http://www.eere.energy.gov/biopower/projects/index.htm
9. http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/rea.pdf
10. http://www.eere.energy.gov/state_energy/states_currfuelmix.cfm?state=IN
11. http://www.nrel.gov/
12. http://www.nass.usda.gov/census/census02/volume1/INVolume104.pdf
13. http://www.eere.energy.gov/state_energy/tech_biomass.cfm?state=IN
14. Environmental Law and Policy Center, "Repowering the Midwest: The Clean Energy Development plan for the Heartland," 2001.
15. http://www.eere.energy.gov/biopower/projects/ia_pr_co_IN1.htm
16. J.M. Kramer, "Agricultural biogas casebook", Sept 2002.
17. http://www.nrcs.usda.gov/technical/land/
18. W. Tyner, et al., "The Potential of Producing Energy from Agriculture," Purdue University, 1979.

4. Solar Energy

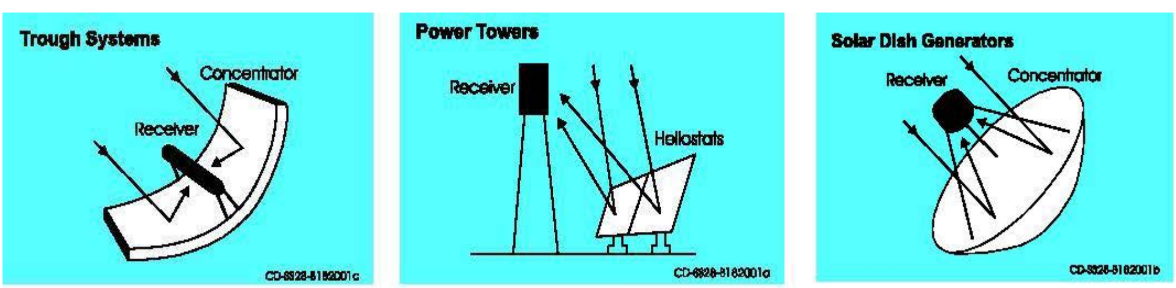
4.1 Introduction

Solar energy entails using the energy from the sun to generate electricity, provide hot water, and to heat, cool, and light buildings [1]. The solar energy can be converted either directly or indirectly into other forms of energy, such as heat or electricity.

Solar thermal energy is usually captured using a solar-energy collector. These collectors could either have fixed or variable orientation and could either be concentrating or non-concentrating. Variable orientation collectors track the position of the sun during the day whereas the fixed orientation collectors remain static. In the non-concentrating collectors, the collector[8] area is roughly equal to the absorber[9] area, whereas in concentrating collectors the collector area is greater[10] than the absorber area [2].

The fixed flat-plate collectors (non-concentrating) are usually used in applications that have low temperature requirements (200^{o}F), such as heating swimming pools, heating water for domestic use and spatial heating for buildings. There are many flat-plate collector designs but generally all consist of (1) a flat-plate absorber, which intercepts and absorbs the solar energy, (2) a transparent cover(s) that allows solar energy to pass through but reduces heat loss from the absorber, (3) a heat-transport fluid (air or water) flowing through tubes to remove heat from the absorber, and (4) a heat insulating backing.

Variable orientation, concentrating collectors are usually utilized in higher energy requirement applications, such as solar-thermal power plants where they use the sun's rays to heat a fluid, from which heat transfer systems may be used to produce steam which in turn is used together with a turbine-generator set to generate electricity. There are three types of solar-thermal power systems in use or under development. These are the parabolic trough, solar power tower, and solar dish [2], which are illustrated in Figure 4-1.



<u>Figure 4-1:</u> <u>Solar-thermal technologies</u> (Source: EIA)

[8] This is the area that intercepts the solar radiation.
[9] This is the area that absorbs the radiation.
[10] Sometimes several hundred times greater.

- The parabolic trough system has collectors that are parabolic in shape with the receiver system located at the focal point of the parabola. A working fluid is then used to transport the heat from the receivers systems to heat exchangers. This system is the most mature of the solar-thermal technologies with commercial production in California's Mojave Desert.
- The solar power tower system utilizes thousands of flat sun-tracking heliostats (mirrors) that concentrate the solar energy on a tower-mounted heat exchanger (receiver). This system avoids the heat loss during transportation of the working fluid to the central heat exchanger. This is a promising technology for large-scale grid connected power plants but is still in the developmental stages although a number of test facilities have been constructed around the world (e.g., in Barstow, California).
- The solar dish system utilizes concentrating solar collectors that concentrate the energy at the focal point of the dish. The concentration ratio achieved with the solar dish system is much higher than that obtained with the solar trough system. The heat generated from a solar dish system is converted to mechanical energy by heating the working fluid that was compressed when cold. The heated compressed working fluid is then expanded through a turbine or piston to produce work. The engine is coupled to an electric generator to convert the mechanical power to electric power. This system is still in the developmental and testing stages.

Table 4-1 illustrates further differences between the three types of solar thermal technologies [3].

	Parabolic Trough	Power Tower	Dish/Engine
Size	30-320 MW*	10-200 MW*	5-25 kW*
Operating Temperature (ºC/ºF)	390/734	565/1,049	750/1,382
Annual Capacity Factor	23-50%*	20-77%*	25%
Peak Efficiency	20%(d)	23%(p)	29.4%(d)
Net Annual Efficiency	11(d')-16%*	7(d')-20%*	12-25%*(p)
Commercial Status	Commercially Available	Scale-up Demonstration	Prototype Demonstration
Technology Development Risk	Low	Medium	High
Storage Available	Limited	Yes	Battery
Hybrid Designs	Yes	Yes	Yes
Cost			
$/m^2	630-275*	475-200*	3,100-320*
$/W	4.0-2.7*	4.4-2.5*	12.6-1.3*
$/W$_p$†	4.0-1.3*	2.4-0.9*	12.6-1.1*

* Values indicate changes over the 1997-2030 time frame.

† $/W$_p$ removes the effect of thermal storage (or hybridization for dish/engine). See discussion of thermal storage in the power tower TC and footnotes in Table 4.

(p) = predicted; (d) = demonstrated; (d') = has been demonstrated, out years are predicted values

Table 4-1: Characteristics of solar thermal electric power systems (Source: DOE)

Like all other renewable technologies, solar thermal energy has distinct advantages and disadvantages. The major advantages include:

- It is a free and inexhaustible resource;
- It helps diversify the portfolio of resources, thus reducing the potential impacts of events affecting other fuel sources, such as price increases;
- It reduces the reliance on imported fuels;
- Energy can be stored in the form of heat and dispatched when needed;
- It is a modular and scalable technology; and
- It is a source of clean, quiet, non-polluting energy (no emissions or chemical waste).

However, there are some disadvantages of solar thermal energy, namely:

- Solar is an intermittent source of energy (i.e., a cloudy day can greatly reduce output); and
- It has high equipment costs when compared to traditional technologies.

See the Appendix to this report for more information on solar thermal energy, including typical performance characteristics from a solar laboratory at Purdue University.

4.2 Economics of solar thermal technologies

The current large-scale (above 10 MW) concentrating solar power technologies have energy costs in the range of 9 cents/kWh to 12 cents/kWh. The hybrid systems which utilize solar technology together with conventional fuels have a cost of around 8 cents/kWh. It is forecast that within the next few decades the advancements in technology would reduce the cost of large-scale solar power to around 5 cents/kWh [4]. Table 4-2 shows the forecast costs of energy (COE) from the solar thermal technologies in areas with high solar resources [5].

		Levelized COE *(constant 1997 cents/kWh)*				
Technology	Configuration	1997	2000	2010	2020	2030
Dispatchable Technologies						
Solar Thermal	Power Tower	--	13.6*	5.2	4.2	4.2
	Parabolic Trough	17.3	11.8	7.6	7.2	6.8
	Dish Engine -- Hybrid	--	17.9	6.1	5.5	5.2
Intermittent Technologies						
Solar Thermal	Dish Engine (solar-only configuration)	134.3	26.8	7.2	6.4	5.9

* COE is only for the solar portion of the year 2000 hybrid plant configuration.

Table 4-2: Comparative costs of different solar thermal technologies (Source: Sandia National Laboratories)

4.3 State of solar energy nationally

The net generation of electricity from solar energy nationally was 494,158 kWh with a total installed capacity of 387 MW in 2001. The generation from solar energy was about 0.6 percent of the total non-hydro renewable energy generated in 2001 [6].

Figures 4-2 and 4-3 show the annual solar radiation in the U.S for different collector categories. Figure 4-2 shows the annual average solar radiation with a fixed, flat-plate, collector orientation fixed at its latitude whereas Figures 4-3 shows the annual average solar radiation for tracking, concentrating collectors [7]. The flat-plate collector's ability to use indirect or diffuse light allows it to outperform the concentrating collectors in areas where there is less direct sunlight. Conversely, the concentrating collector works better in regions with more intense sunlight. For example, the average solar radiation for a flat-plate is about 500 Watt-hours per square meter more than for a concentrating collector, while concentrating collectors pick up about 1,000 more Watt-hours per square meter in the Mojave Desert region of California.

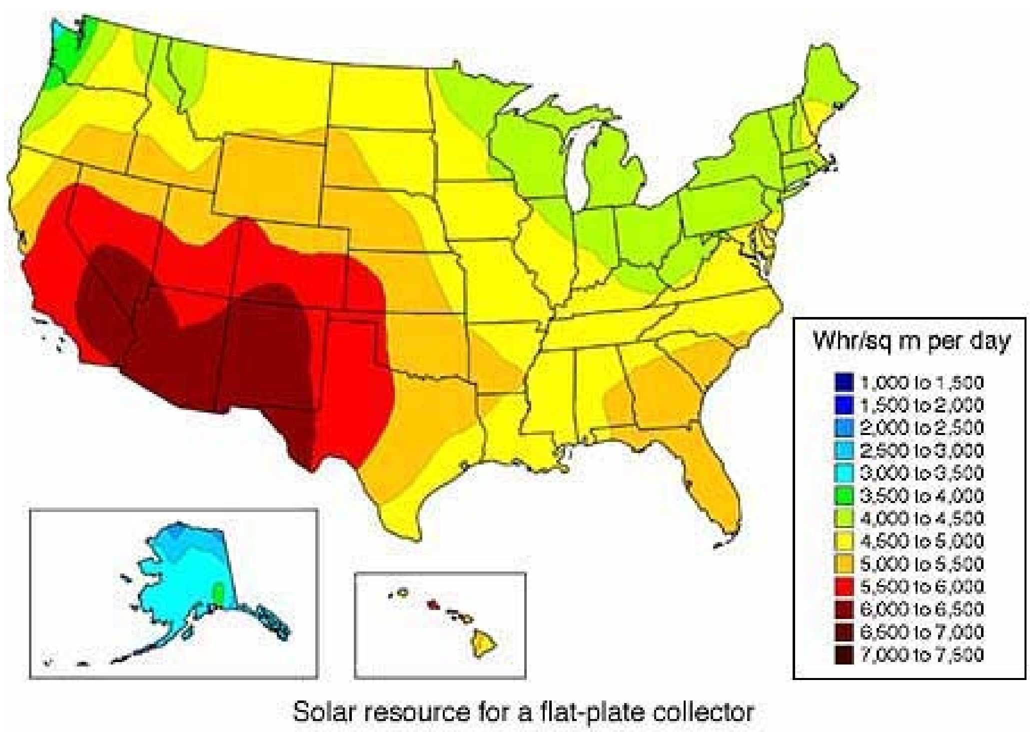


Figure 4-2: Annual average solar radiation for a flat-plate collector (Source: DOE)

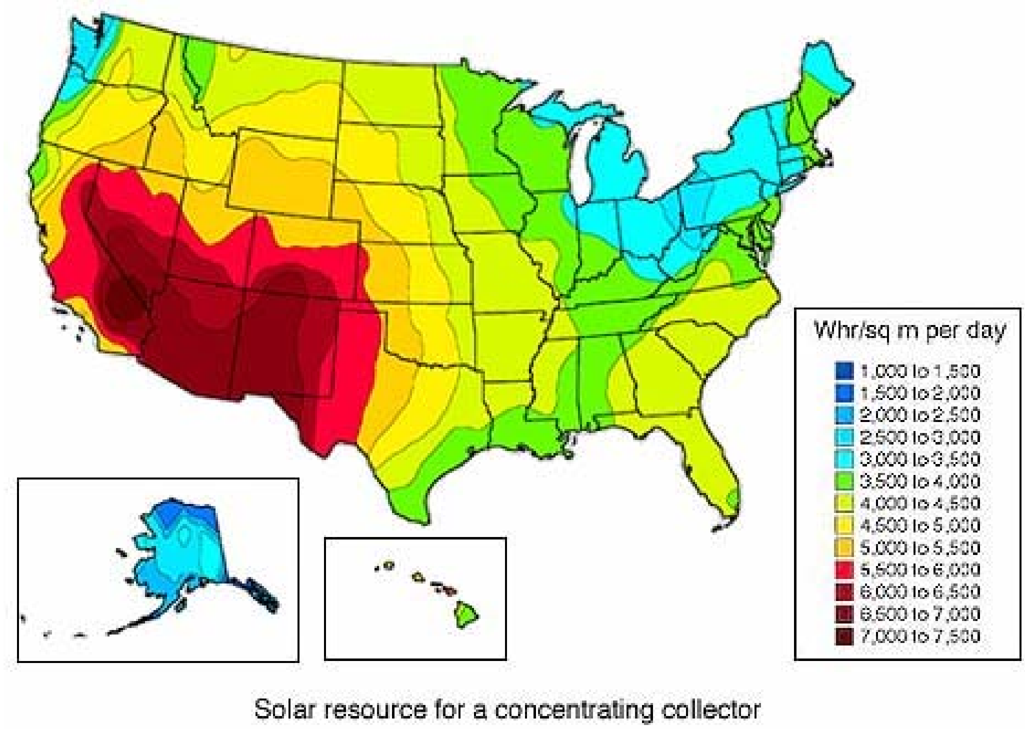


Figure 4-3: Annual average solar radiation for a concentrating collector (Source: DOE)

These maps clearly illustrate the potential for solar power in the southwestern parts of the United States. There are currently several solar projects in this area [8]. In the California Mojave Desert lies the largest grid connected solar project in the nation. It is a parabolic trough system and has an installed capacity of around 360 MW. This is over 95 percent of the total solar power capacity in the U.S. It is a hybrid station which also has gas as an input to assist the system during periods of low levels of solar energy. The system is mainly used as a peaking station as the system peak in the area is predominantly driven by air-conditioning loads that coincide with the maximum output of the facility.

The other major solar project is in Barstow, California where the Solar Two Power Tower is located. The Solar Two facility is a continuation of the Solar One facility with modifications made to the heat transfer systems. The Solar One facility used oil as the transfer fluid whereas the Solar Two facility uses molten salt. The facility consists of 1,818 heliostats and a total generating capacity of 10 MW. There are currently many projects in the Southwest investigating the long term use of solar dish systems [9].

The total domestic shipments of solar thermal collectors were 11.0 million square feet in 2002 [6]. This represents an increase from 10.3 millions square feet in the previous year. The majority of shipments were low-temperature type collectors (96 percent) while medium-temperature collectors represented 4 percent of total shipments. Virtually all low temperature solar thermal collectors shipped in 2001 were used for the heating of swimming pools. Medium-temperature collectors were used primarily for water and space heating applications. Florida and California were the top destinations of solar thermal collectors, accounting for over half of all domestic shipments. Figure 4-4 illustrates the top states for domestic shipments of solar thermal collectors in 2002.

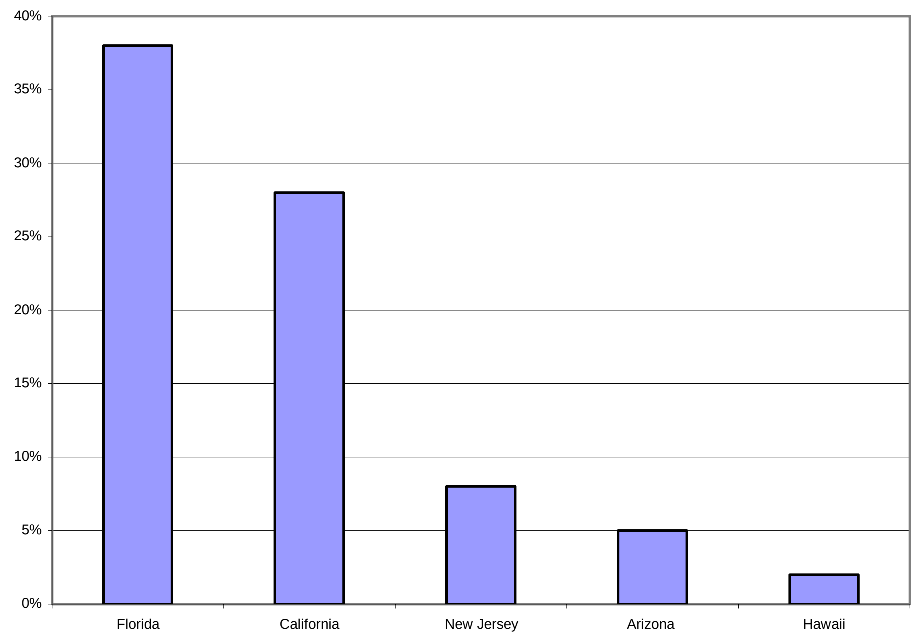


Figure 4-4: Top domestic destinations for solar thermal collectors (Source: EIA)

4.4 Solar energy in Indiana

Indiana has relatively little potential for grid-connected solar projects like those in California [7] because of the lack of annual solar radiation, as shown in Figures 4-2 and 4-3. There is, however, some potential (more so in the southern part of the state) for water (swimming pool and domestic) and building heating using flat-plate collectors. In 2002, Indiana had very few domestic shipments of solar thermal collectors.

The actual viability of installing solar energy water heating within Indiana would depend on the microclimate of the area of concern. The typical initial cost of the solar water heating system is about $1,500 to $3,000 and the typical payback period is between 4 to 8 years [10].

There is currently an initiative being pursued by DOE's Solar Building Program where the aim is to displace some 0.17 percent of the total energy consumption with the aid of solar water heating, space heating and cooling [11]. DOE's Million Solar Roofs program is also aimed at increasing the number of buildings using solar power for their water and space heating and cooling needs. The goal is to have one million buildings using this technology by 2010. This is not limited to thermal solar but also includes photovoltaics.

The following incentives [12] could help with the introduction of solar energy within Indiana:

- Renewable Electricity Production Credit which credited renewable energy producers 1.8 cents/kWh during the first ten years of operation. This federal program expired at the end of 2003. A renewal of the program was included in the comprehensive energy legislation that did not make it out of Congress in 2003. It may be considered in upcoming sessions.
- Renewable Energy Systems Exemption provides property tax exemptions for active solar equipment used for heating and cooling.
- Alternative Power and Energy Grant Program offers grants of up to $30,000 to enable businesses and institutions to "install and study alternative and renewable energy system applications" (solar thermal is an acceptable technology).
- Green Pricing Program is an initiative offered by some utilities that gives consumers the option to purchase power produced from renewable energy sources at some premium.
- Net Energy Credit: Facilities generating less than 1000 kWh per month from renewable sources are eligible to sell the excess electricity to the utility. Facilities generating more than 1000 kWh per month need to request permission to sell the excess electricity to the utility.
- Emissions Credits: Electricity generators that do not emit nitrogen oxides (NO_x) and that displace utility generation are eligible to receive NO_x emissions credits under the Indiana Clean Energy Credit Program [13]. These credits can be sold on the national market.

The reduction in cost of low temperature solar thermal technology together with Federal and State incentives and programs would be essential to increase the use of solar thermal energy within Indiana.

4.5 References

1. http://www.eere.energy.gov/RE/solar_basics.html
2. http://www.eia.doe.gov/kids/renewable/solar.html#Solar%20Dish
3. http://www.eere.energy.gov/power/pdfs/solar_overview.pdf
4. http://www.energylan.sandia.gov/sunlab/overview.htm
5. http://www.energylan.sandia.gov/sunlab/PDFs/financials.pdf
6. http://www.eia.doe.gov/cneaf/solar.renewables/page/solarthermal/solarthermal.html
7. http://www.eere.energy.gov/state_energy/tech_solar.cfm?state=IN
8. http://www.energylan.sandia.gov/sunlab/documents.htm
9. http://www.energylan.sandia.gov/sunlab/projects.htm
10. http://www.eere.energy.gov/erec/factsheets/solrwatr.html
11. http://www.eere.energy.gov/solarbuildings/market.html
12. http://www.dsireusa.org
13. http://www.in.gov/idem/energycredit/ecreditfct.pdf

5. Photovoltaic Cells

5.1 Introduction

Photovoltaic (PV) cells allow the conversion of photons in sunlight into electricity. The photovoltaic cell is a non-mechanical device constructed from semiconductor material (see Figure 5-1). When the photons in light strike the surface of a photovoltaic cell, the photon may be reflected, pass through or be absorbed by the cell. The absorbed photons cause free electrons to migrate thus causing "holes." The front surface of the photovoltaic cell is made more receptive to these migrating electrons. The resulting imbalance of charge between the cell's front and back surfaces creates a voltage potential like the negative and positive terminals of a battery. When these two surfaces are connected through an external load, electricity flows [1].

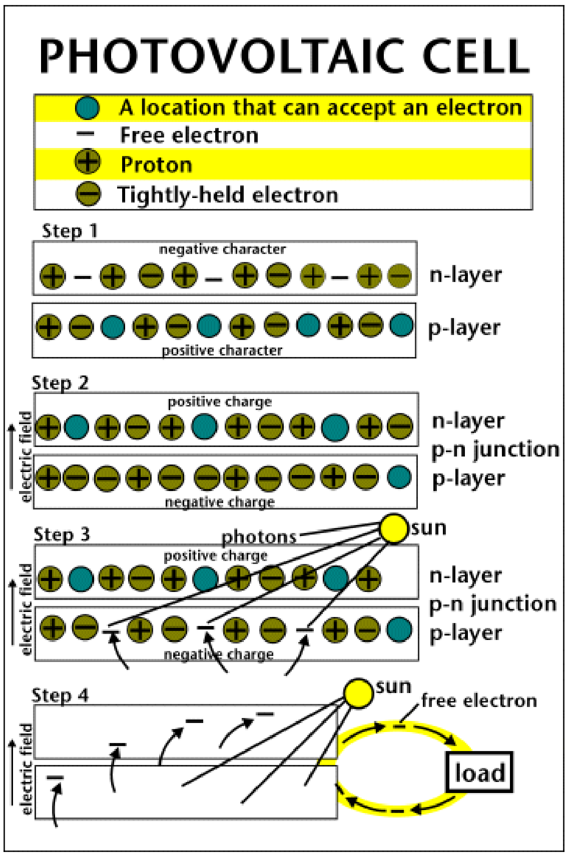


Figure 5-1: Photovoltaic cell operation (Source: EIA)

The photovoltaic cell is the basic building block of a PV system. The individual cells range in size from 0.5 to 4 inches across with a power output of 1 to 2 watts. To increase the power output of the PV unit, the cells are usually electrically connected into a packaged weather-tight module. About 40 cells make up a module, providing enough power for a typical incandescent light bulb. These modules could further be connected into arrays to increase the power output. About 10 modules make up an array and about

10 to 20 arrays are enough to supply power to a house [2]. Hundreds of arrays could be connected together for larger power applications. The performance of PV units depend upon sunlight, the more sunlight the better the performance.

Simple PV systems are used to power calculators and wrist watches, whereas more complicated systems are used to provide electricity to pump water, power communication equipment, and even provide electricity to houses.

There are currently two major types of PV cells: crystalline silicon-based and thin film-based. Silicon PV cells, the most common, typically cost more but are more efficient. Efficiency ranges of 12 to 15 percent are normal with SunPower Corporation recently announcing the development of a silicon-based cell that achieves 21.5 percent efficiency [3]. Thin-film cells have a normal efficiency of 7 percent with a reported high of 10.7 percent [3].

"Flat-plate" PV arrays can be mounted at a fixed-angle facing south, or they can be mounted on a tracking device that follows the sun, allowing them to capture more sunlight over the course of a day. Some PV cells are designed to operate with concentrated sunlight, and a lens is used to focus the sunlight onto the cells. This approach has both advantages and disadvantages compared with flat-plate PV arrays. The main idea is to use very little of the expensive semiconducting PV material while collecting as much sunlight as possible. The lenses cannot use diffuse sunlight, but must be pointed directly at the sun. Therefore, the use of concentrating collectors is limited to the sunniest parts of the country.

The main advantages to using PV systems are [4]:

- For PV systems, the conversion from sunlight to electricity is direct so no bulky mechanical generator systems are required, leading to high system reliability;
- The input fuel to PV systems is sunlight which is free thus implying low fuel costs and also the lack of moving parts[11] results in lower maintenance costs;
- There are no emissions (by-products) from PV systems;
- The modular nature of PV systems (PV arrays) allow for variable output power configurations; and
- PV systems are usually located close to the load site and this reduces the amount of transmission capacity (lines and substations) needed to be constructed.

The main disadvantages to using PV systems are:

- The sun is an intermittent source of energy (i.e., a cloudy day can greatly reduce output); and
- It has high equipment costs when compared to traditional technologies.

[11] There are no moving parts for fixed-orientation PV units and minimal slow-moving parts for tracking PV units.

Despite the intermittent nature of sunlight, PV has added potential as a supplier of electricity during periods of peak demand, since it produces more electricity during sunny days when air conditioning loads are the greatest. It is at a relative disadvantage in providing continuous baseload power since the supply is intermittent and variable. Thus, other fuels or storage devices might be required to ensure a reliable supply during periods of low solar radiation.

See the Appendix to this report for more information on PV systems, including typical performance characteristics from a solar laboratory at Purdue University.

5.2 Economics of PV systems

The cost of PV installation depends on the installation size and the degree to which it utilizes standard off-the-shelf components [5]. The capital costs range from $5/Watt for bulk orders of small standardized systems to around $11/Watt for small, one-of-a-kind grid connected PV systems [2, 5]. The recent trend in PV module prices is shown in Figure 5-2 [6]. From August 2001 to April 2004, PV prices dropped by 16 percent. The recent leveling of prices is believed to be due to increased demand. As production increases in response to the higher demand, prices are expected to continue to fall.

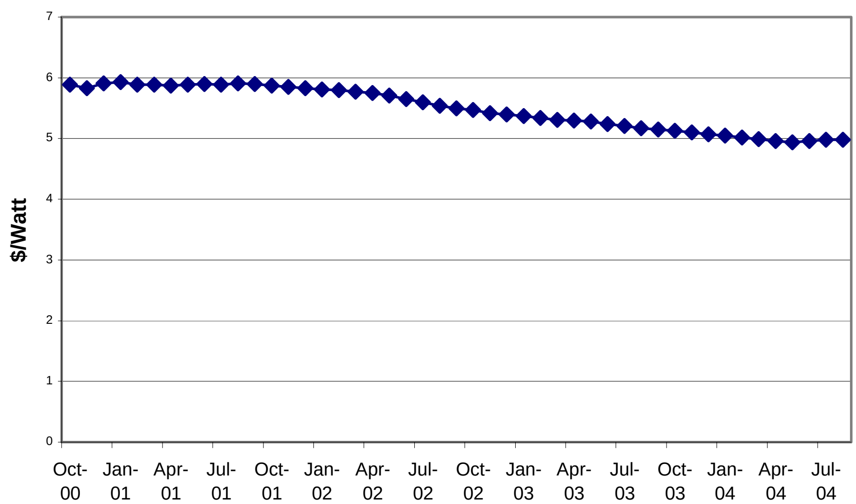


Figure 5-2: Historical PV module prices (Source: Solarbuzz)

The operating and maintenance (O&M) costs for PV systems are very low. The estimates for these O&M costs currently range from about 0.5 cents/kWh to 0.63 cents/kWh [5, 7]. These low O&M costs lead to levelized PV energy costs ranging from about 20 cents/kWh to 50 cents/kWh [2, 5, 8]. At these prices, PV is cost effective for residential customers located farther than a quarter of a mile from the nearest utility line [8] because of the relatively high costs of distribution line construction. The energy costs of PV systems are expected to decline in the future to below 20 cents/kWh in 2020 [5, 9].

5.3 State of PV systems nationally

Since the flat-plate PV system can utilize direct and indirect (diffuse) sunlight as compared to the concentrating type PV system [10], the solar resources for these two systems are different in the U.S. as shown in Figures 5-3 and 5-4.

As can be seen from the solar resource maps, the southwestern United States has the highest solar resources in the country for both the flat plate and the concentrating PV systems, while the Northeast has the worst solar resources. Accordingly, California leads the nation in the amount of PV capacity installed. According to NREL's REPiS, California had 48.5 MW of grid-connected PV capacity at the end of 2002, with another 74.5 MW planned. Arizona was second with 9.5 MW of installed PV capacity [11].

At present, the majority of the PV market lies in off-grid applications (e.g., telecommunications and transportation construction signage); however, there is an increase in the number of PV systems being used in the residential sector [10]. Off-grid applications are especially suited to PV systems as usually high levels of reliability and low levels of maintenance are required, while the high cost of grid connection would make the PV system economically advantageous [2, 12].

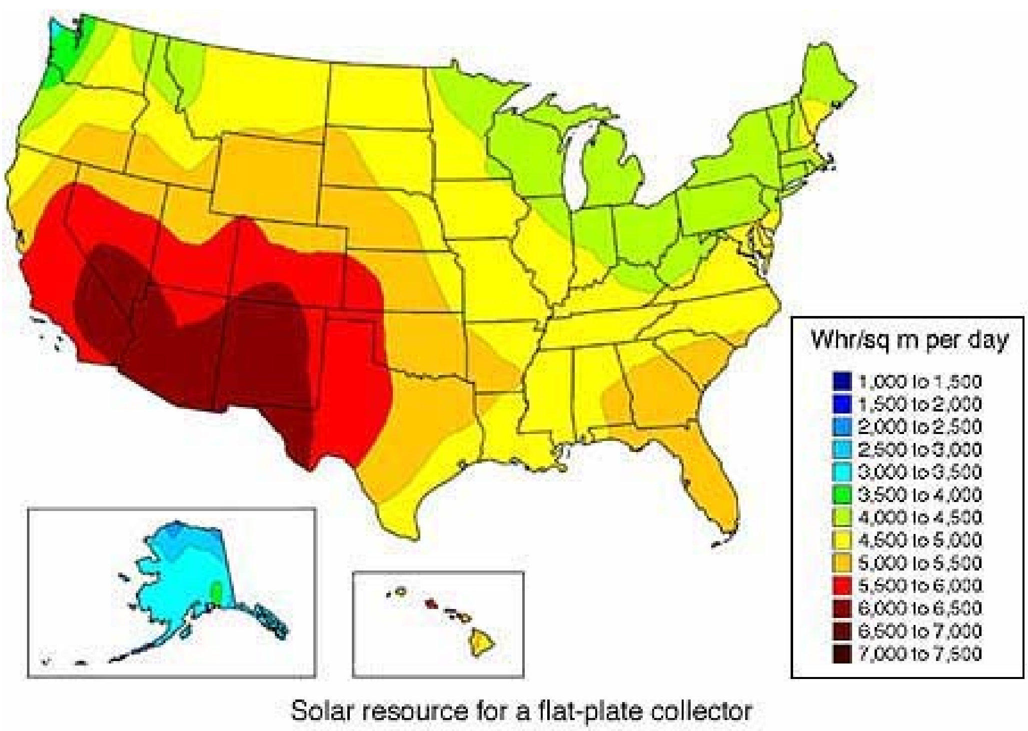


Figure 5-3: Annual average solar radiation for a flat-plate collector (Source: DOE)

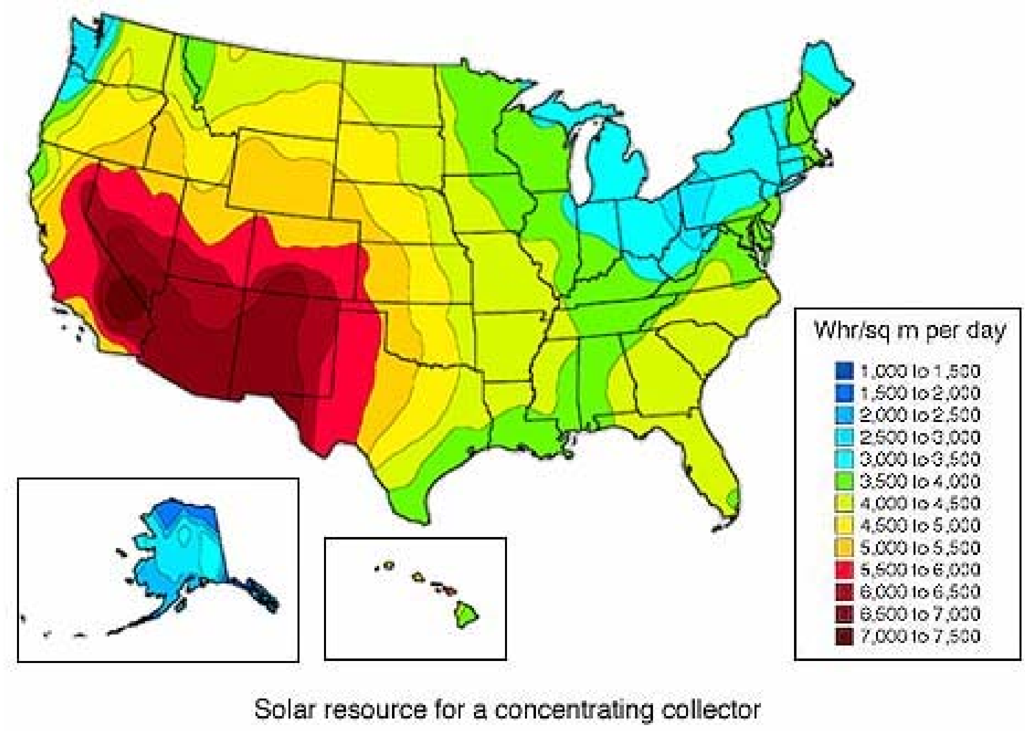


Figure 5-4: Annual average solar radiation for a concentrating collector (Source: DOE)

In 1998, a study was carried out by EIA [13] to determine the trends in the U.S. photovoltaic industry. The report divided the national PV market into several niche markets that accounted for 15 MW of the 1998 domestic shipments, as shown in Table 5-1. These markets were labeled and described as follows [13]:

- Building Integrated Photovoltaics (BIPV): These are PV arrays mounted on building roofs or facades. For residential buildings, analyses have assumed BIPV capacities of up to 4 kW per residence. Systems may consist of conventional PV modules or PV shingles. This market segment includes hybrid power systems, combining diesel generator set, battery, and photovoltaic generation capacity for off-grid remote cabins.
- Non-BIPV Electricity Generation (grid interactive and remote): This includes distributed generation (e.g., stand-alone PV systems or hybrid systems including diesel generators, battery storage, and other renewable technologies), water pumping and power for irrigation systems, and power for cathodic protection. The U.S. Coast Guard has installed over 20,000 PV-powered navigational aids (e.g., warning buoys and shore markers) since 1984.
- Communications: PV systems provide power for remote telecommunications repeaters, fiber-optic amplifiers, rural telephones, and highway call boxes. Photovoltaic modules provide power for remote data acquisition for both land-based and offshore operations in the oil and gas industries.

- Transportation: Examples include power on boats, in cars, in recreational vehicles, and for transportation support systems such as message boards or warning signals on streets and highways.
- Consumer Electronics: A few examples are calculators; watches; portable and landscaping lights; portable, lightweight PV modules for recreational use; and battery chargers.

EIA currently tracks the shipments[12] of PV systems within the nation [12]. These domestic shipments provide an indication of the status of the PV market. Table 5-1 shows the annual domestic shipments and imports of PV cells in the United States.

Year	Domestic photovoltaic cells and modules (kilowatts)	Imported photovoltaic cells and modules (kilowatts)
1993	6,137	1,767
1994	8,363	1,960
1995	11,188	1,337
1996	13,016	1,864
1997	12,561	1,853
1998	15,069	1,931
1999	21,225	4,784
2000	19,839	8,821
2001	36,310	10,204
2002	45,313	7,297
Total	**189,021**	**41,818**

Table 5-1: Annual domestic shipments and imports of PV cells and modules in the United States (Source: EIA)

As can be seen from Table 5-1, the total use of PV systems is increasing. Electricity generation is currently the largest end-use application of PV systems (grid interactive and remote) with communications and transportation coming in second and third respectively [12].

Several projects are currently underway to increase the number of grid-connected PV systems [14]. The following list includes some projects from the Midwest region [4]:

- Five hundred houses in Wisconsin to be equipped with rooftop PV systems by 2005 and several dozen schools equipped with 20-50kW PV systems are planned in Ohio, Illinois and Wisconsin. These projects will be run under DOE's Million Solar Roofs (MSR) project.
- The "Brownfields to Brightfields" project in Chicago is a partnership between Spire Solar and the City of Chicago where the city is committed to purchase PV

[12] The reason for keeping track of shipments rather that energy produced could be because of the large number of off-grid PV applications.

systems for industrial sites in exchange for the development of PV manufacturing capability in the city.

- City of Toledo (Ohio) is working on a partnership with First Solar and Powerlight and is planning several 100kW PV projects at schools and large commercial buildings.

The national PV Roadmap [15] provides a guide to building the domestic PV industry. One of the objectives stated in the roadmap is that PV grid applications should increase such that 10 percent of the national peak generation capacity should be met with PV systems by 2030. The cumulative installed capacity in 2020 is expected to be 15 GW. It is expected that of the 2020 PV installations, 50 percent of the applications will be in AC distributed capacity generation (remote, off-grid power for applications including cabins, village power, and communications), 33 percent in DC and AC value applications (consumer products such as cell phones, calculators, and camping equipment), and 17 percent in AC grid (wholesale) generation (grid-connected systems including BIPV systems) [13, 15]. The forecast end-user price in the roadmap is between $3/W and $4/W by 2010 [15].

Distributors have identified markets where photovoltaic power is cost-effective now, without subsidies [9]. Examples include: (1) rural telephones and highway call boxes, (2) remote data acquisition for both land-based and offshore operations in the oil and gas industries, (3) message boards or warning signals on streets and highways, and (4) off-grid remote cabins, as part of a hybrid power system including batteries. In the longer term, it will take a combination of wholesale system price below $3/W and large volume dealers for PV to be cost-effective in the residential grid-connected market. PV installed system costs must fall to a range where they are competitive with current retail electric rates of 8 to 12 cents/kWh in the residential market and 6 to 7 cents/kWh in the commercial market.

Federal incentives such as the MSR initiative are aimed at increasing the amount of grid-connected PV systems nationally. The MSR program neither directs nor controls the activities of the state and community partnerships, nor does it provide funding to design, purchase or install solar systems. Instead, MSR brings together the capabilities of the federal government with key national businesses and organizations, and focuses them on building a strong market for solar energy applications on buildings. MSR partnerships apply annually for DOE grant funding. The grants sponsor a variety of activities in conjunction with state and local resources. These include [16]:

> *"1) Work with local and regional home builders to include solar energy systems in new homes;*
> *2) Work with local lending institutions to develop financing options for solar energy systems;*
> *3) Develop and implement marketing and consumer education plans and workshops;*
> *4) Work with local officials to develop standard building codes and practices for solar installations;*

5) Develop training programs for inspectors and installers."

In 2001, 34 partners were awarded $1.5 million for development and implementation activities [16]. Further state driven programs and initiatives such as the "Green" power programs where consumers are willing to pay a premium for clean energy (e.g., PV) would further help increase the use of PV systems [13].

5.4 PV systems in Indiana

While Indiana does not have excellent solar resources, there is some potential for fixed, flat-plate PV systems. As of 2002, Indiana had grid-connected photovoltaic installations with a total installed capacity of 21.8 kW at several locations within the state [11, 17], as shown in Table 5-2. These range from providing electricity to schools to residential and commercial applications.

Location	Fuel Type	Plant Name	Capacity (kW)
Fort Wayne	Solar	American Electric Power	0.8
Lafayette	Solar	Commercial	3.6
Lafayette	Solar	IBEW	5.6
Fort Wayne	Solar	MSR School	1.0
Indianapolis	Solar	Orchard School	1.2
Unknown	Solar	PV installation in Indiana	1.0
Unknown	Solar	Residential Installation in Indiana	3.6
Fort Wayne	Solar	Science Central	1.0
Buffalo	Solar	Residential Installation	4.0

Table 5-2: Grid-connected PV systems in Indiana (Source: DOE)

In addition, six schools installed PV systems in the PSI Energy service territory in 2003. Two additional schools are planning on installing PV systems. PSI Energy has contracted with Altair Energy and the NEED Project to provide an educational program for these schools. Also, four residential homes in PSI Energy's service territory installed 1.6 kW PV systems in 2003. The schools are:

- Carmel High School
- Greenwood Middle School
- Doe Creek Middle School
- Rushville High School
- New Albany High School
- West Lafayette High School
- Clay City Junior/Senior High School (to be installed)
- Manchester High School (to be installed)

PSI Energy is also installing an 8 kW PV system at its Bloomington field office. The system is to be grid-connected and operational in the summer of 2004.

In Indianapolis in 2001, BP Amoco opened the first of its BP Connect stores in the U.S. The store incorporates thin film PV collectors in the canopy over the fuel islands to produce electricity for use on site [18].

The remote locations of farming residences in the state of Indiana make the PV alternative more attractive. The high installation costs are offset by little or no operating costs, since there is no fuel required[13] and there are no moving parts. Energy from PV systems currently ranges from 20 cents/kWh to 50 cents/kWh [2]. Although this is high for grid connected consumers, it may be acceptable for remote consumers and applications where grid connection is too expensive or where diesel generators are too expensive and unreliable.

The lack of solar resources combined with low electricity costs within the state results in the break-even cost of grid-connected PV systems being low in Indiana, as shown in Figure 5-5 [19].

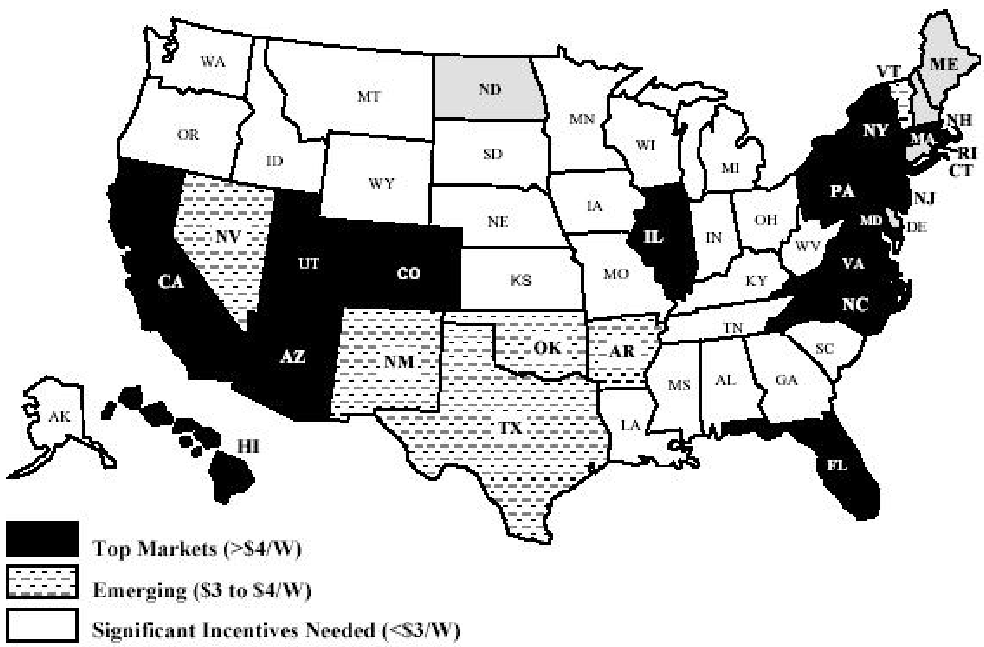


Figure 5-5: 1999 State-by-state mapping of break-even prices for grid-connected PV systems (Source: DOE)

[13] Besides the energy from the sun.

Thus, for grid-connected PV systems to become competitive within Indiana, Federal and State government incentives are required. The forecast cost of PV systems is between $3 and $4/W by 2010 [15] but this is still above the break-even costs of entry of PV systems within Indiana. There are several Federal and State incentives available within Indiana[14]:

- Million Solar Roofs Initiative which was discussed in Section 5.3.
- Renewable Electricity Production Credit which credited renewable energy producers 1.8 cents/kWh during the first ten years of operation. This federal program expired at the end of 2003. A renewal of the program was included in the comprehensive energy legislation that did not make it out of Congress in 2003. It may be considered in upcoming sessions.
- Distributed Generation Grant Program offers awards of up to $30,000 to commercial, industrial, and government entities to “install and study alternatives to central generation” (PV falls under one of these alternatives).
- Alternative Power and Energy Grant Program offers grants of up to $30,000 to enable businesses and institutions to “install and study alternative and renewable energy system applications (PV is an acceptable technology).
- Green Pricing Program is an initiative offered by some utilities that gives consumers the option to purchase power produced from renewable energy sources at some premium.
- Net Energy Credit: Facilities generating less than 1000 kWh per month from renewable sources are eligible to sell the excess electricity to the utility. Facilities generating more than 1000 kWh per month need to request permission to sell the excess electricity to the utility.
- Emissions Credits: Electricity generators that do not emit nitrogen oxides (NO_x) and that displace utility generation are eligible to receive NO_x emissions credits under the Indiana Clean Energy Credit Program [20]. These credits can be sold on the national market.

5.5 References

1. http://www.eia.doe.gov/kids/energyfacts/sources/renewable/solar.html
2. http://www.eere.energy.gov/state_energy/technology_overview.cfm?techid=1
3. http://www.eere.energy.gov/solar/cfml/news_detail.cfm/news_id=6712
4. http://www.eere.energy.gov/solar/photovoltaics.html
5. Environmental Law and Policy Center, “Repowering the Midwest: The Clean Energy Development plan for the Heartland,” 2001.
6. http://www.solarbuzz.com/ModulePrices.htm
7. http://www.eere.energy.gov/power/pdfs/pv_overview.pdf
8. http://www.eere.energy.gov/pv/pvmenu.cgi?site=pv&idx=1&body=aboutpv.html
9. http://www.energylan.sandia.gov/sunlab/PDFs/financials.pdf
10. http://www.eere.energy.gov/state_energy/tech_solar.cfm?state=IN
11. http://www.nrel.gov
12. http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/rea.pdf
13. http://www.eia.doe.gov/cneaf/solar.renewables/rea_issues/solar.html

[14] These initiatives are also discussed in Section 4.4.

14. http://www.eia.doe.gov/oiaf/aeo/assumption/pdf/0554(2003).pdf
15. http://www.sandia.gov/pv/docs/PVRMPV_Road_Map.htm
16. http://www.millionsolarroofs.org/articles/static/1/1023898520_1023713795.html
17. http://www.eere.energy.gov/state_energy/opfacbytech.cfm?state=IN
18. http://www.bp.com/genericarticle.do?categoryId=120&contentId=2001318
19. http://millionsolarroofs.org/articles/static/1/binaries/Residential_Customer_Sited_PV_Markets_1999_with_Emissions_Data.pdf
20. http://www.in.gov/idem/energycredit/ecreditfct.pdf

6. Fuel Cells

6.1 Introduction

A fuel cell converts chemical potential energy to electrical energy similar to a battery except that it does not "run down" or require charging but will produce energy as long as fuel is supplied [1]. The basic fuel cell consists of two electrodes encompassing an electrolyte, as shown in Figure 6-1 below.

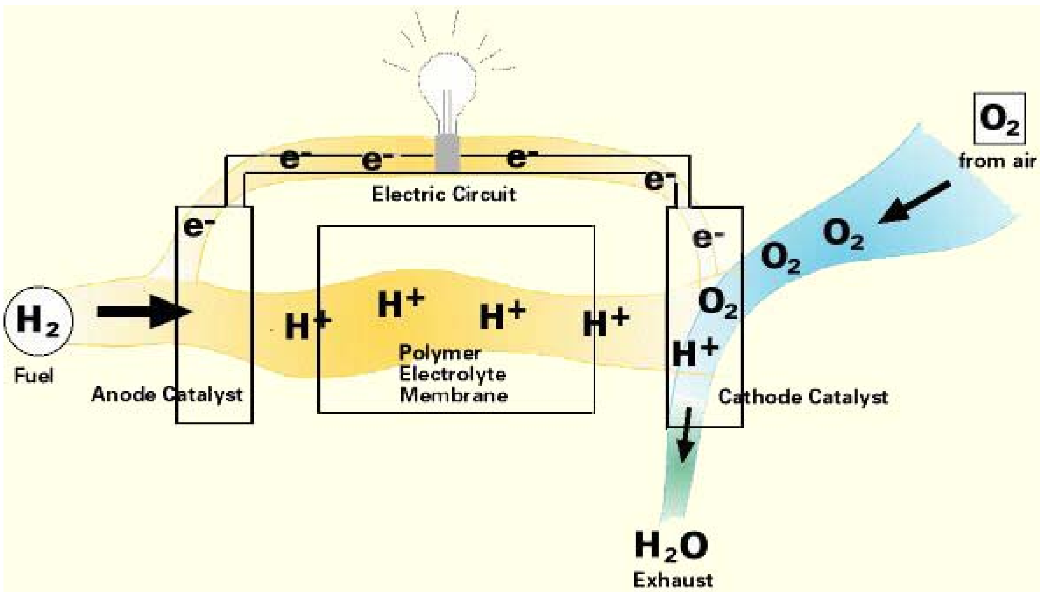


Figure 6-1: Schematic of basic fuel cell operation (Source: www.fuelcells.org)

Hydrogen (H) is fed into the anode and oxygen (or air) enters the fuel cell through the cathode. The hydrogen atom releases its electron (e^-) with the aid of a catalyst in the anode and the proton (H^+) and electron pursue separate paths before rejoining at the cathode. The proton passes through the electrolyte whereas the electron flows through an external electric circuit (electric current). The proton, electron and oxygen are rejoined at the cathode to produce water as the exhaust emission [1].

There are five basic fuel cell types which are currently being pursued by manufacturers. These are the phosphoric acid (PAFC), proton exchange membrane (PEMFC), molten carbonate (MCFC), solid oxide (SOFC) and alkaline (AFC). Currently the PAFC is commercially available. The PEMFC seems to be most suitable for small-scale distributed applications (e.g., building co-generation systems for homes and businesses) and the higher temperature SOFCs and MCFCs might be suitable for larger-scale utility applications because of their high efficiencies[15] [2].

There are four main attractive features of fuel cell technology [2]:

[15] The efficiencies of fuel cells are increased through the reuse of high temperature "waste" heat.

- High generation efficiencies exceeding 80 percent;
- Virtual elimination of most energy-related air pollutants;
- Modularity that enables fuel cells to be used in a wider variety of applications of differing energy requirements; and
- Lack of moving parts (chemical process); therefore there is less noise and less maintenance than conventional generation technologies (turbine-generator sets).

There are some drawbacks to using fuel cells, mostly the high capital cost of fuel cells and fuel extraction [1]. Although the fuel cells run on hydrogen, the most plentiful gas in the universe, hydrogen is never found alone in nature. Therefore, efficient methods of extracting hydrogen in large quantities are required. Currently, hydrogen is more expensive that other energy sources such as coal, oil or natural gas [1]. Researchers are working on improving “fuel reformers” to extract hydrogen from fossil fuels[16] (natural gas) or water. Using fossil fuels is seen as a commercial short-term solution whereas the electrolysis of water from solar or wind energy is seen as a more appropriate long-term solution for obtaining hydrogen for fuel cells [2].

Fuel cells have many potential applications ranging from powering motor vehicles to providing primary (or backup) power for homes and industries (stationary applications) [3]. Stationary fuel cells are used for backup power, power for remote locations, stand-alone power plants for towns and cities, distributed generation and co-generation systems. A typical residential fuel cell system consists of three main components [1]:

- <u>Hydrogen Fuel Reformer:</u> This unit allows the extraction of hydrogen from the hydrogen-rich fuel, e.g., natural gas;
- <u>Fuel Cell Stack:</u> Converts the hydrogen and oxygen from air into electricity, water vapor and heat; and
- <u>Power Conditioner:</u> Converts the direct current (DC) from the fuel cell to alternating current (AC) for use by residential appliances.

Fuel cells have also been extensively used in landfill/wastewater treatment plants. The hydrogen for these fuel cells is extracted from the methane gas produced in the landfills. The Northeast Regional Biomass program has completed a study on the feasibility of using bio-based fuels with stationary fuel cell technologies [4]. The results show that this is technically feasible for providing a source of clean, renewable electricity over the long-term.

[16] Although fossil fuels could be used, since the extraction of the hydrogen is via a chemical process and not by combustion, less pollutants are released.

6.2 Economics of fuel cells

The currently available PAFC units cost around $3,000/kW [1, 2]. These units are only produced in 200 kW sizes which are suitable for larger power applications. Several companies are currently researching the production of smaller scale (2 to 4 kW) fuel cell units for residential use. Fuel Cell Technologies (FCT) estimates that the cost of residential fuel cell units will drop to between $500/kW and $1000/kW once commercial production begins [1]. Others estimate the cost of these units to reach levels as low as $200/kW [2]. The expected payback period for the residential fuel cell units is forecast to be around 4 years [1]. According to DOE, the price of fuel cells needs to fall to the $400/kW to $750/kW range for them to be commercially viable [5].

6.3 State of fuel cells nationally

Fuel cells are currently in service at over 150 landfills and wastewater treatment plants in the United States. A few of these projects include [1]:

- Groton Landfill (Connecticut): Installed fuel cell in 1996. This plant produces about 600,000 kWh of electricity per year.
- Yonkers Wastewater Treatment Plant (New York): Installed fuel cell in 1997 and produces over 1.6 million kWh/year.
- City of Portland: Installed fuel cell that utilizes anaerobic digester gas from a wastewater facility. It generates 1.5 million kWh/year and reduces the electricity bill of the treatment plant by $102,000/year.

In addition to landfill/wastewater plant applications, there are also several stationary fuel cell demonstration projects throughout the country. Some of these are [6]:

- Chugach Electric Association (Anchorage, Alaska): Installed 1 MW (5x200 kW) fuel cell system at the U.S. Postal Service's Anchorage mail handling facility. The system runs on natural gas and provides primary power for the facility as well as half of the hot water needed for heating (co-generation). The excess electricity flows back onto the grid.
- Town of South Windsor Fuel Cell Project (Connecticut): Installed a natural gas powered 200 kW fuel cell system. This unit provides heat and electricity to the local high school. It is also used as an education center for fuel cells.
- Department of Defense (DOD) Fuel Cell Demonstration Program: This began in the mid-1990s to advance the use of fuel cells at DOD installations. Currently fuel cells are located at about 30 sites throughout the Armed Services providing primary and or back-up electrical power and heat.

These demonstration projects are seen as critical to market acceptance of fuel cells as well as validate the reliability of the product in real life situations [3].

As stated in Section 6.2, the commercial availability of fuel cells is currently limited to larger power applications (200 kW). Smaller residential-type fuel cells are being researched and commercial production of these units is expected soon with General Motors and Toyota exploring the stationary fuel cell market [1, 2]. GE Fuel Cell Systems (GEFCS) is building a network of regional distributors to market, install and service its residential fuel cell. GEFCS have already signed distributors in New Jersey, Michigan, Illinois, Indiana, New York City and Long Island [1].

To promote the commercialization of fuel cells for power generation, Fuel Cells and Hydrogen: The Path Forward recommends that Congress should enact a tax credit program beginning in 2003 and continuing to 2007 [3]. This would credit purchasers of fuel cell systems that provide power to businesses and residential property one-third the cost of the equipment or $1000/kW, whichever is less. It is also recommended that an additional 10 percent tax credit be available for residences, businesses or commercial properties that utilize fuel cells for both heat and power [3].

6.4 Fuel cells in Indiana

In July 2004, FuelCell Energy of Danbury, CT completed construction of a 2 MW fuel cell installation at the Wabash River coal gasification site near Terre Haute. This installation is designed to run on gasified coal, or syngas, from the nearby gasification facility. Partial funding for the project was obtained from DOE's Clean Coal Technologies Program.

In general, fuel cells are quite expensive but the cost per kW is expected to decrease as the commercial production of smaller residential-type units begins [1, 2]. Once this occurs there is expected to be an increase in the number of fuel cell installations in the Midwestern states although the assumed numbers are small [2]. The following factors will determine the extent of the market penetration by fuel cells within Indiana:

- The cost of electricity from fossil fuel plants and alternative renewable sources;
- The market cost of fuel cell units;
- The cost of fuel for the fuel cell units (e.g., natural gas); and
- The extent of federal and state incentives.

In 1999, Indiana had the eighth cheapest retail electricity prices in the nation [7]. The low cost of electricity in Indiana might provide a barrier to entry for the emerging fuel cell technology and other renewable sources.

The commercial production of fuel cells would lead to reductions in the unit costs thus making them more competitive to both grid and off-grid applications. The signing of the distribution rights of GEFCS's fuel cells within Indiana is further indication that there would be an active promotion of fuel cell usage within the state. In Repowering the Midwest: The Clean Energy Development plan for the Heartland, the Environmental Law and Policy Center assumed that a small number of fuel cells would be installed in each Midwestern state but acknowledged that this was a pessimistic view and did not take into account the promising near-term market for smaller-scale distributed fuel cells [2].

The current short-term viability of fuel cells is seen as using existing natural gas supplies to extract hydrogen for the fuel cell[17] [1, 2]. Figure 6-2 shows the average annual residential price of natural gas in the nation and within Indiana [8]. The cost of natural gas within Indiana is slightly below the national average but not enough so as to give Indiana a significant advantage in terms of costs.

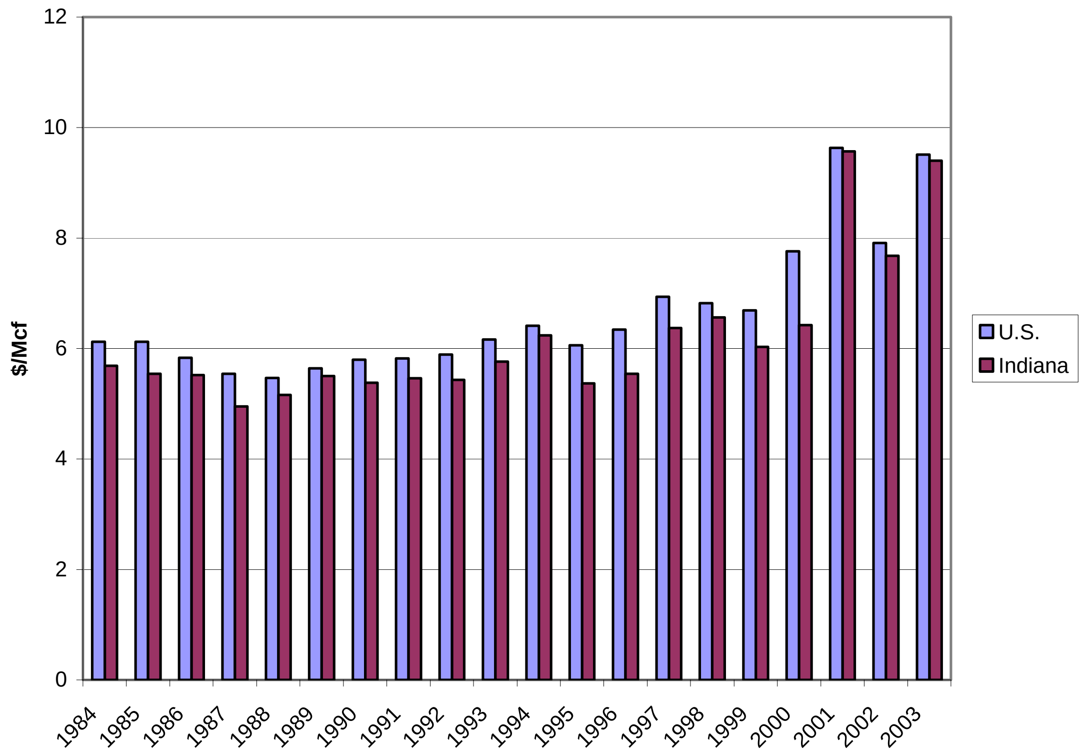


Figure 6-2: National and Indiana residential natural gas prices (Source: EIA)

Certain farms within Indiana where biogas supplies are available (e.g., dairies) might benefit from the reduced costs of fuel cells in the future. The biogas could be used to supply hydrogen to the fuel cell thus reducing the electricity requirements of the facility and reducing costs. Net metering rules that allow the sale of excess electricity sent back to the grid could also aid the facility. Landfill and wastewater treatment plants within the state could utilize the methane produced to supply hydrogen to the fuel cell and receive the same benefits as stated above.

Government incentives are seen as critical in terms of commercializing the use of fuel cells in stationary power applications, particularly when commercial availability is in its infancy [1, 3]. The tax credit proposed in [3] would help in this regard. Further state incentives could also assist the introduction of fuel cells within Indiana. These include [9]:

[17] This would occur in the fuel reformer module of the fuel cell unit.

- Distributed Generation Grant Program offers awards of up to $30,000 to commercial, industrial, and government entities to "install and study alternatives to central generation" (fuel cells fall under one of these alternatives).
- Alternative Power and Energy Grant Program offers grants of up to $30,000 to enable businesses and institutions to "install and study alternative and renewable energy system applications" (fuel cells are an acceptable technology if powered by a renewable source).
- Net Energy Credit: Facilities generating less than 1000 kWh per month from renewable sources are eligible to sell the excess electricity to the utility. Facilities generating more than 1000 kWh per month need to request permission to sell the excess electricity to the utility.
- Emissions Credits: Electricity generators that do not emit nitrogen oxides (NO_x) and that displace utility generation are eligible to receive NO_x emissions credits under the Indiana Clean Energy Credit Program [10]. These credits can be sold on the national market.

A wider variety of fuel cells will be available commercially in the near future. The impact of fuel cells on the profile of Indiana's renewable electricity generation sector depends to a large extent of the price of the units, the efficiency of the units and the government (Federal and State) incentives in commercializing this technology for stationary applications.

6.5 References

1. http://www.fuelcells.org/
2. Environmental Law and Policy Center, "Repowering the Midwest: The Clean Energy Development plan for the Heartland", 2001.
3. http://www.fuelcellpath.org/full%20feb%202003.pdf
4. www.nrbp.org/pdfs/pub31.pdf
5. http://www.eere.energy.gov/hydrogenandfuelcells/fuelcells/fc_challenges.html
6. http://www.eere.energy.gov/hydrogenandfuelcells/fuelcells/stationary_power.html
7. http://www.eia.doe.gov/cneaf/electricity/st_profiles/indiana.pdf
8. http://tonto.eia.doe.gov/dnav/ng/ng_sum_lsum_dcu_nus_a.htm
9. http://www.dsireusa.org/library/includes/map2.cfm?CurrentPageID=1&State=IN
10. http://www.in.gov/idem/energycredit/ecreditfct.pdf

7. Hydropower from Existing Dams

7.1 Introduction

Hydroelectric energy is produced by converting the kinetic energy of falling water to electrical energy [1]. The moving water rotates a turbine, which in turn spins an electric generator to produce electricity. There are several different types of hydropower facilities. These are [2, 3]:

- Impoundment hydropower: This facility uses a dam to store the water. Water is then released through the turbines to meet electricity demand or to maintain a desired reservoir level. Figure 7-1 from the Idaho National Engineering and Environmental Laboratory (INEL) shows a schematic of this type of facility.
- Pumped storage: Water is pumped from a lower reservoir to an upper reservoir when electricity demand is low and the water is released through the turbines to generate electricity when electricity demand is higher.
- Diversion projects: This facility channels some of the water through a canal or penstock. It may require a dam but is less obtrusive than that required for impoundment facilities.
- Run-of-river projects: This facility utilizes the flow of water within the natural range of the river requiring little or no impoundment. Run-of-river plants can be designed for large flow rates with low head (the elevation difference between water level and turbine) or small flow rates with high head.
- Microhydro projects: These facilities are small in size (about 100kW or less) and can utilize both low and high heads. These would typically be used in remote locations to satisfy a single home or business.

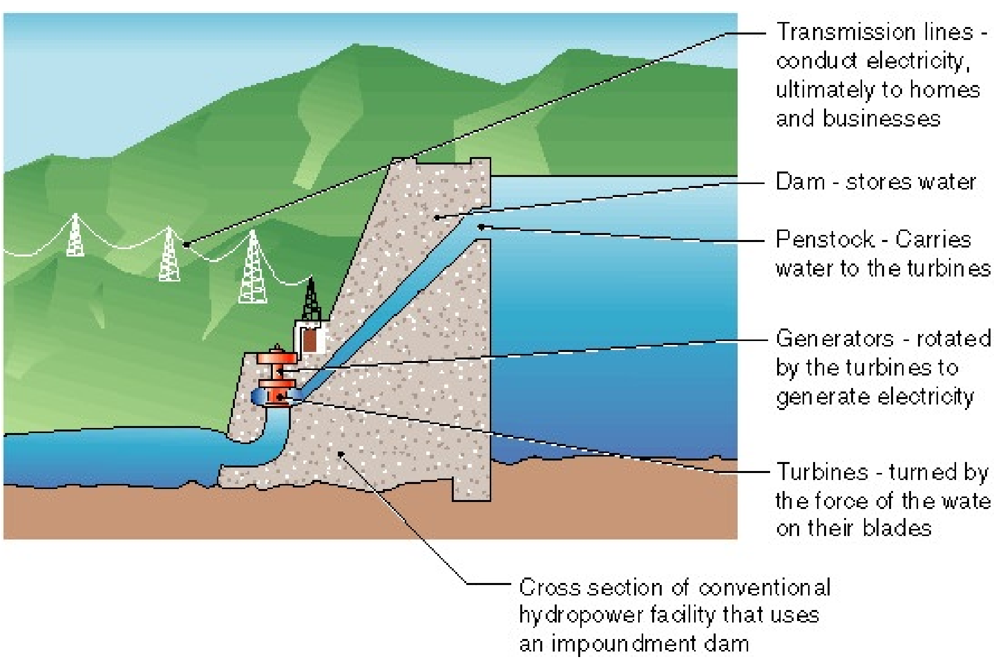


Figure 7-1: Schematic of impoundment hydropower facility (Source: INEL)

Hydropower is a renewable resource that has many benefits, including [1]:

- Hydropower is a clean, renewable and reliable source of energy.
- Current hydropower turbines are capable of converting 90 percent of the available energy to electricity. This is more efficient than any other form of generation.
- Hydroelectric facilities have very low startup and shutdown times thus making them an operationally flexible asset. This characteristic is even more desirable in competitive electricity markets.

There have also been some concerns raised about the environmental impact of hydroelectric facilities which include [4]:

- The blockage of upstream fish passage.
- Fish injury and mortality from passage through the turbine.
- Changes in the quality and quantity of water released below dams and diversions.

Other factors may act as deterrents to potential (and continuation of existing) hydropower projects. This includes the increasingly costly and uncertain process of licensing (relicensing) hydropower projects. It was stated that through 2017 about 32 GW of hydroelectric capacity needs to go through federal licensing which is estimated to cost more than $2.7 billion (2001 dollars) for processing [1]. It was also stated the typical time taken for obtaining a new license varies from 8 to 10 years.

7.2 Economics of hydropower

An obstacle to large hydropower projects is the large up-front capital costs [1]. Even with these large capital costs, hydropower is extremely competitive over the project lifetime with initial capital costs of $1,700-$2,300/kW and levelized production costs of around 2.4 cents/kWh [2]. Figures 7-2 and 7-3 illustrate the competitiveness of hydropower with respect to other generator plant types.

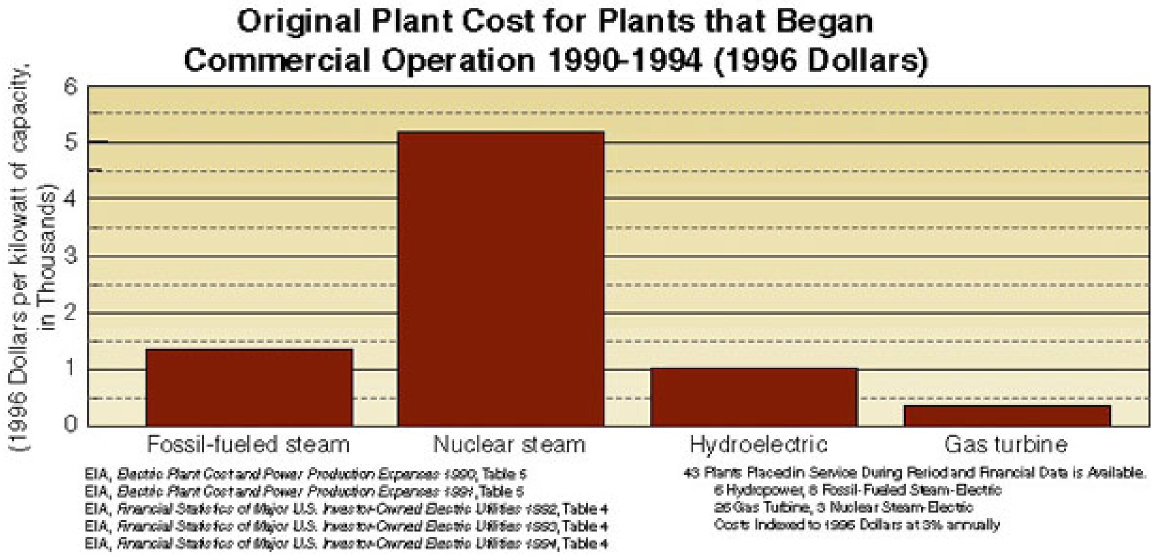


Figure 7-2: Plant costs per unit installed capacity (Source: INEL)

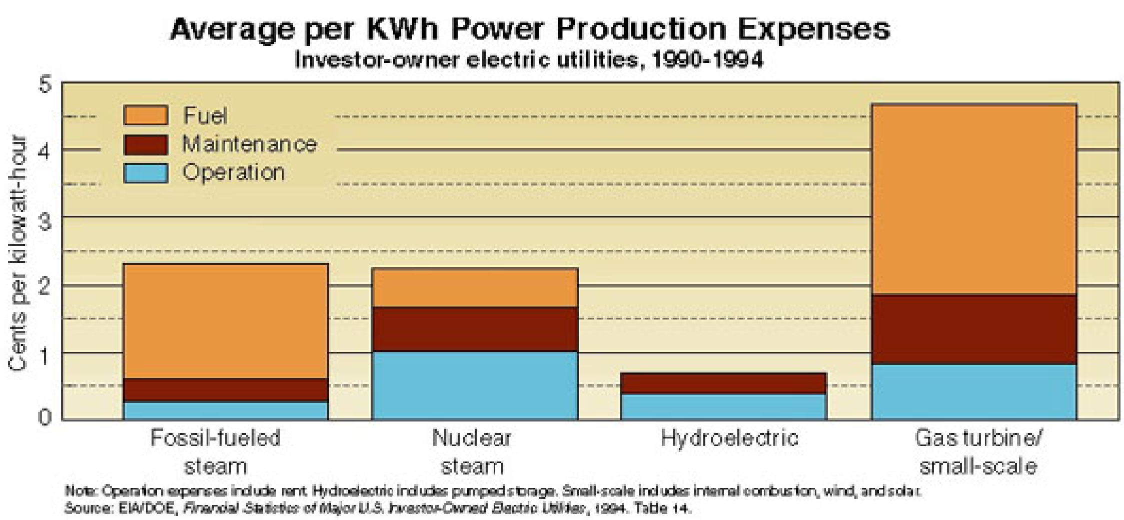


Figure 7-3: Average production costs of various types of generating plants (Source: INEL)

7.3 State of hydropower nationally

In 2002, the United States consumed 5.881 quadrillion Btu of renewable energy[18]. Of this, 2.668 quadrillion Btu (45.4 percent) was from conventional hydroelectric energy [5]. Hydroelectric generation capacity[19] constitutes (in 2002) about 8 percent of the total

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[18] This was about 6.02 percent of the total energy consumption [5].

[19] This is excluding pump storage schemes.

generation capacity [5]. The total (including pumped storage) installed hydroelectric generation capacity in the U.S. is 103.8 GW [1]. Hydroelectric generation varies throughout the nation. The states of California, Oregon and Washington account for 53 percent of the total electricity generation from hydropower with Washington having the most capacity [6]. Figure 7-4 shows the operational hydroelectric capacity by state in 2002 [11].

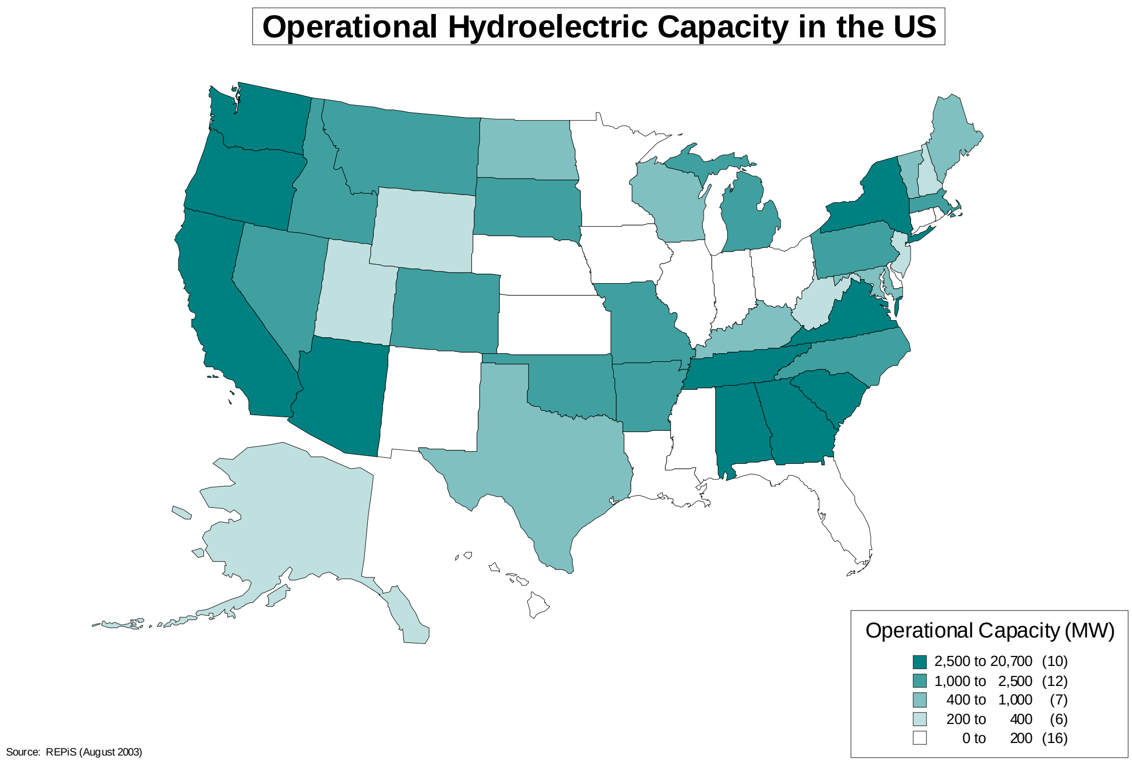


Figure 7-4: Operational hydroelectric capacity in the U.S. (Source: NREL)

In 1998 DOE published a report assessing the resources for hydropower in the country [7]. The DOE Hydropower Program developed a computer model, Hydropower Evaluation Software (HES) which utilizes environmental, legal and institutional attributes to help assess the potential for domestic undeveloped hydropower capacity. HES identified 5,677 sites in this study with a total undeveloped capacity of 30 GW [7]. Of this amount, 57 percent (17.052 GW) are at sites with some type of existing dam or impoundment but with no power generation. Another 14 percent (4.326 GW) exists at projects that already have hydropower generation but are not developed to their full potential and only 8.5 GW (28 percent) of the potential would require the construction of new dams [1]. Therefore the potential for hydropower from existing dams is about 21.378 GW. The breakdown of the state contribution to the total 30 GW identified by HES is shown in Figure 7-5.

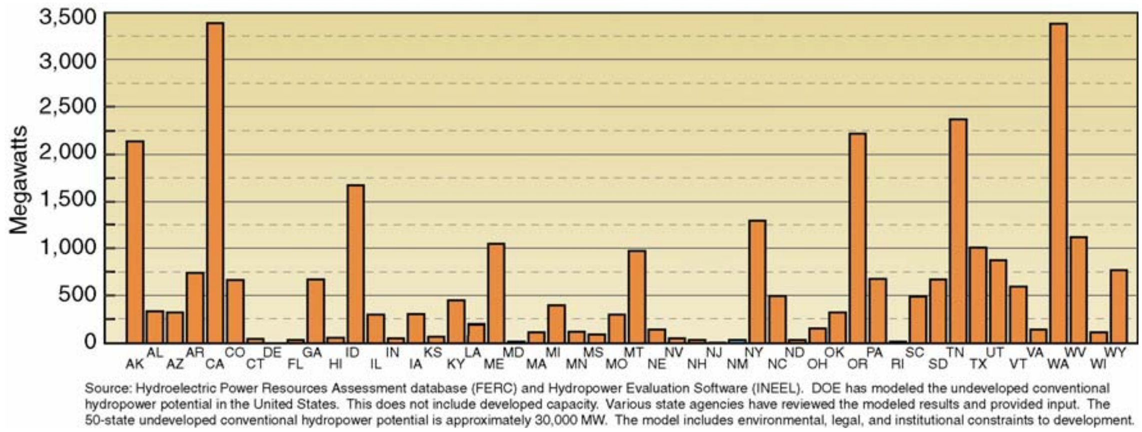


Figure 7-5: State breakdown of potential hydropower capacity (Source: INEL)

Although there are substantial undeveloped resources for hydropower (from existing dams and new facilities), hydropower's share of the nation's total generation is predicted to decline through 2020 with almost no new hydropower capacity additions during this time [4]. The reason for this is due to a combination of environmental issues, regulatory complexities and pressures, and changes in economics [4]. Due to the environmental concerns, the most currently viable of the available hydropower potential is the 4.326 GW of "incremental" capacity available at existing hydropower facilities. Improvements in turbine design to minimize environmental impacts and Federal and State government incentives could help further develop the potential hydropower projects from existing dams.

7.4 Hydropower from existing dams in Indiana

Hydroelectric energy contributed only 0.3 percent (406,000 MWh) of the total electricity generated in the Indiana in 1999, as shown in Figure 7-6. Indiana has 91.4 MW of hydroelectric generation capacity, which makes up about 0.3 percent of the state's total generation capacity [8, 9]. In 2001, the total hydroelectric generation in Indiana was 570,692 MWh (0.4 percent of total state generation). Thus it can be seen that currently hydropower plays a very small role in Indiana's generation mix.

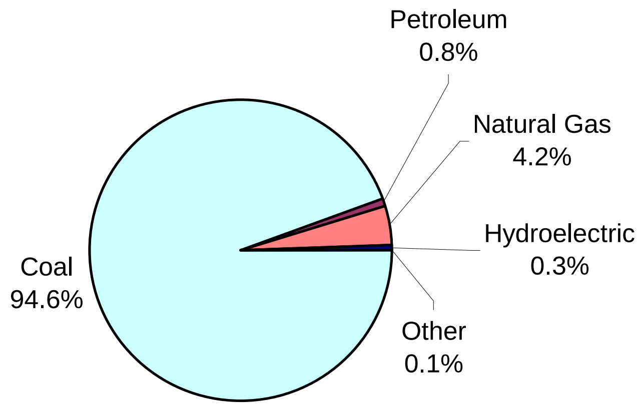


Figure 7-6: Contribution of various generation sources to total electricity generated in Indiana in 1999 (Source: EIA)

In 1995 a report was published for DOE which assessed the potential hydropower resources[20] available in Indiana [10]. The results of this study indicated a total of 30 sites[21] that were identified within Indiana and assessed, using HES, as potential undeveloped hydropower sources. Table 7-1 shows a breakdown of these identified sites.

The following key[22] was used to indicate the status of the potential hydropower site [10]:

- With Power: Developed hydropower site with current power generation, but the total hydropower potential has not been fully developed.
- W/O Power: This is a developed site without current hydropower generation. The site has some type of developed impoundment (dam) or diversion structure but no power generating capability.
- Undeveloped: This site does not have power generating capability nor any impoundment or diversion structure.

[20] Undeveloped pumped-storage hydropower potential was not included.
[21] A complete list of these projects is given in [10].
[22] In terms of the hydropower potential projects relevant for this report, only the first two (With Power and W/O Power) categories are of interest.

	Number of projects	Identified potential (MW)	HES-modeled potential (MW)
With Power	3	15.9	8.0
W/O Power	24	50.8	33.7
Undeveloped	3	16.7	1.7
State Total	30	83.5	43.4

Table 7-1: Undeveloped hydropower potential in Indiana (Source: Francfort)

From Table 7-1 it can be seen that the HES modeled potential projects was much less than the identified potential. This was particularly apparent in the undeveloped projects where environmental and legislative constraints made these potential projects less viable. In terms of projects with existing dams (or diversion structures) a total of 41.7 MW of potential capacity was available within Indiana (at 27 sites). The majority of the potential projects within Indiana have capacities below 1 MW [10]. This would imply predominantly smaller hydropower and microhydro projects.

All of the identified projects were located within the five major river basins. The Wabash River Basin was seen as having the most undeveloped hydropower potential (about 23 MW) of the Indiana river basins [10].

The viability of these projects could be increased with Federal and State government incentives. The current incentives for hydropower within Indiana include the following [11]:

- Renewable Energy Systems Exemption provides property tax exemptions for the entire renewable energy device and affiliated equipment.
- Alternative Power and Energy Grant Program offers grants of up to $30,000 to enable businesses and institutions to “install and study alternative and renewable energy system applications (hydropower is an acceptable technology).
- Green Pricing Program is an initiative offered by some utilities that gives consumers the option to purchase power produced from renewable energy sources at some premium.

Indiana has marginal potential hydropower from existing dams (about 41.7 MW) as illustrated in Figure 7-5. Most of these projects were below 1 MW in capacity and would therefore typically be micro hydro-type projects. Even with the realization of this potential, hydropower would not significantly impact the generation mix within Indiana.

7.5 References

1. www.hydro.org
2. http://hydropower.inel.gov
3. www.eere.energy.gov/power/consumer/tech_hydropower.html
4. DOE Hydropower Program Annual Report – 2002
5. http://www.eia.doe.gov/cneaf/solar.renewables/page/trends/table1.html
6. http://www.eia.doe.gov/cneaf/electricity/epm/table1_12b.html
7. http://hydropower.inel.gov/resourceassessment/pdfs/doeid-10430.pdf
8. http://www.eia.doe.gov/cneaf/electricity/st_profiles/indiana/in.html
9. http://www.nrel.gov/
10. J.E. Francfort, "U.S. Hydropower Resource Assessment for Indiana," DOE/ID-10430(IN), Dec. 1995.
11. http://www.dsireusa.org/library/includes/map2.cfm?CurrentPageID=1&State=IN

Appendix — Solar Energy Conversion Technologies

A.1 Introduction

Solar energy conversion technologies can be grouped into two major categories: solar thermal collectors that convert solar energy into heat, and photovoltaic (PV) panels that convert solar energy directly into electricity. An introduction to solar energy conversion technologies is given in sections four and five of this report. Those two sections provide an overview of the cost of the technologies, and an overview of the state of the technologies nationally and in Indiana. This appendix takes this treatment further by comparing the state of the solar energy conversion industry in the U.S. and Indiana to the rest of the world. In addition the section presents some Indiana-specific typical performance characteristics of solar energy conversion technologies using a real time online solar laboratory operated by the Department of Mechanical Engineering Technology at Purdue.

A.2 Solar thermal collectors worldwide

In February 2004 the International Energy Agency published a report [1] summarizing the status of the solar thermal collectors installed by the year 2001 in important markets worldwide. The study encompassed two major types of thermal collectors: those that use water as the energy carrier, and those that use air as the energy carrier. The water-based collectors surveyed include unglazed, glazed, and vacuum tube collectors, while the air-based collectors include glazed and unglazed. Unglazed water-based collectors are the dominant type of collectors in the United States and are mainly used for heating of swimming pools. The flat-plate glazed water-based collectors and evacuated tube collectors are more common in other regions of the world such as China, Europe, and Japan.

According to the International Energy Agency report, the 26 nations surveyed represent about half of the world's population (1.3 billion) and 85 – 90 percent of the solar thermal collectors market worldwide. These nations are Australia, Austria, Belgium, Canada, China, Denmark, Finland, France, Germany, Greece, India, Ireland, Israel, Italy, Japan, Mexico, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom, and the United States.

As can be seen from Figure A.1, the U.S. with a total installed collector of 25.2 million square meters ranks second to China, which had a total collector surface area of 32 million square meters. Over 90 percent of the 25.8 million square meters of collectors reported in the U.S. and Canada were unglazed plastic collectors used for heating swimming pools. However, on a per capita basis the U.S. ranks 17th behind Israel, Greece, Austria, Turkey, Japan, Australia, Denmark, Germany, Switzerland, China, Portugal, Sweden, New Zealand, Netherlands, Spain, and France.

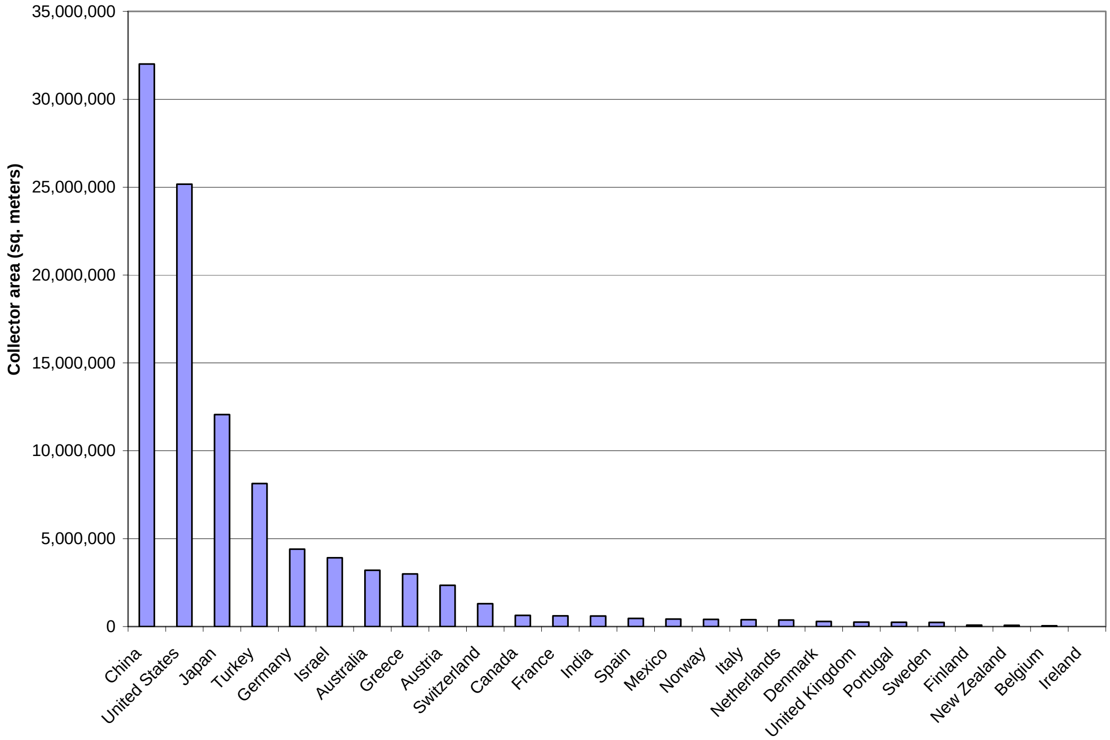


Figure A-1: Total water and air collectors in year 2001 (Data source: International Energy Agency)

Figure A-2 shows that the United States is a net importer of solar heating collectors [2]. The situation is reversed for photovoltaic modules, where the U.S. is a net exporter. More detailed treatment of the photovoltaic panels is given in section A.3.

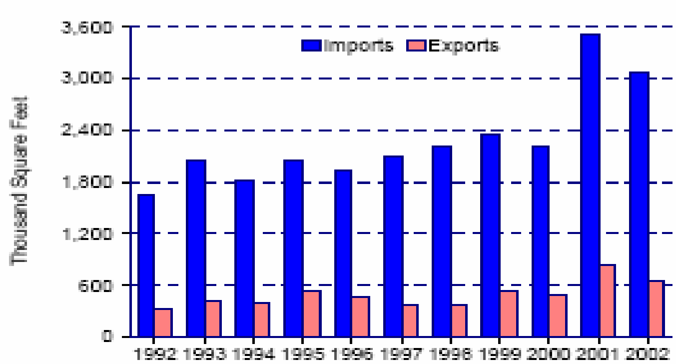


Figure A-2: U.S. import and export shipments of solar thermal collectors (Source: EIA)

A.3 Photovoltaic panels worldwide

Installed capacity
According to the *Annual World Solar Photovoltaic Market Report* published on the *Solarbuzz* webpage [3], the PV market in the world has seen rapid growth in recent years. It grew 34 percent between 2002 and 2003 to a capacity of 574 MW. Germany, the U.S., and Japan led the world in both installed capacity and growth rate of PV installations. As shown in Figure A-3, the U.S., with 11 percent of the world's installed capacity is third behind Japan (39 percent) and Germany (25 percent). Among them, these three nations accounted for 75 percent of the PV market installations in the world in 2003. According to this report, Germany had the fastest growing PV market having grown at a rate of 76 percent between the years 2002 and 2003.

The capacity installed in 2003 was as follows.

- 219 MW in Japan;
- 149 MW in Germany; and
- 66 MW in the U.S., the majority of which is in California.

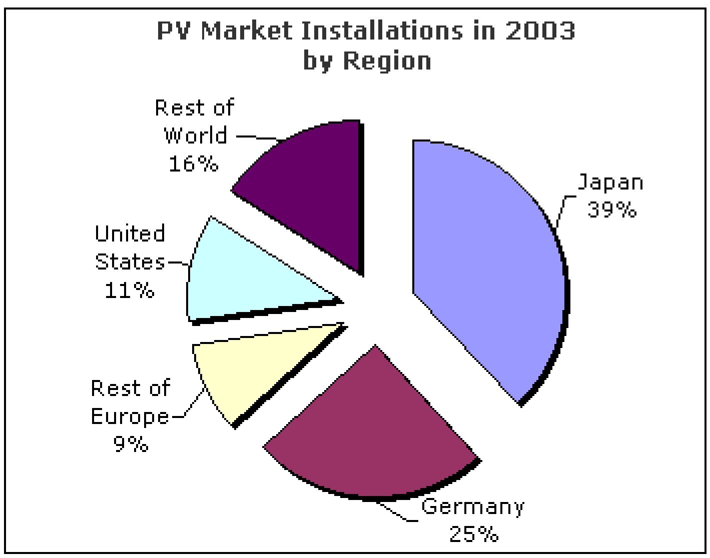


Figure A-3: PV installations worldwide (Source: Solarbuzz)

Photovoltaic cell production worldwide
To match the robust growth rate of PV installations worldwide, the production of PV units increased by 40 percent in 2003 to 743 MW. In that year, the Japanese share of the market rose to 40 percent of world production, while the U.S. share of the world production dropped to 12 percent [3]. However, as shown in Figure A-4, the U.S. is still a net exporter of PV cells and modules.

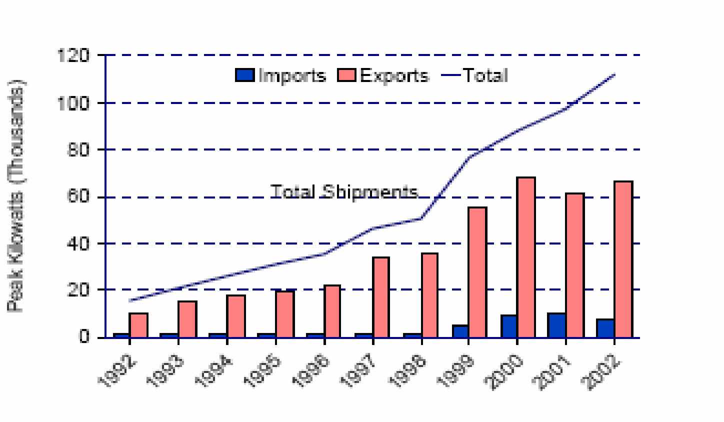


Figure A-4: U.S. import and export shipments of photovoltaic cells and modules (Source: EIA)

Government investment in PV industry

Due to the current high cost of PV generated electricity compared to conventional technologies the extent of solar penetration into the electricity supply infrastructure is dependent on government and utility funding programs. Figure A-5 compares the government funding for PV programs in the three leading PV countries: the United States, Japan, and Germany. The rapid aggressive increase in government expenditure in research and subsidies in Japan starting in the mid 1990s has resulted in an increase in the Japanese share of the world wide production of PV cells and modules.

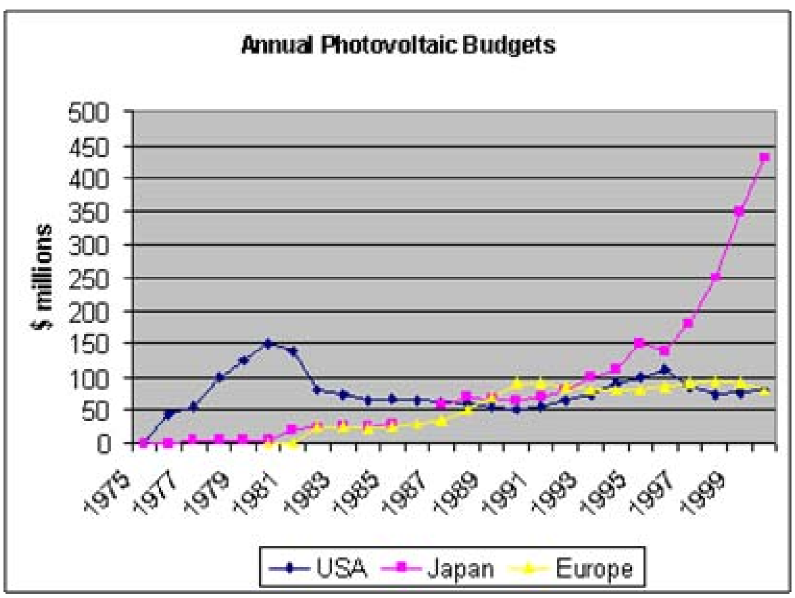


Figure A-5: Annual government PV budgets (Source: Solarbuzz)

The breakdown of the national PV budgets in the three leading PV nations is shown in Table A-1 in millions of U.S. dollars [4].

	Japan	U.S.	Germany
Research and development	51.0	35.0	26.7
Demonstration	16.5	0.0	5.5
Market stimulation	188.4	84.6	29.6
Total budget	255.9	119.6	61.8

Table A-1: Breakdown of 2001 PV budgets in millions of U.S. dollars (Data source: Solarbuzz)

A.4 Indiana solar installations compared to the rest of the U.S.

Table A-2 shows the state of solar thermal collectors nationwide by comparing domestic shipments of collectors by destination state or territory [5]. Out of the national domestic shipment of 11 million square feet of thermal collectors in 2002, approximately 16 thousand square feet were destined in Indiana. In contrast, over 4 million square feet were destined for Florida, 3 million square feet for California, and 937 thousand square feet to New Jersey.

	Destination State	Shipments ft^2			Destination State	Shipments ft^2			Destination State	Shipments ft^2
1	Florida	4,368,364		17	Georgia	50,664		33	Delaware	2,206
2	California	3,212,809		18	Michigan	46,206		34	Oklahoma	2,188
3	New Jersey	936,649		19	Massachusetts	42,630		35	Kentucky	2,101
4	Arizona	529,737		20	Wisconsin	36,738		36	Tennessee	1,985
5	Hawaii	274,143		21	Louisiana	20,917		37	Virgin Isles.	1,913
6	Illinois	255,949		22	Colorado	19,179		38	West Virginia	1,354
7	Connecticut	213,875		23	Minnesota	18,766		39	Mississippi	1,114
8	Virginia	140,969		24	North Carolina	17,792		40	Rhode Island	852
9	Puerto Rico	113,872		25	Washington	16,142		41	Alabama	502
10	Pennsylvania	113,441		**26**	**Indiana**	**15,975**		42	Iowa	437
11	Nevada	108,208		27	South Dakota	9,577		43	Maine	349
12	New York	99,426		28	Maryland	8,174		44	Kansas	335
13	Oregon	97,933		29	Vermont	5,936		45	N Hampshire	271
14	Texas	86,574		30	Utah	4,671		46	Arkansas	116
15	Ohio	63,299		31	South Carolina	4,390		47	Missouri	113
16	New Mexico	52,635		32	Idaho	2,923		48	Wyoming	66

Table A-2: Shipment of thermal collectors by destination state or territory in 2002 (Data source: EIA)

As stated in section 5.4 of this report, Indiana total installed capacity of photovoltaic modules in the year 2002 was 21.8 kW. In comparison, the total U.S. installed capacity was 112 MW [5].

A.5 The Purdue Remotely Accessible Solar Laboratory

The Purdue remotely accessible solar laboratory is a unique facility designed with a real time access to the data [6]. The laboratory is equipped with a set of solar thermal collectors and a set of photovoltaic modules (see Figure A-6). Five out of the eight thermal collectors use a glycol/water mix as the energy carrier; the other three collectors use air as the energy carrier.

Figure A-6: The equipment at the Purdue Solar Laboratory (Source: Purdue University)

Figure A-7 shows the average efficiencies of the solar thermal collectors and a representative PV panel installed at the Purdue remotely accessible solar laboratory [6]. These efficiencies were observed at several times from January to March 2004. The top line represents the maximum efficiency observed for that collector and the top of the rectangle represents the next highest observation. Similarly, the bottom of the line and the bottom of the rectangle indicate the lowest and second lowest efficiencies, respectively. Collector numbers one to five are the ones that use the glycol/water mix as the energy carrying fluid. The maximum observed efficiencies of the collectors are:

- Collector number 5, an aluminum flat plate type of collector has the high of 89 percent in its efficiency range;
- Collector number 3, an aluminum flat plate type, is second with a high of 80 percent in its efficiency range;
- The third in ranking is collector number 4, a black surface with no fins, with a high point in its efficiency range of 75 percent;
- Collector number 2, a copper surface with no fins is fourth with a high in its efficiency range of 38 percent; and
- Collector number 1, a concave mirror had the lowest efficiency with a high of 32 percent.

The typical efficiencies achieved by the photovoltaic panels installed at the remotely accessible lab range from a low of 5 percent to a high of 12 percent. While PV units have a lower efficiency than solar collectors, they convert the energy to a form that is easily transmitted over long distances (electricity). If the heat output of a collector were converted to electricity, its efficiency would be reduced.

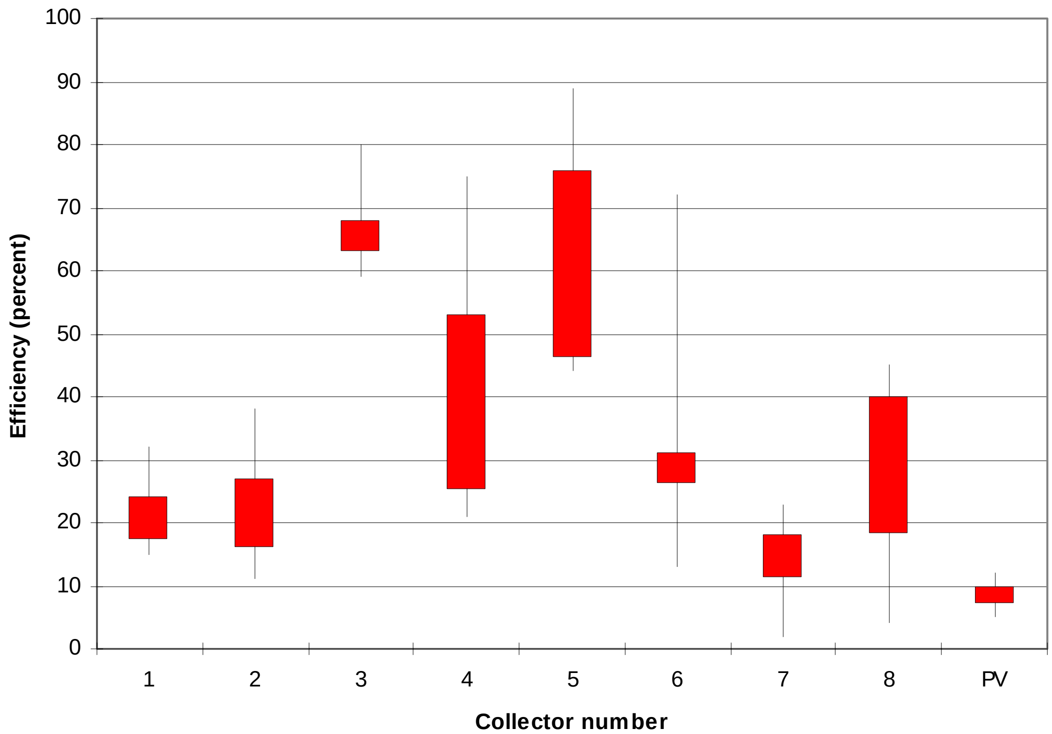


Figure A-7: Typical efficiencies of solar thermal collectors and PV panels (Source: Purdue University)

Figures A-8 through A-10 show the output characteristics of the solar equipment at the Purdue remotely accessible laboratory over a three day period [6]. Figure A-8 is the output of three of the liquid-based thermal collectors, Figure A-9 the three air-based thermal collectors, and Figure A-10 the photovoltaic panels. As is evident from the three figures, a limiting characteristic of solar energy conversion devices is the intermittent nature of their output, which is directly related to the amount sunshine available. In contrast, the output from conventional fossil fueled generators can be adjusted by the operator to respond to the changing demand. This intermittent output characteristic is not unique to solar, but also to wind energy and to some degree to hydroelectric power.

Among the power conversion technologies, the intermittent output is not as much of a problem in solar thermal collectors as in PV arrays converting solar energy directly into electricity since heat is much easier to store than electricity. Some sort of storage capacity is required to store the electricity from a PV array for use when the sun goes down or a cloud cover reduces the output of the array. The storage can be either in the form of batteries or in the case of a grid-connected PV, have the grid serve as a virtual storage device; that is, the PV-owning customer sells power to the grid when the PV output is greater than the customer's demand and conversely, buys power from the grid when the PV array output does not satisfy his or her demand. For this reason, the photovoltaic market has tended to grow fastest in those regions where grid-interconnection rules have been most favorable to small customers.

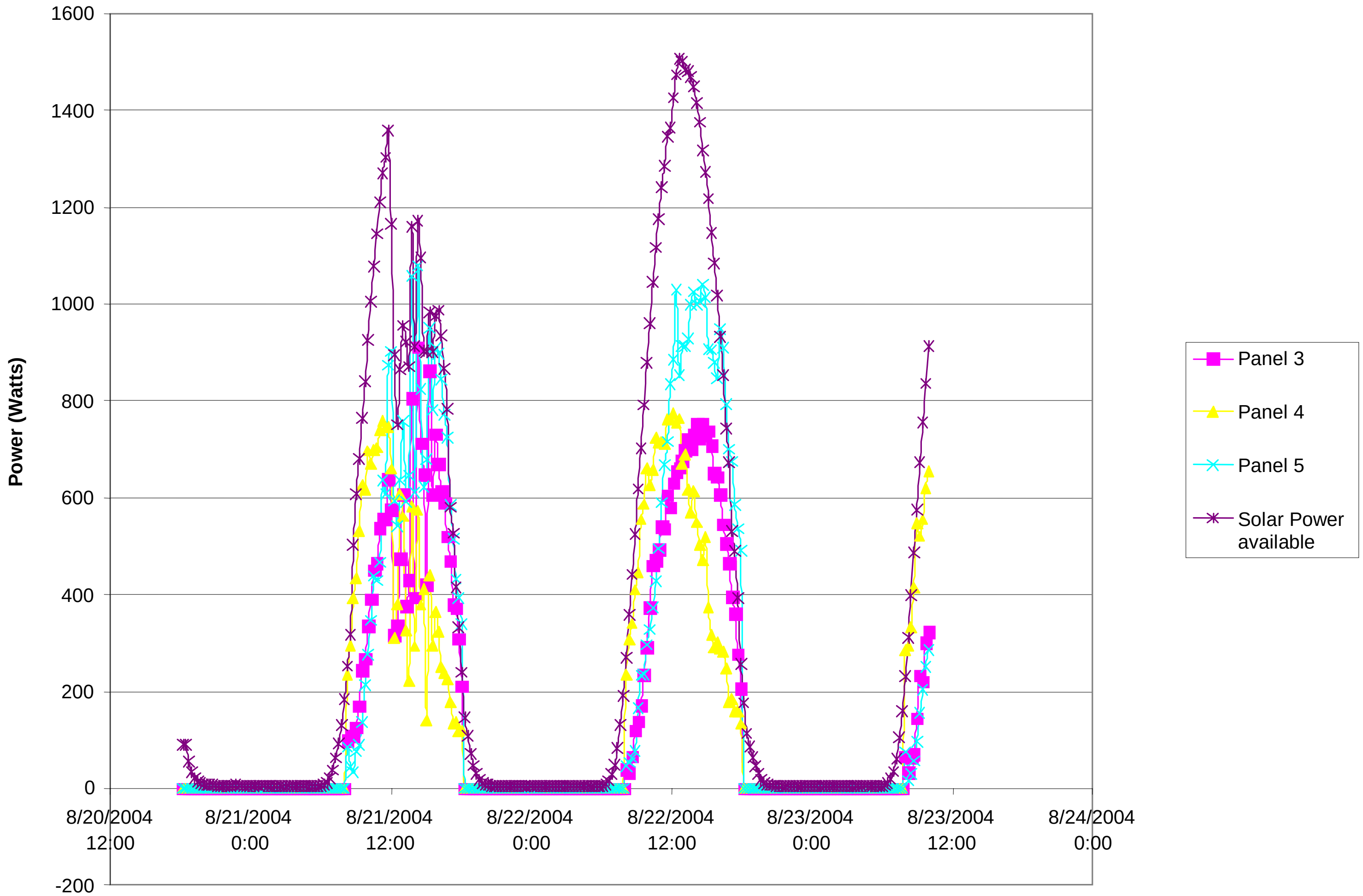


Figure A-8: Typical output from the glycol/water thermal collectors (Data source: Purdue University)

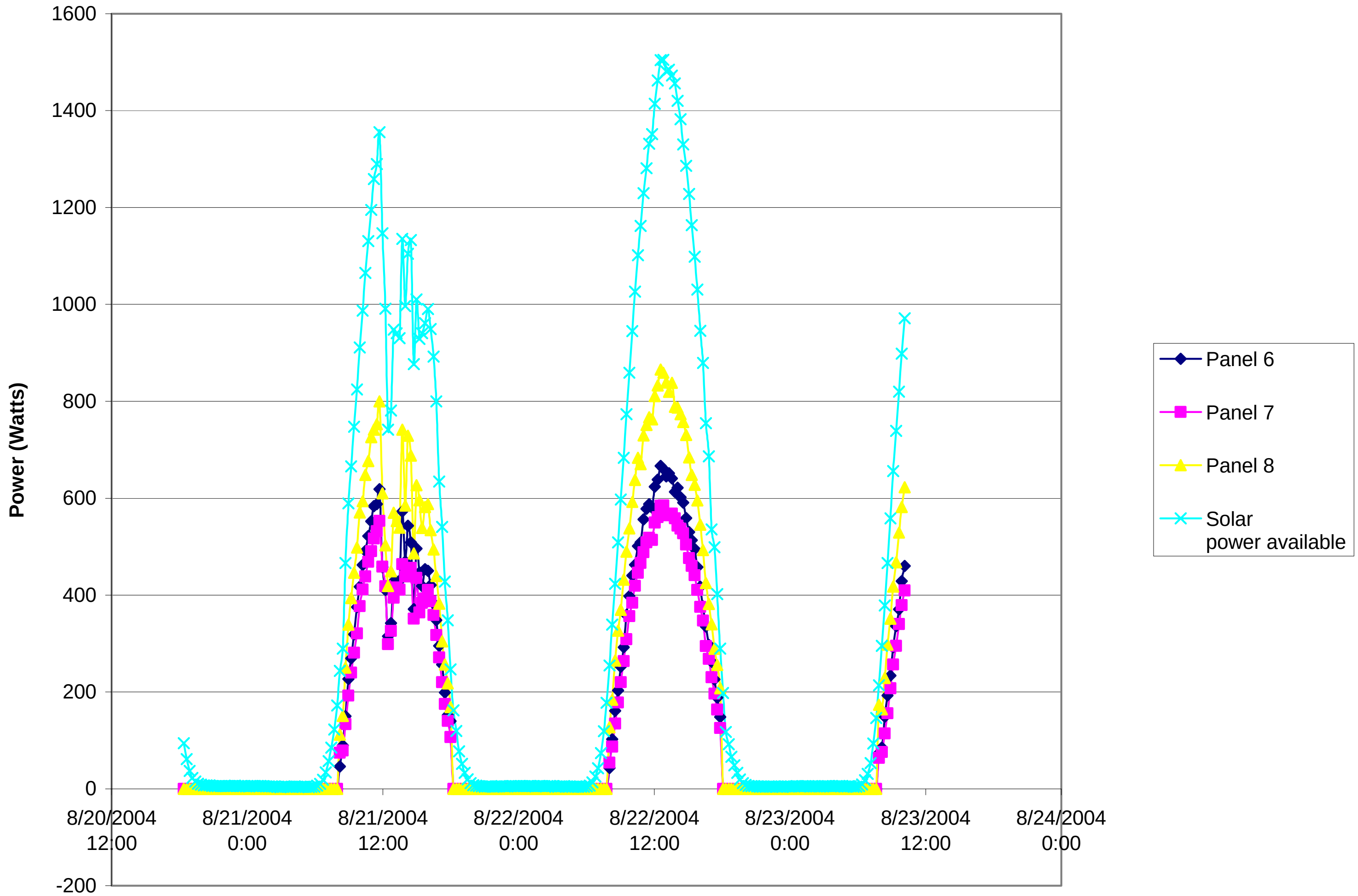
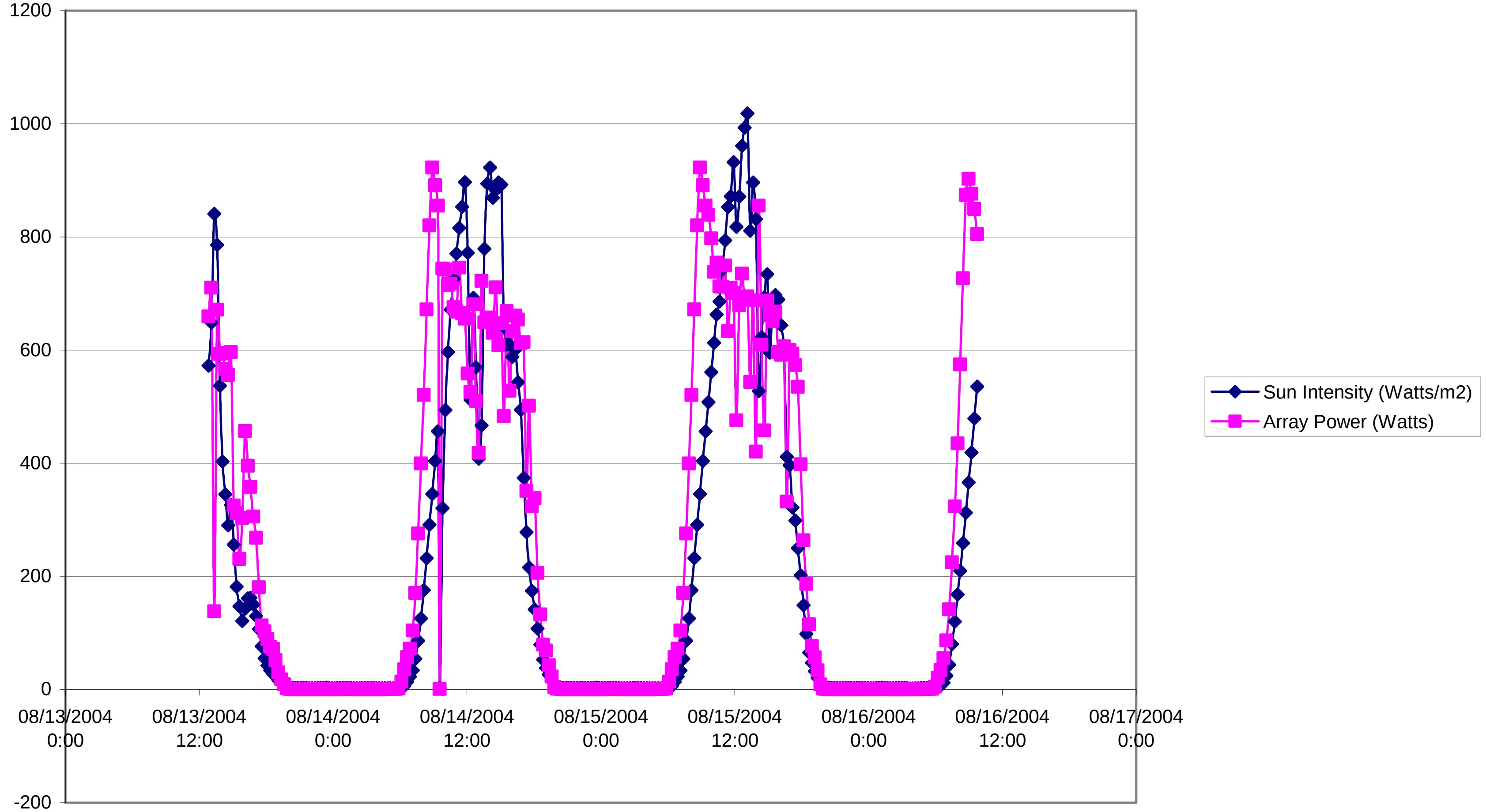


Figure A-9: Typical output from the air-based thermal collectors (Data source: Purdue University)



<u>Figure A-10:</u> <u>Typical output from the photovoltaic panels</u> (Data source: Purdue University)

A.6 References

1. International Energy Agency, Solar Heating and Cooling Programme, "Solar Heating Worldwide, Markets and Contribution to Energy Supply 2001," February 2004. http://www.iea-shc.org/welcome/welcome_page.htm.
2. Energy Information Administration (EIA), US Department of Energy, "Renewable Energy Annual, 2002."
   http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/rea.pdf
   http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/rea_sum.html
3. Solarbuzz, "Annual World Solar Photovoltaic Market Report."
   http://www.solarbuzz.com/Marketbuzz2004-intro.htm.
4. Solarbuzz, "Photovoltaic Industry Statistics: Countries."
   http://www.solarbuzz.com/StatsCountries.htm.
5. Energy Information Administration (EIA), US Department of Energy, "Renewable Energy Annual, 2002," Table 30.
   http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/rea.pdf.
6. Remotely Accessible Solar Laboratory, Department of Mechanical Engineering Technology,
   http://www.ihets.org/progserv/education/grants/02-03/proposals/pur/pur07.pdf,
   http://www.tech.purdue.edu/met/facilities/knoy427/remote/hs/index.html.