2005 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 third 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 report consists of eight sections. Section one provides an overview of the renewable energy industry in the United States and in Indiana. It includes a discussion on trends in penetration of renewable energy into the energy supply, both nationally and in Indiana. It also includes a presentation on the trends in the cost characteristics of renewable and a subsection on the federal renewable energy production tax credit and the effect it has had on wind capacity additions.

The other seven sections are each devoted to a specific renewable resource: energy from wind, dedicated crops grown for energy production, organic biomass waste, solar energy, photovoltaic cells, fuel cells, and hydropower from existing dams. They are arranged to maintain the format in the previous reports as follows:

- 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.

For further information, contact SUFG at:

State Utility Forecasting Group
Purdue University
500 Central Drive
West Lafayette, IN 47907-2022
Phone: 765-494-4223
Fax: 765-494-2351
e-mail: sufg@ecn.purdue.edu
https://engineering.purdue.edu/IE/Research/PEMRG/SUFG/

1. OVERVIEW

This section gives an overview of the renewable energy industry. It includes trends in renewable energy penetration, trends in the economics of renewable technologies and a discussion of the effect of the federal renewable energy production tax credit on the wind industry.

1.1 Trends in renewable energy penetration into the energy supply

Figure 1-1 shows the historical renewable energy consumption in the United States in quadrillion British thermal units (Btu) and its percent contribution to the total energy. The contribution of renewable resources peaked in 1996 at 7.1 quadrillion Btu (7.5 percent of total U.S. energy) and fell steadily through the succeeding years to a low of 5.3 quadrillion Btu (approximately 5.4 percent of U.S. total energy) in 2001. According to the Energy Information Administration (EIA) 2003 Renewable Energy Trends report [1], the 1996 peak and subsequent substantial decline in renewable energy in the United States is attributable primarily to the record hydroelectric output levels in the mid 1990s and the subsequent decline in hydropower production in the late 1990s up to 2001. In 2002 and 2003 hydropower production increased a total of 26 percent. This increase combined with a 9 percent increase in biomass energy production, accounts for the 16 percent increase in renewable energy between 2001 and 2003.

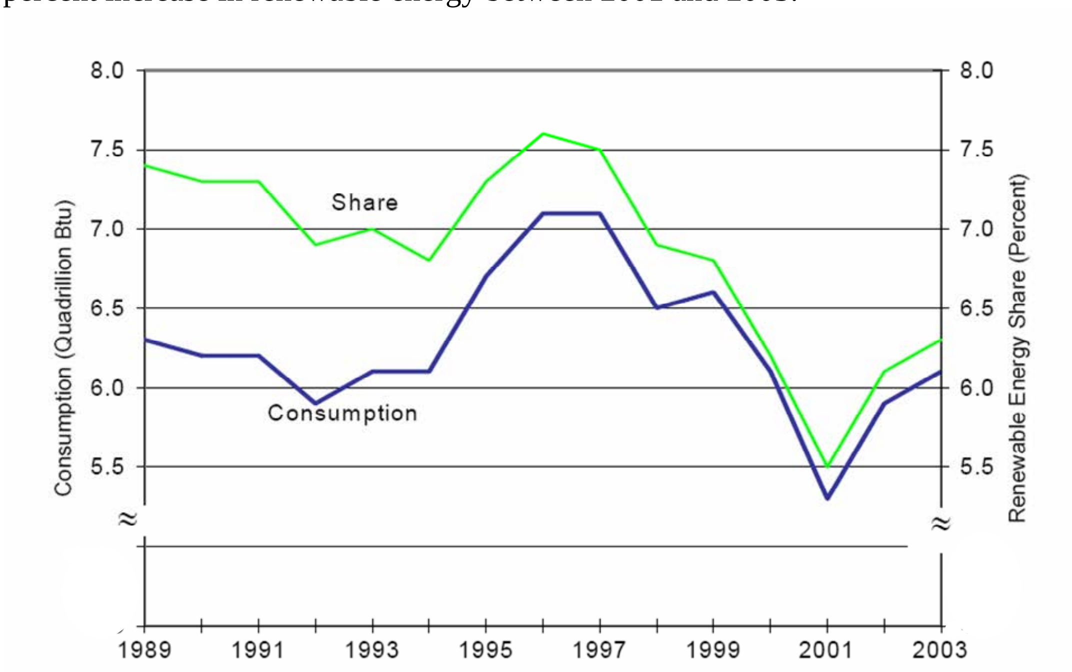


Figure 1-1: Historical renewable energy consumption 1989-2003 (Source: EIA)

As can be seen in Figure 1-2 biomass and hydropower comprise 92 percent of all the renewable energy produced in the United States in 2003. All the renewables combined contributed 6 percent of United States total energy in 2003. Figure 1-3 shows the equivalent numbers for Indiana. In Indiana the renewables contribution to the total energy used in Indiana in 2001 is 1 percent. Biomass (including ethanol blend in gasoline) contributed 87 percent of the renewable energy and the rest was from hydropower (13 percent).

According to the Renewable Energy Trends report referred to previously [1] a substantial portion of the increase in biomass use is accounted for by the increased presence of ethanol as an oxygenate additive to gasoline. Ethanol increase surged by 65 percent between 2001 and 2003. Alcohol has risen to replace MTBE whose use has been reduced and altogether banned in some states due to fears of groundwater contamination from leaking tanks.

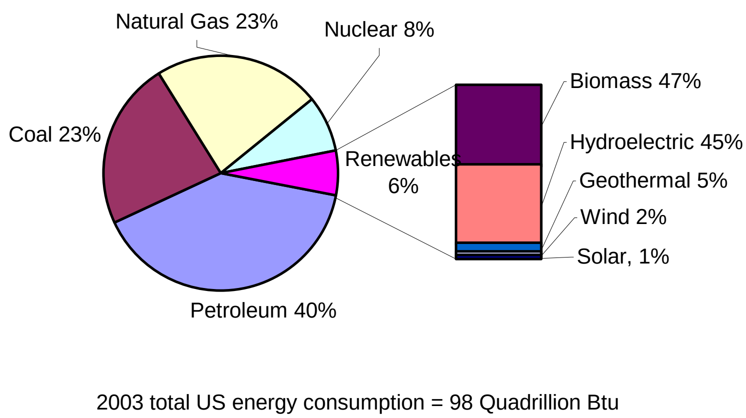


Figure 1-2: 2003 United States total energy consumption by energy source (Source: EIA)

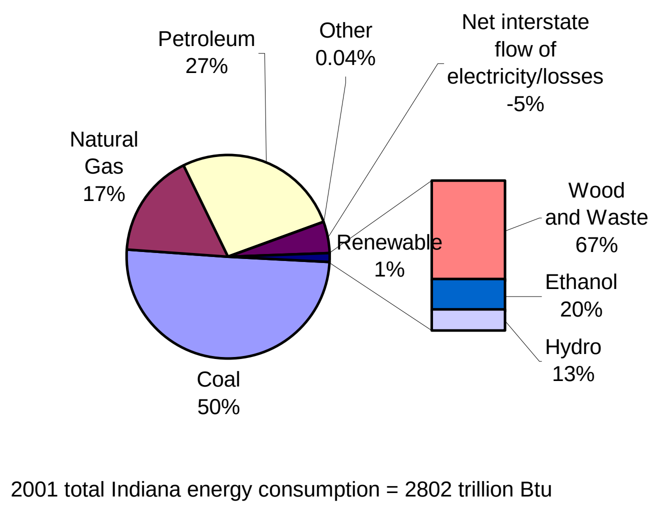


Figure 1-3: 2001 Indiana total energy consumption by energy source (Source: EIA)

When one considers the renewable energy used for electricity generation, hydropower takes a much greater role than biomass, contributing over 250,000 Gigawatthours (GWh) or 74 percent of the net United States renewable electricity generation in 2002 (Figure 1-4). The contribution of biomass drops to 18 percent. Similarly in Indiana, as shown in Figure 1-5, hydropower accounts for 76 percent of the renewable energy used for electricity generation and other renewables (primarily biomass) accounts for the remaining 24 percent [2].

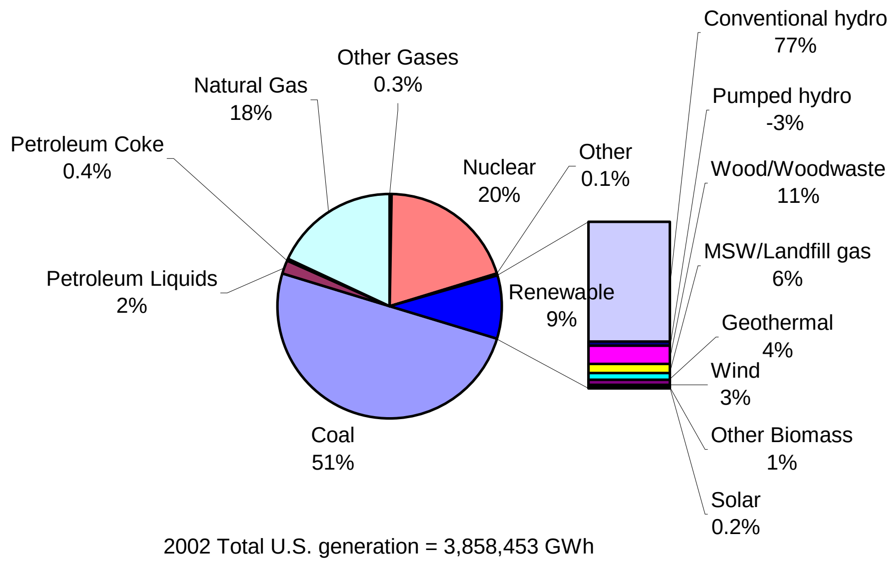


Figure 1-4: 2002 United States net electricity generation by energy source (Source: EIA)

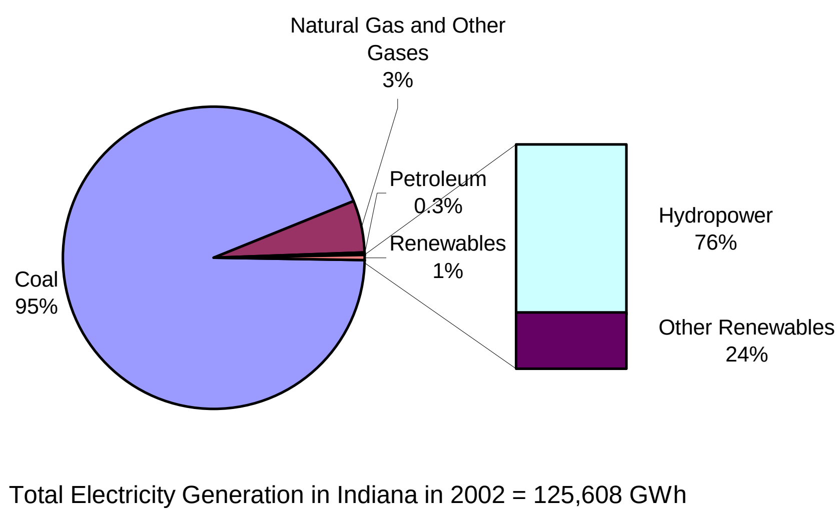


Figure 1-5: 2001 Indiana electricity generation by fuel type (Source: EIA)

As shown in Figure 1-6, the 542 GWh of renewable energy generated in Indiana in 2002 constituted 0.2 percent of the 351,251 GWh of renewable energy generated nationally [3]. The major contributors to the renewable generation were the hydropower-rich states of Washington, California and Oregon which together contributed almost half of the total renewable generation in that year. Three states: Kansas, New Mexico and Rhode Island produced less renewable energy than Indiana in 2002 while EIA did not have 2002 renewable generation data for Delaware and the District of Columbia.

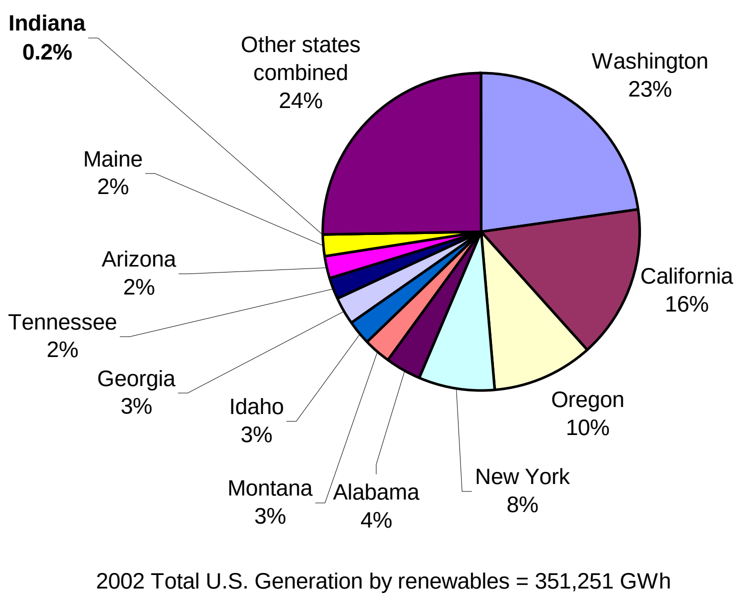
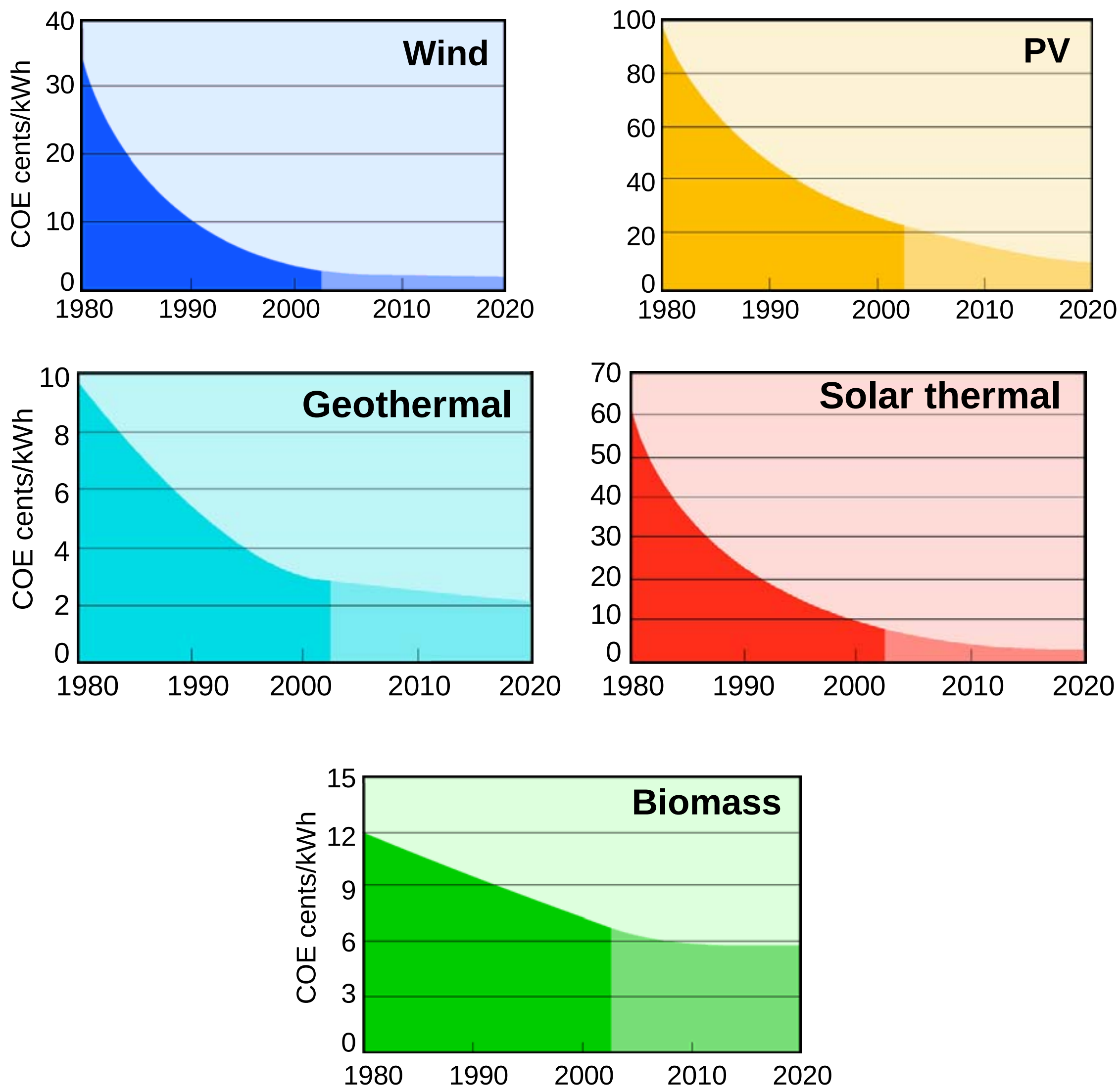


Figure 1-6: 2002 states' share of total U.S. renewable generation (Data Source: DOE)

1.2 Trends in the economics of renewable energy resources

One of the principle causes of the low penetration of renewable resources in both the nation and Indiana is the high cost. Figure 1-7 shows the levelized cost of energy (COE) of several renewable technologies including wind, photovoltaic (PV), geothermal, solar-thermal and biomass, in constant 2000 dollars as estimated by the National Renewable Energy Laboratory (NREL) [4].



<u>Figure 1-7:</u> <u>Renewable energy cost trends in constant 2000 dollars</u> (Source: NREL)

1.3 Effect of the federal renewable energy production tax credit on wind power capacity

The federal renewable energy production tax credit (PTC) has been the most effective federal incentive for the development of renewable energy, especially wind, since it was put in place in 1992. The deployment of wind turbines have grown in parallel with the several expiration and renewal cycles that the PTC has gone through, as shown in Figure 1-8.

The PTC is a per kilowatt-hour tax credit for electricity generated by qualified renewable resources. It was enacted in 1992 as part of the Energy Policy Act of 1992 to last until June of 1999. In December of 1999 it was extended until December 31, 2001. It was renewed three months later in March of 2002 and extended to December 31, 2003. This time it remained dormant until October of 2004 when it was extended to December 31, 2005. Many in the wind industry are lauding its current extension to December 2007 in the Energy Policy Act of 2005 for having broken the on-off cycle that has characterized it for the last 13 years.

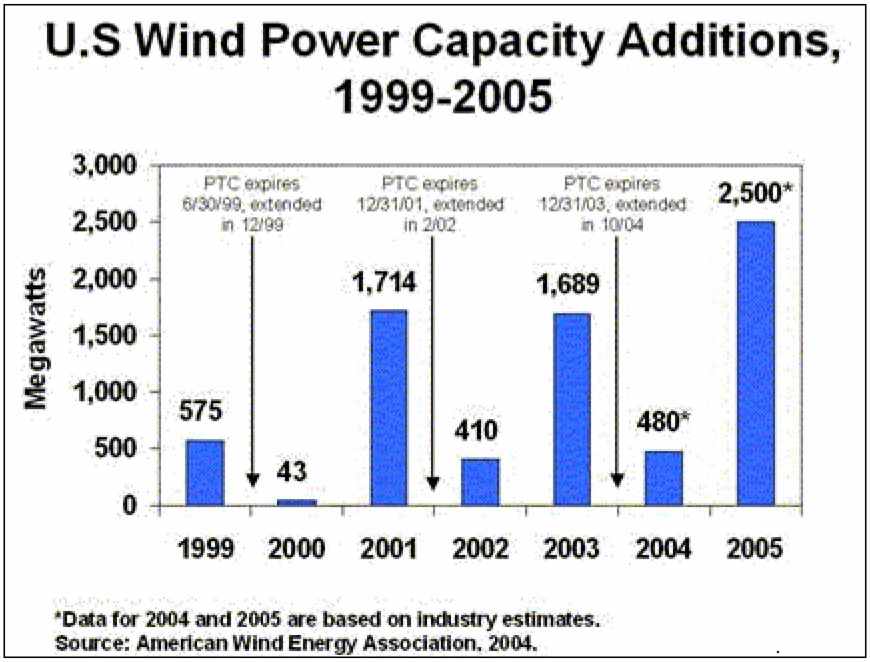


Figure 1-8: Effect of the renewable energy production credit on wind capacity additions (Source: Union of Concerned Scientists [5])

The PTC provides a tax credit of 1.9 cents/kWh, adjusted annually for inflation for ten years from the installation date of the qualifying facility. The credit, initially provided for wind and biomass, has now been extended to include wind, closed-loop biomass, open-loop biomass, geothermal, and solar.

1.4 References

1. Energy Information Administration, Renewable Energy Trends 2003, July 2004.
2. Energy Information Administration, State Electricity Profiles 2002.
3. http://www.eere.energy.gov/state_energy/opfacbytech.cfm?state=IN
4. National Renewable Energy Laboratory, Renewable electricity technology cost trends, power point slides, http://www.nrel.gov/analysis/docs/cost_curves_2002.ppt, October 2002.
5. Union of Concerned Scientists http://www.ucsusa.org/clean_energy/renewable_energy/page.cfm?pageID=121

2. Energy from Wind

2.1 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 2-1:

- 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.

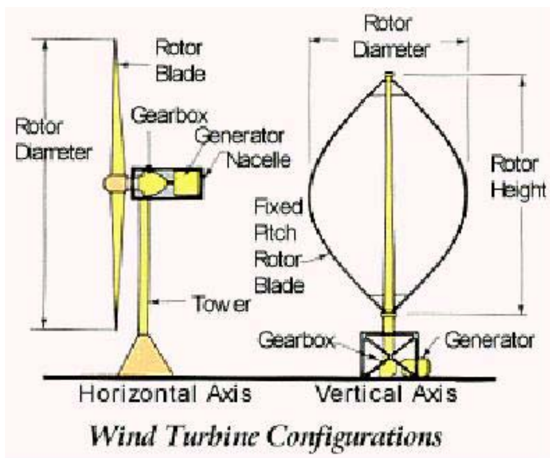
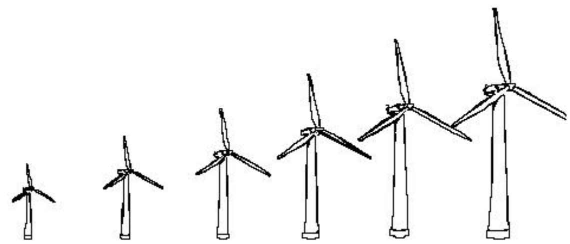


Figure 2-1: Types of wind turbines (Source: American Wind Energy Association)

The physical size and power output of wind turbines has increased dramatically over the past two decades [1], as shown in Figure 2-2. 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 Megawatts (MW). For example, the largest coal power plant in Indiana is composed of five units rated at over 600 MW each adding up to a total plant capacity of over 3000 MW. In comparison the largest wind farm proposed for Benton County, Indiana is composed of 67 seven wind turbines rated at 1.5 MW each to make a total wind farm capacity of 100 MW. Furthermore the total energy output from a wind turbine will tend to be much less than that from that of a conventional generator since the wind turbine only generates when the wind is blowing at sufficient levels.



	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

<u>Figure 2-2:</u> <u>Sizes of wind turbines</u> (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 2-1 lists the class distinctions currently used.

The major <u>advantages</u> 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 helps achieve attainment of Clean Air Act Standards (reducing pollution control costs for taxpayers).

However, there are some <u>disadvantages</u> 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

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

Table 2-1: Wind resource classification (Source: DOE)

2.2 Economics of wind energy

The levelized[1] cost of wind energy has been decreasing over the past twenty years, as shown in Figure 2-3. Currently, wind turbines are capable of producing electricity at 4.5-5.5 cents/kWh in the Class 4 wind regions and 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 of 1.9 cents/kWh during the first tens years of production is available, having been extended recently to December of 2007 in the Energy Policy Act of 2005 [4]. 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.

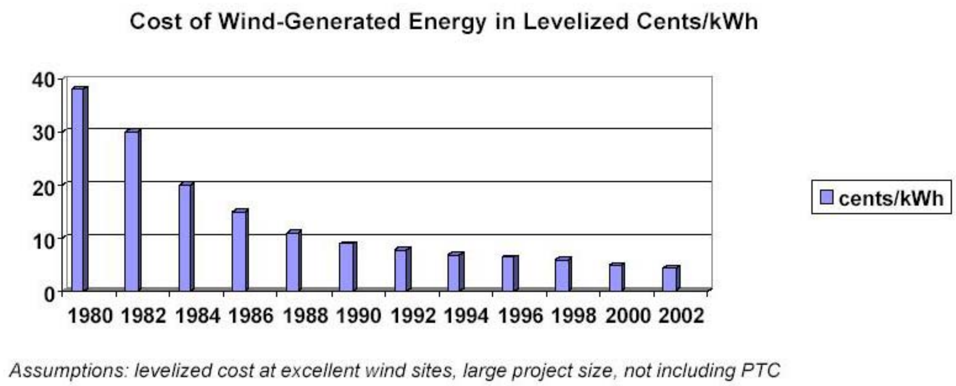


Figure 2-3: Cost of wind energy at excellent wind sites not including production tax credits[2] (Source: American Wind Energy Association)

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 [5]. 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]. Furthermore, DOE is seeking to reduce the cost of energy (COE) from small wind systems to the point where they have the same cost effectiveness in Class 3 wind resources in 2007 as they currently have in class 5 resources. The COE from wind as projected by DOE's National Renewable Energy Laboratory (NREL) is shown in Figure 2-4 [3].

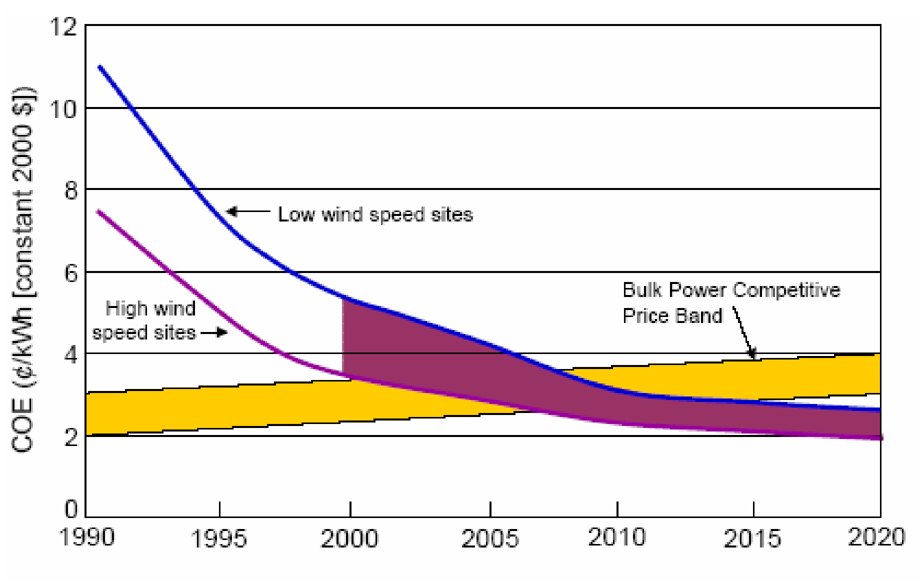


Figure 2-4: Projected cost of wind energy (Source: NREL)

[2] Also called Renewable Electricity Production Credit.

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

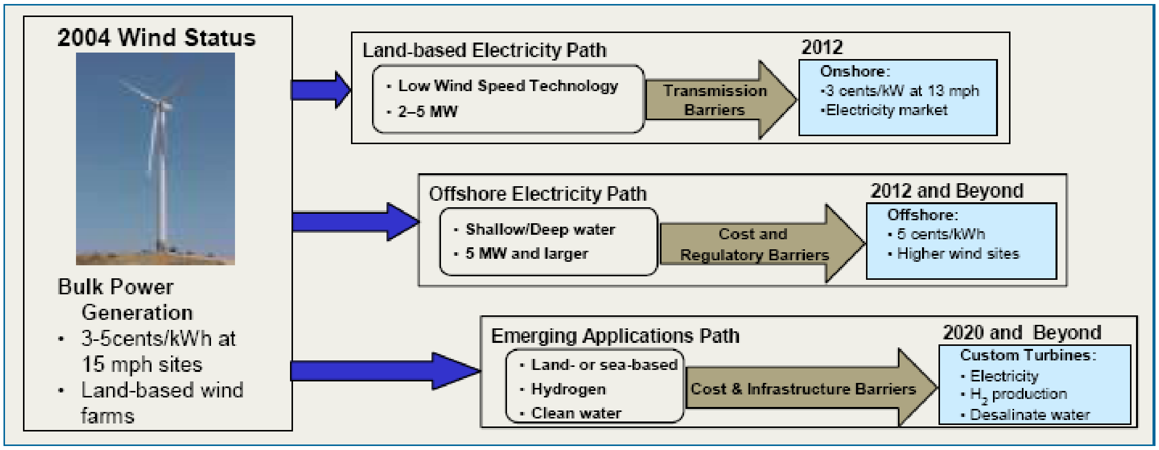
DOE's wind energy program is designed to focus on the following three paths that utility-scale wind technology may follow: Land-Based Electricity, Offshore Electricity, and Emerging Applications. All three paths emanate from current technology, which is oriented towards producing bulk power from land-based wind farms.

With respect to the land-based electricity path, according to the Office of Energy Efficiency and Renewable Energy (EERE), DOE

> "*envisions that land-based systems will continue to grow in size, to the 2-5 MW range* (Figure 2-5). *This is expected to result in very cost-competitive turbine technology in the 2012 timeframe. Moreover, this effort will open up vast resources to wind development and will bring wind-generated electricity closer to major load centers. Turbine technology development efforts, as previously discussed, will aid in making the technology cost-competitive. Ultimately, the primary barriers to this technology with be those presented by system integration issues, including the capability and availability of the U.S. transmission system"*
>
> *"The second evolution pathway envisioned is a migration of current technology to offshore sites. At first, wind technology will be expanded into relatively shallow waters, and then later into deeper waters. Offshore turbines are expected to be significantly large – in the 5 MW and greater range. Eventually, the DOE has a goal of 5 cents/kW (*Figure 2-5*) for class 5 shallow water sites by 2012 and is currently evaluating what other goals might be appropriate for deep water technology. As this program continues to proceed, cost and regulatory (siting) barriers are likely to be the most significant obstacles to offshore development."*

Finally, the emerging applications path for wind technology

> "*leads toward the design of turbine systems tailored for emerging applications like hydrogen production or for the production and delivery of clean water. These efforts would open up an opportunity for wind to provide a low cost, clean energy for the transportation sector. However, both of these applications present significant new challenges to the wind community, and cost and infrastructure barriers are expected to be significant* [6]."



<u>Figure 2-5:</u> <u>Three evolution pathways for utility-scale wind technology</u> (Data Source: EERE)

2.3 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 2-6. 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.

Wind capacity has been expanding rapidly, with 6,740 MW as of the beginning of 2005 as shown in Figure 2-7 [8]. 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. California currently leads the nation in available wind generation capacity as well as annual energy produced from wind sources. 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. The leading wind capacity states at the beginning of 2005 are as follows: California – 2,096, Texas – 1,293, Iowa – 632, Minnesota – 615, Wyoming – 285. Indiana's neighbors are ranked as follows: Illinois – 51MW, Ohio – 7 MW and Michigan – 2 MW.

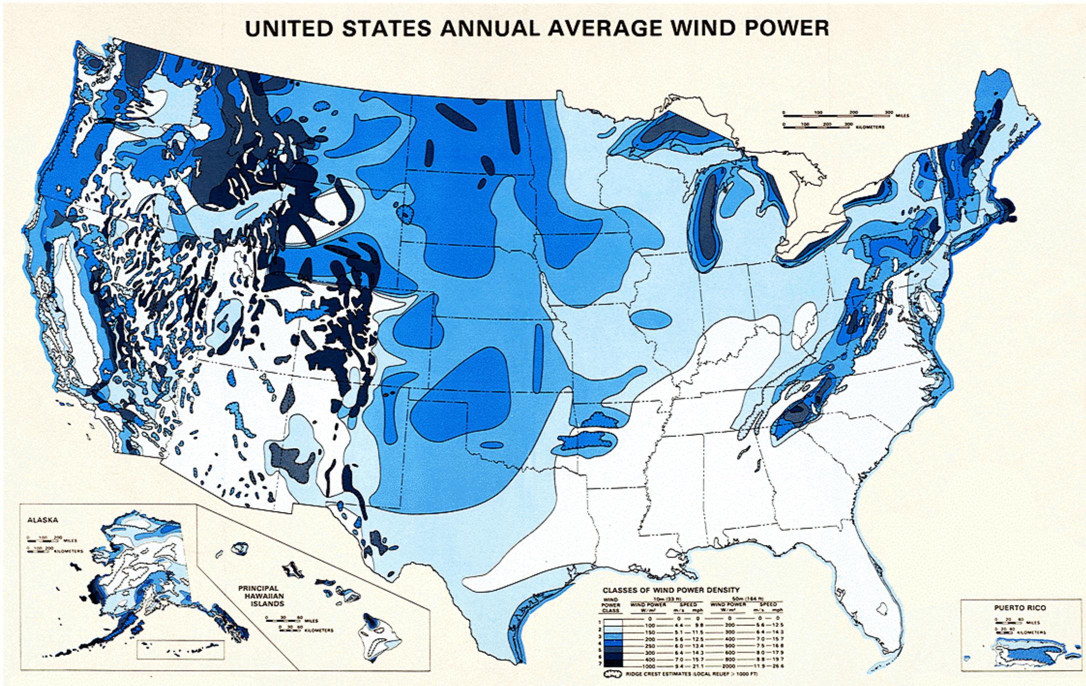


Figure 2-6: National wind energy resource map (Source: NREL)

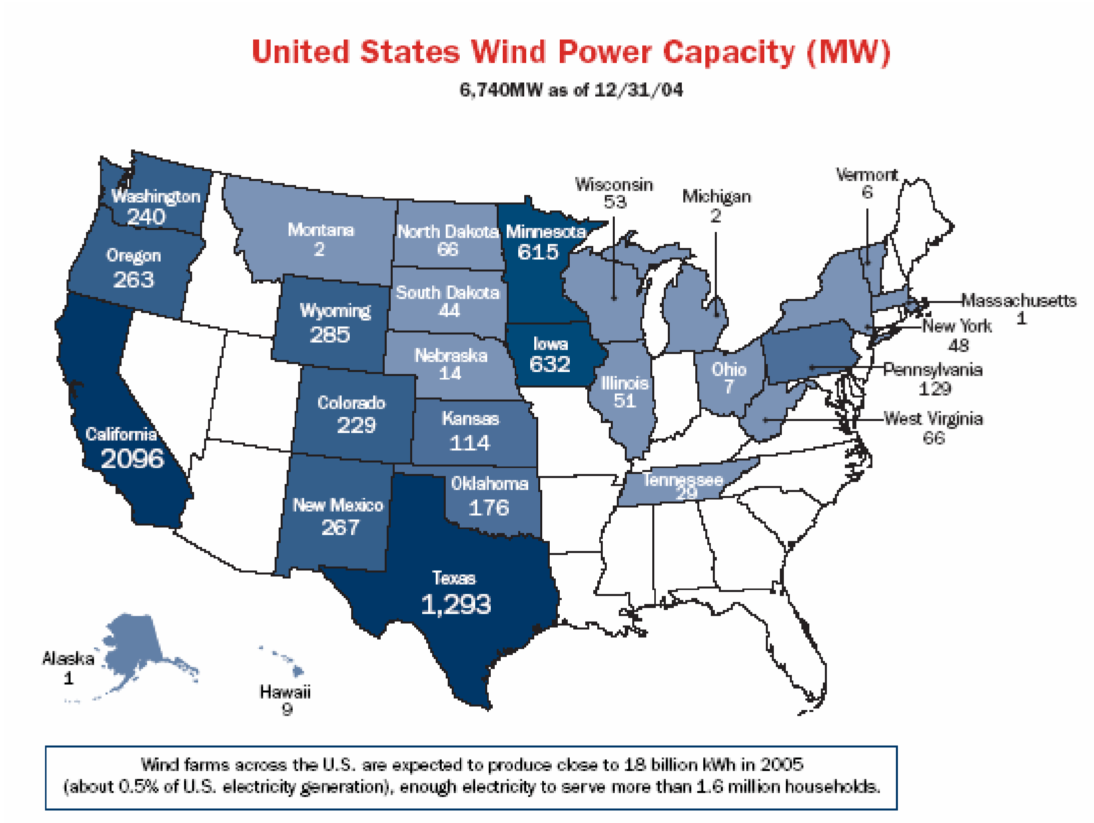


Figure 2-7: Wind energy installed generation capacity (Source: EERE/NREL)

According to the American Wind Energy Association Rankings report [1] the largest wind farms operating in the U.S. at the end of 2004 were as follows

1. Stateline, Oregon-Washington – 300MW
2. King Mountain, Texas – 278MW
3. New Mexico Wind Energy Center, New Mexico – 204MW
4. Storm Lake, Iowa – 193 MW
5. Colorado Green, Colorado – 162 MW
6. High Winds, California – 162 MW

The largest owners of wind energy installations were:

1. FPL Energy – 2,758
2. Shell Wind Energy – 315 MW
3. AEP – 311 MW
4. enXco – 298 MW
5. PPM Energy – 225 MW

The companies that bought the most wholesale wind power were:

1. Southern California Edison– 1,025 MW
2. Xcel Energy – 884 MW
3. Pacific Gas & Electric Co. – 680 MW
4. PPM energy – 606 MW (for resale)
5. TXU – 580 MW

Figure 2-8 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 2-8: Top twenty states for wind energy production potential (Source: American Wind Energy Association)

2.4 Wind energy in Indiana

Figure 2-9 shows the distribution of wind energy resources in Indiana [9]. The highest wind category in Indiana is class 3, or 11.5 – 12.5 miles per hour (mph), compared to class 7 winds occurring in such wind rich states like Minnesota. The class 3 winds occur in areas around Benton, Clinton and Boone counties. The rest of the state is divided approximately evenly, with the northern half having class 2 winds (9.8 – 11.5 mph) and the southern half class 1 winds (0 – 9.8 mph). Table 2-2 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.

According to national Renewable Electric Plant Information System (REPiS) [10], as of 2002 Indiana had only 10 kW of wind generation. The wind turbine owned by AEP Corporation is located in Fort Wayne [11]. In January 2005, Cinergy/PSI commissioned a 10 kW grid connected demonstration project at a rest stop on I-65 in White County that provides supplemental power to the rest area north of Lafayette [12]. This brings the total installed wind capacity in Indiana that SUFG could find on record to 20 kW.

A proposal has been in place since 2003 by the wind developer enXco to build a 100 MW wind farm in Benton County in Northwest Indiana. According to a press release on the enXco web page dated January 2004 [13], the construction was scheduled to start this summer (2005). Attempts to get a confirmation from the enXco Corporation on the status of the project at the time of writing this report were not successful. This wind farm, if constructed would make a significant contribution to the renewable energy portfolio in Indiana.

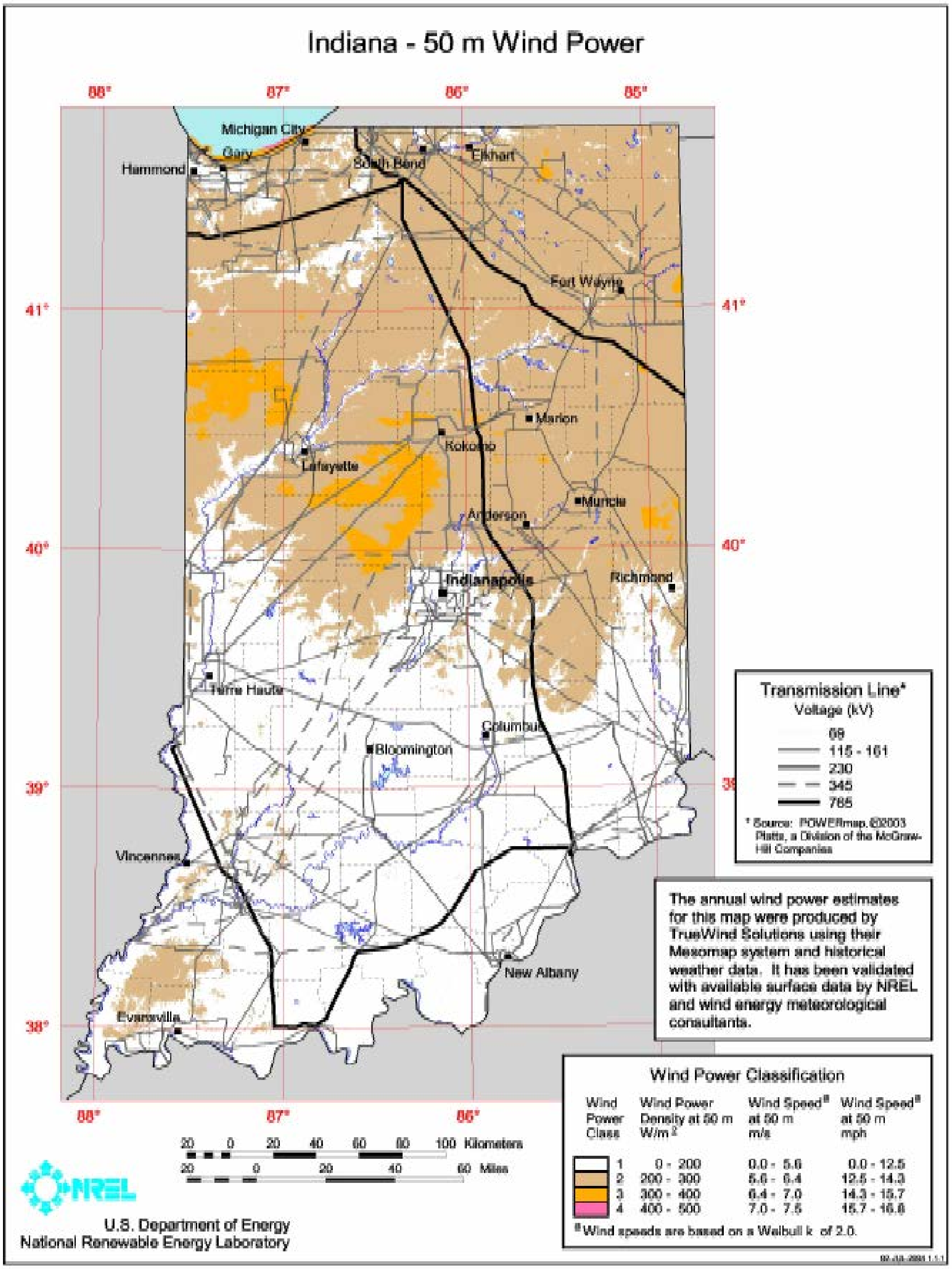


Figure 2-9: Indiana wind energy resource map (2004) (Source: NREL)

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

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 [14]. These are:

- Renewable Electricity Production Tax Credit (PTC) which credits wind energy producers 1.9 cents/kWh during the first ten years of operation. The PTC originally covered wind and biomass and has been expanded in the Energy Policy Act of 2005 to include closed and open loop biomass, geothermal and solar [4].
- Renewable Energy Systems Exemption provides property tax exemptions for the entire renewable energy device and affiliated equipment.
- Renewable Energy Production Incentive (REPI) provides financial incentive payments for electricity produced and sold by new qualifying renewable energy generation facilities. Eligible projects must have commenced operations between October 1, 1993 and September 30, 2003. Qualifying facilities are eligible for annual incentive payments of 1.5 cents/kWh for the first ten year period of their production, subject to the availability of annual appropriations in each Federal fiscal year of operation.
- 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).
- Conservation Security Program (CSP) Production Incentive: Enacted in March 2005, this program provides financial and technical assistance to promote the conservation and improvement of soil, water, air, and other conservation proposed on tribal and private working land. Eligible producers receive $2.50 per 100 kWh of electricity generated by new wind, solar, geothermal, and methane-to-energy systems (up to $45,000 per year for 10 years).
- 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.
- Net metering rule: Solar, wind and hydroelectric facilities with a maximum capacity of 10 kW are under this September 2004 rule qualified for net metering where the net excess generation is credited to the customer in the next billing cycle.
- 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

[4] As in the 10kW installation in Fort Wayne owned by the American Electric Power Co. Inc. [12]

under the Indiana Clean Energy Credit Program [15]. These credits can be sold on the national market.

- Modified Accelerated Cost-Recovery System (MACRS): This program allows business to recover investments in solar, wind and geothermal property through depreciation deductions. The MACRS establishes a set of class lives for various types of property over which the property may be depreciated.

Figure 2-10 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 2-11 shows the locations that have incentives for small residential wind installations.

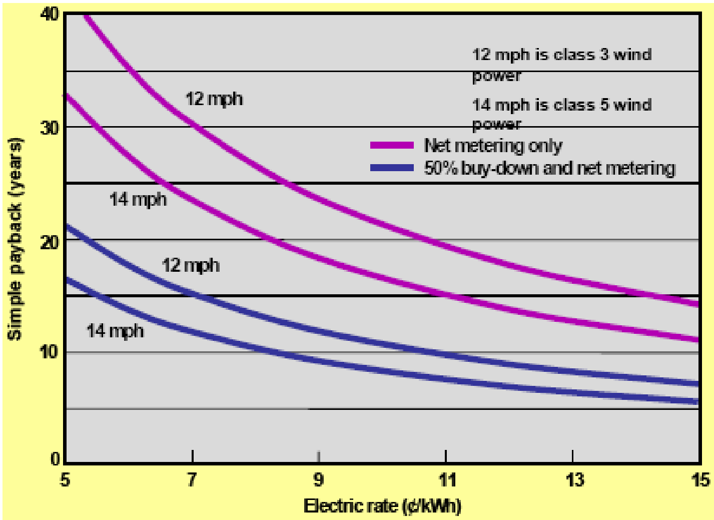


Figure 2-10: Economic payback for small wind systems (Source: DOE)

[5] A buy-down is a subsidy or grant that covers a portion of the purchase cost.

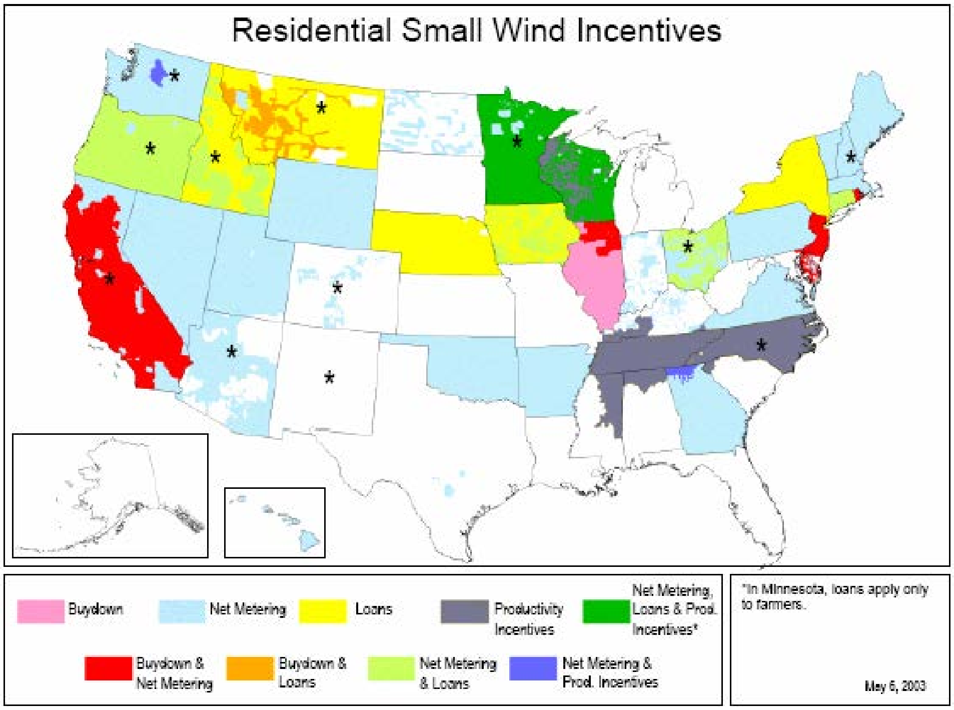


Figure 2-11: Residential small wind incentives (Source: DOE Wind Powering America)

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 [16]:

- 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 [17]. These national initiatives could assist in the introduction of wind energy within the rural areas of Indiana.

- Wind Resource Validation: The ability to accurately predict when the wind will blow will help remove barriers to wind energy development by allowing wind-power-generating facilities to commit to power purchases in advance [18]. In addition, the development of short-term forecasting tools will help energy producers proceed with new wind farm projects and avoid the penalties they must pay if they do not meet their hourly generation targets.

2.5 References

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

3.1 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.

- Biomass direct combustion: 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.
- Biomass cofiring: 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. This allows the energy in biomass to be converted to electricity with the high efficiency (in the 33-37% range) of a modern coal-fired power plant. Typically five to ten percent of the input fuel is biomass with the rest being the fossil fuel [3].
- Chemical conversion: 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.
- Biomass gasification: 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.
- Pyrolysis: Research is being conducted on a smoky-colored, sticky liquid that forms when biomass is heated in the absence of oxygen. Called pyrolysis oil, this liquid can be burned like petroleum to generate electricity. Unlike direct

combustion, cofiring, and gasification, this technology is not yet in the marketplace [4].

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 2.7773 quadrillion British thermal units (Btu) supplied by biomass in 2002, 1.705 quadrillion Btu was consumed in the industrial sector, 0.515 quadrillion Btu was consumed in the electricity sector and 0.313 quadrillion Btu was consumed in the residential sector [5]. A total of 0.156 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 approximately 70 percent of biomass electricity generation [5]. A complete overview of organic waste biomass is presented in Section 4 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 3-1 [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 3-1: 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].

3.2 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.

3.3 State of energy crops nationally

Energy crops can be grown on most of the more than 369 million acres classified as cropland in the nation, as shown in Figure 3-1 from the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) [7]. Overall, the Nation's cropland acreage declined from 420 million acres in 1982 to 369.6 million acres in 2001, a decrease of about 12 percent. A subset of these lands is defined as prime farmland – those lands with the best combination of physical and chemical characteristics for producing food, fiber, energy crops and other vegetation. Energy crops offer many environmental advantages when produced on erosive lands or lands that are otherwise limited for conventional crop production.

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].

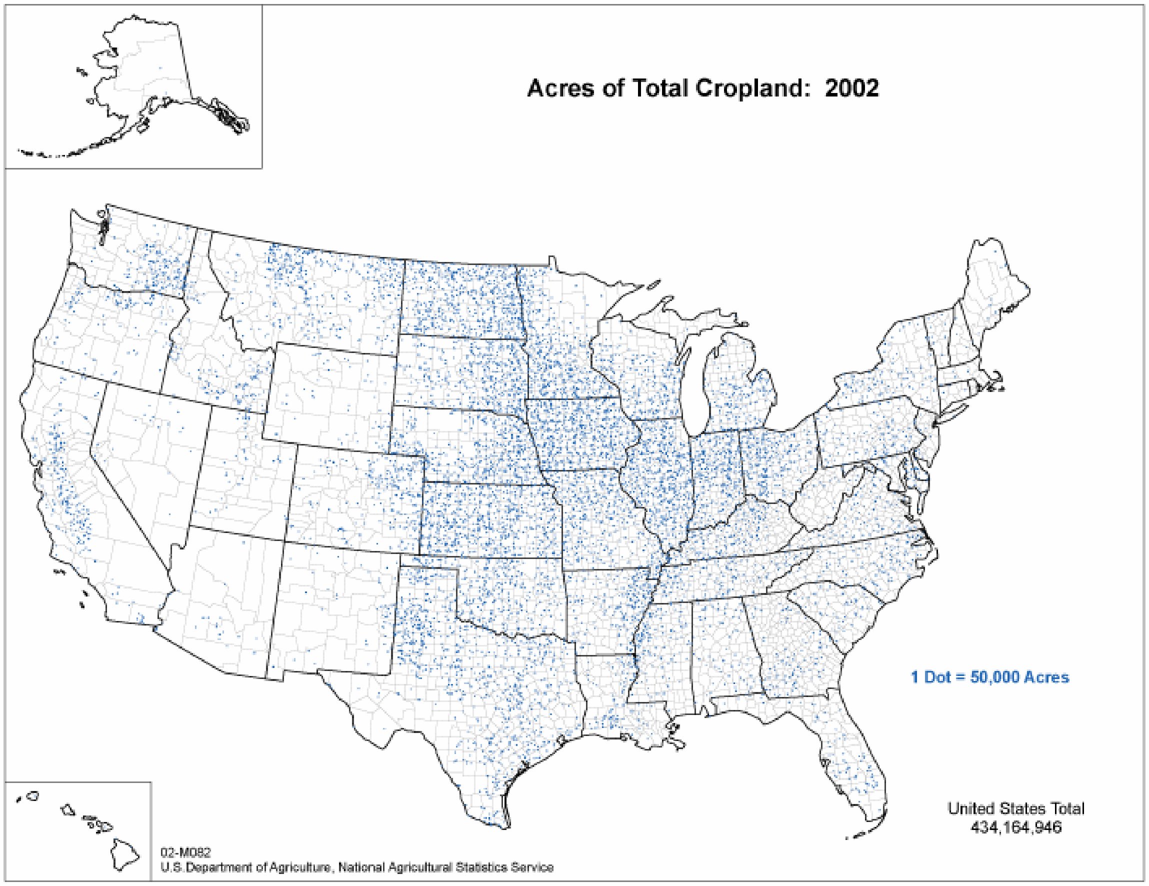
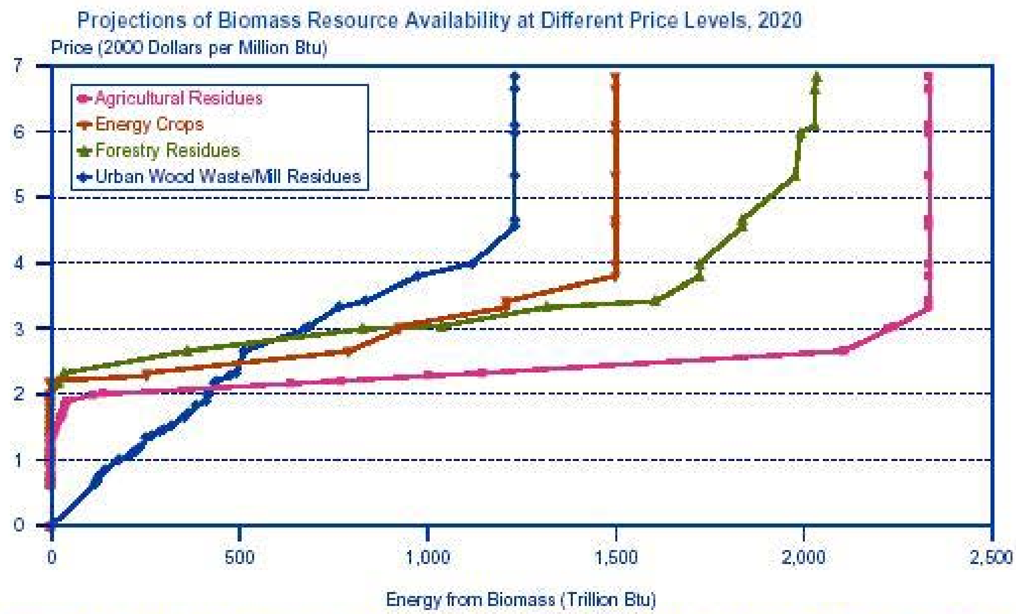


Figure 3-1: Cropland distribution in the United States (Source: NRCS)

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 3-2.

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 corn belt. 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 3-3. The final panel in Figure 3-3 shows the acreage in the Conservation Reserve Program

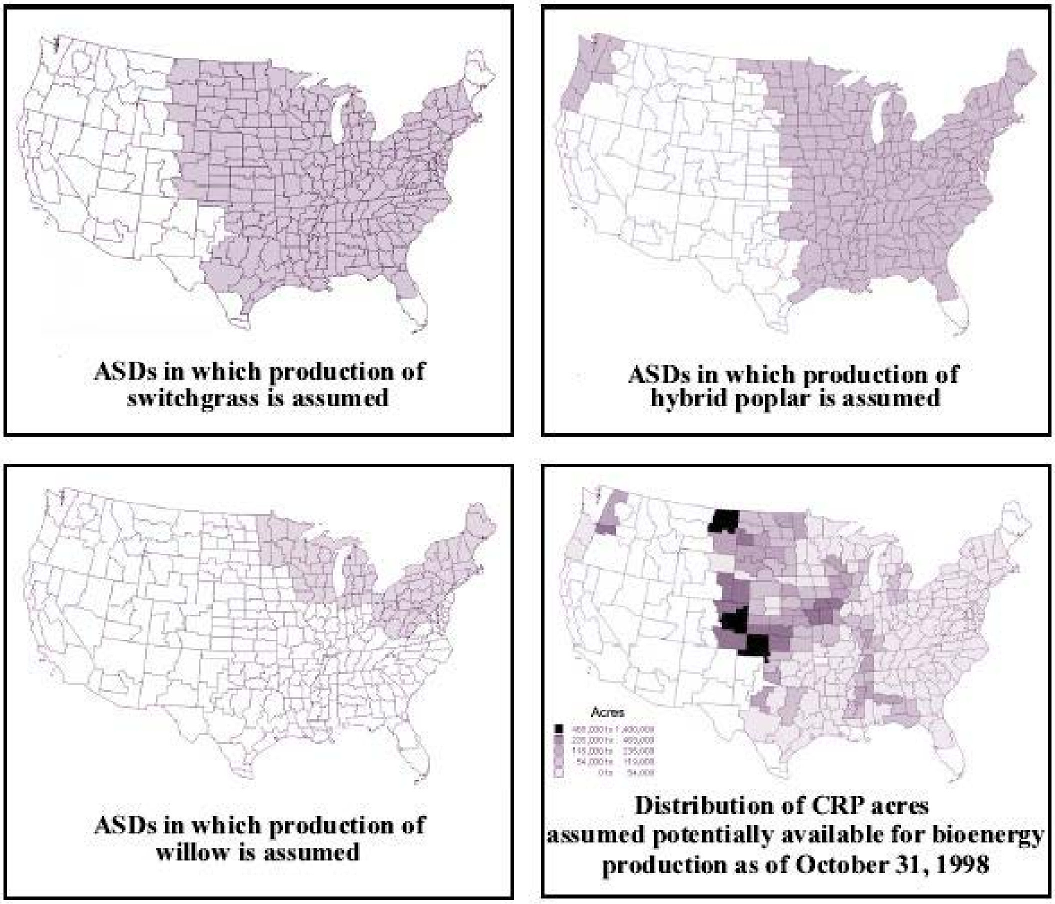
(CRP) that is assumed potentially available for bioenergy. These and further assumptions ORNL used with the POLYSYS model are discussed in ORNL's <u>The Economic Impacts of Bioenergy Crop Production on U.S. Agriculture</u> [11].



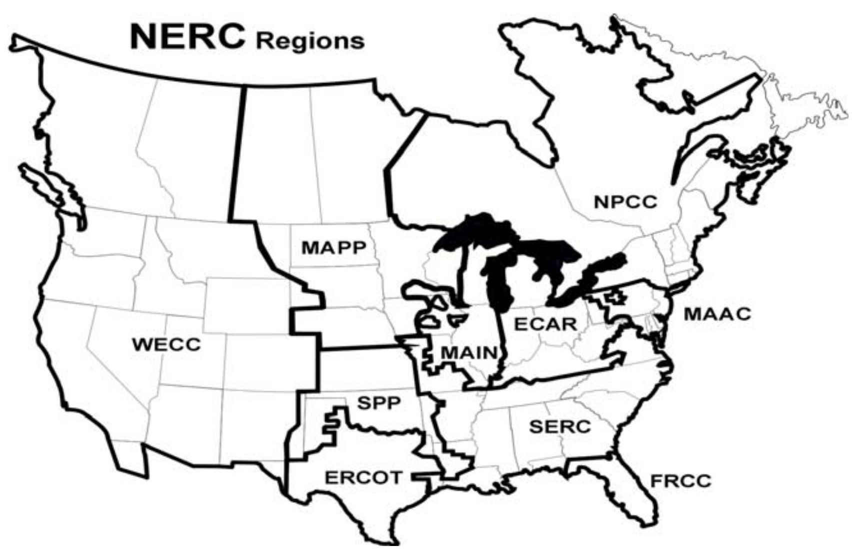
Sources: A.F. Turhollow and S.M. Cohn, *Data and Sources of Biomass Supply*, unpublished report (Oak Ridge, TN: Oak Ridge National Laboratory, January 1994); M. Walsh et al., *Biomass Feedstock Availability in the United States: 1999 State Level Analysis* (Oak Ridge, TN: Oak Ridge National Laboratory, 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).

<u>Figure 3-2:</u> <u>POLYSYS estimated biomass supply curve for year 2020</u> (Source: EIA)

Figure 3-2 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 3-2 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 3-4.



<u>Figure 3-3:</u> <u>POLYSYS assumed Agricultural Statistical Districts (ASDs) for energy crop production</u> (Source: ORNL)



<u>Figure 3-4:</u> <u>NERC defined regions</u> (Source: www.nerc.com)

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 3-2: POLYSYS estimated biomass supply for year 2020 for NERC regions (Source: EIA)

The energy crop yield assumptions that have been used for POLYSYS model are illustrated in Table 3-3. According to the EIA analysis paper, Biomass for Electricity Generation by Zia Haq [6],

> *the variation in yields is due to differences in weather and soil conditions across the country. The lowest yields are assumed to be in the Northern Plains and the highest in the heart of the corn belt, as is the pattern observed with traditional crops. In addition, POLYSYS assumes that different varieties of switchgrass, hybrid poplar, and willow are produced in different parts of the country, with different yield assumptions. Energy crop production costs are estimated using the same full-cost accounting approach that is used by USDA to estimate the cost of producing conventional crops. The approach includes both fixed costs (such as equipment) and variable costs (such as labor, fuel, seed, and fertilizers).*
>
> *Switchgrass stands are assumed to remain in production for 10 years before replanting, to be harvested annually, and to be delivered as large round bales. The plants can regenerate, and the same plant can continue to produce switchgrass for up to 10 years. It is assumed that new switchgrass varieties will have been developed after 10 years, and that it will be financially beneficial to plow under the existing switchgrass stand and replant with a new variety. Once established, a switchgrass field could be maintained in perpetuity, but the advantages of new, higher yield varieties would warrant periodic replanting.*

Hybrid poplars are assumed to be planted at spacings of 8 feet by 10 feet (545 trees per acre) and to be harvested after 6, 8, and 10 years of growth in the Pacific Northwest, southern United States, and northern United States, respectively. Harvesting is assumed to be by custom operation, and the product is assumed to be delivered as whole tree chips.

Willow production is assumed only in the northern United States. Willows can technically be grown throughout the entire eastern United States, but limited research has been done for areas outside the Northeast and North Central regions. Willows are produced in a coppice system with a replant every 22 years. They are planted in 2 x 3 double rows (6,200 trees per acre) with first harvest in year 4 and subsequent harvests every 3 years for a total of 7 harvests. Willow is delivered as whole tree chips.

In terms of product quality, hybrid poplar and willow contain about 45 to 50 percent moisture when harvested. The trees would typically be fed into a wood chipper, which generally would provide chips between 0.5 and 1 inch square and less than 0.25 inch thick. Switchgrass is harvested at about 15 percent moisture, baled, and generally ground in a tub grinder before use.

Energy Crop	Land Currently Planted with Major Crops	Idle and Pasture Land
Switchgrass	2.0 to 6.7	1.7 to 5.7
Hybrid poplar	3.25 to 6.0	2.8 to 5.1
Willow	3.15 to 5.8	2.7 to 4.9

Table 3-3: Energy crop yield assumptions for the POLYSYS model (dry tons per acre per year) (Source: EIA) [6]

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 3-5 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.

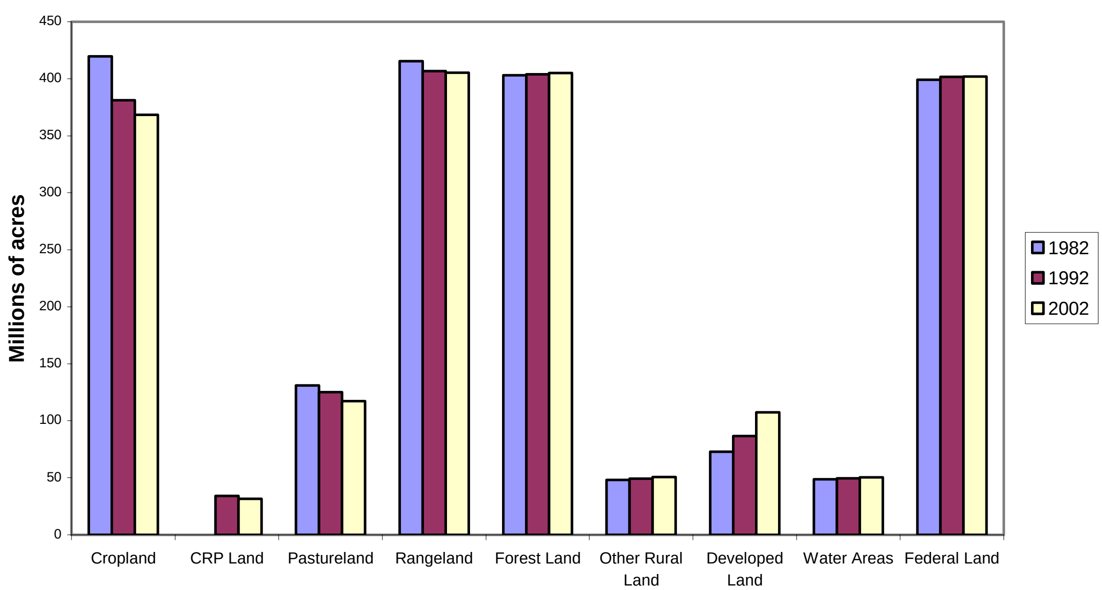


Figure 3-5: Land use in the contiguous United States (Source: NRCS)

3.4 Energy crops in Indiana

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]. 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 3-6.

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

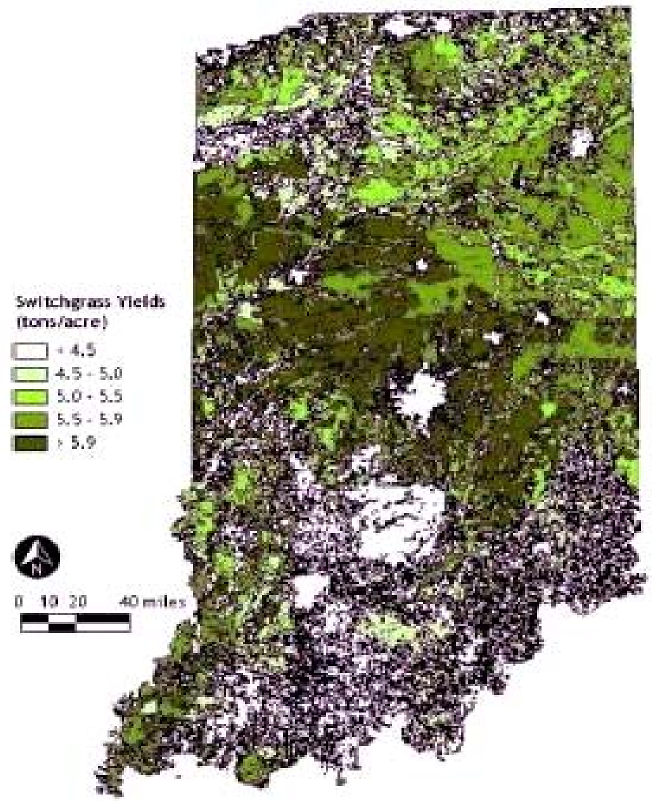


Figure 3-6: Switchgrass potential in Indiana (Source: Brown, et al.)

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 3-4.

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	418,042	5,026,234

Table 3-4: 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 (PTC) is a per Kilowatt-hour tax credit for electricity generated by qualified energy resources. It was renewed in October of 2004 such that the PTC would provide a tax credit of 1.5 cents/kWh, adjusted annually for inflation, for wind, solar, closed-loop biomass and geothermal. The adjusted credit amount for projects in 2005 is 1.9 cents/kWh. Electricity from open-loop biomass, small irrigation hydroelectric, and municipal solid waste resources will receive half that rate -- currently 0.9 cents/kWh. The duration of the credit for closed-loop biomass and wind continues to be 10 years, while open-loop biomass, solar, geothermal, small irrigation hydropower and municipal solid waste resources are eligible for the credit for a five-year period.
- Renewable Energy Systems and Energy Efficiency Improvements Program: Section 9006 of the 2002 Farm Bill requires the U.S. Department of Agriculture (USDA) to create a program to make direct loans, loan guarantees, and grants to agricultural producers and rural small businesses to purchase renewable-energy systems and make energy-efficiency improvements. This program is known as the Renewable Energy Systems and Energy Efficiency Improvements Program.
The USDA has implemented this program through a Notice of Funds Availability (NOFA) for each of the last three years. The latest round of funding, totaling $22.8 million was made available in March 2005. Half ($11.4 million) of this sum is available immediately for competitive grants. Renewable-energy grants range from $2,500 to $500,000 and may not exceed 25 percent of an eligible project's cost.
- Value-Added Producer Grant Program: A total of $14.3 million in grants was allocated for fiscal year 2005 from USDA to support the development of value-added agriculture business ventures. Value-Added Producer Grants are available to independent producers, agricultural producer groups, farmer or rancher cooperatives, and majority-controlled producer-based business ventures seeking funding. Grant awards for fiscal year 2005 supported energy generated on-farm through the use of agricultural commodities, wind power, water power or solar power. The maximum award per grant was $100,000 for planning grants and $150,000 for working capital grants. Matching funds of at least 50 percent were required.
- 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).
- Energy Education and Demonstration Grant Program: This program makes small-scale grants for projects that demonstrate applications of energy efficiency and renewable energy technologies for businesses, public and non-profit institutions, schools, and local governments.

- Energy Efficiency and Renewable Energy (EERE) Set-Aside: Indiana's Energy Efficiency and Renewable Energy (EERE) Set-Aside is a joint effort of the Indiana Energy and Recycling Office (ERO) and the Indiana Office of Air Quality (OAQ) that offers potential financial incentives to large-scale energy-efficiency projects and renewable-energy projects that significantly reduce nitrogen-oxide (NOx) emissions.
- Renewable Energy Production Incentive: The Renewable Energy Production Incentive (REPI) provides financial incentive payments for electricity produced and sold by new qualifying renewable energy generation facilities. Eligible electric production facilities include publicly-owned electric utilities, rural electric cooperatives, and local or state governments that sell the project's electricity to someone else. Eligible projects had to commence operations between October 1, 1993 and September 30, 2003. Qualifying facilities are eligible for annual incentive payments of 1.5 cents per kilowatt-hour (1993 dollars and indexed for inflation) for the first ten year period of their operation, subject to the availability of annual appropriations in each Federal fiscal year of operation. The period for payment under this program ends with fiscal year 2013.
- 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.

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4. Organic Waste Biomass

4.1 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 (MSW): 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 3, 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 DOE, the United States can produce nearly 1 billion dry tons of biomass annually and still continue to meet food, feed, and export demands. This projection includes 428 million dry tons of annual crop residues, 377 million dry tons of perennial

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

crops, 87 million dry tons of grains used for biofuels, and 106 million dry tons of animal manures, process residues, and other miscellaneous feedstock. Important assumptions that were made include the following [3]:

- *Yields of corn, wheat, and other small grains were increased by 50 percent;*
- *The residue-to-grain ratio for soybeans was increased to 2:1;*
- *Harvest technology was capable of recovering 75 percent of annual crop residues;*
- *All cropland was managed with no-till methods;*
- *55 million acres of cropland, idle cropland, and cropland pasture were dedicated to the production of perennial bioenergy crops;*
- *All manure in excess of that which can be applied on-farm for soil improvement under anticipated EPA restrictions were used for biofuel; and*
- *All other available residues were utilized."*

Furthermore, according to EIA [4], 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 making it the single largest renewable energy source, recently surpassing hydropower (Figure 4-1). More than 50 percent of this biomass comes from wood residues and pulping liquors generated by the forest products industry. Currently, biomass accounts for approximately [5]

- 13 percent of renewably generated electricity,
- 97 percent the industrial renewable energy use, and
- 84 percent of the energy consumption in the residential sectors and 90 percent of the energy consumption in the commercial sectors.

A large portion of the bioenergy usage is for cogeneration that takes place at the pulp and 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 [4].

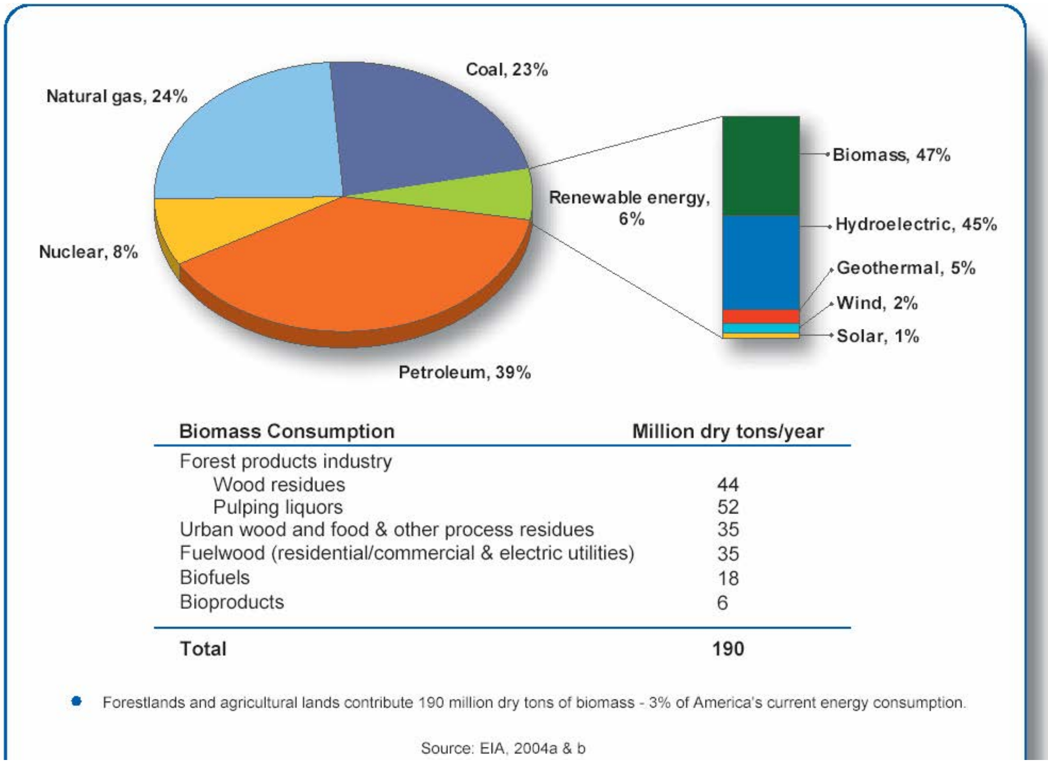

Figure 4-1: Summary of biomass resource consumption (Source: EIA)

The energy content in the various organic waste biomass fuels vary as shown in Table 4-1 [6].

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 4-1: Average heat content of selected biomass fuels (Source: EIA)

4.2 Economics of organic waste biomass-fired generation

Co-firing with biomass fuels utilizes existing power plant infrastructure to minimize costs while maximizing environmental and economic benefits [5]. 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 [7].

The following excerpt was extracted from DOE's website [7]:

> *"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."*

4.3 State of organic waste biomass-fired generation nationally

In 2002, the total biomass-based generation capacity in the U.S. was 9,733 MW [8]. Of this installed capacity 5,886 MW was dedicated to generation from wood and wood wastes (mostly by pulp and paper mills), 3,308 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 [7]. This translates to about 7,500 MW of additional generation capacity. According to the DOE Biomass Program [9],

> *"Biomass Program analysts estimate that 512 million dry tons of biomass equivalent to 8.09 quads of primary energy could initially be available at less than $50/dry ton delivered. Of this, 36.8 million dry tons (0.63 Quads) of urban wood wastes were available in 1999. In the wood, paper, and forestry industrial sectors, they estimate that 90.5 million dry tons (1.5 Quads) of primary mill*

residues were available in 1999 and 45 million dry tons (0.76 Quads) of forest residues were available at a delivered price of less than $50/dry ton. An estimated 150.7 million dry tons (2.3 Quads) of agricultural residues (corn stover and wheat straw) would be available annually."

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 [10]:

- 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 4-2 [10].

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 4-2: 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 [10]. 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 [10]. A listing of other pilot projects can be found on DOE's website [11].

Despite all the benefits offered by biomass gasification, there are a variety of technical barriers to its implementation as well. For example, the raw gases from biomass systems may not meet the strict quality standards for downstream fuel or chemical synthesis catalysts. Thus, extra gas cleaning and conditioning technologies must be developed at a price that is economically feasible. Moreover, effective process control is needed at biomass gasification plants. Emissions at target levels with varying loads, fuel properties, and atmospheric conditions must be monitored with sensors and a variety of other analytical instruments. Finally, as with all new process technologies, demonstrating sustained integrated performance that meets technical, environmental and safety requirements at sufficiently large scale is essential to supporting commercialization [12].

In 2004, DOE and USDA funded 22 projects with $25,480,628 to further the Biomass Research and Development Initiative. Including the cost sharing of the private sector partners, the total value of the projects is nearly $38 million. The funds will be used for biomass research, development and demonstration projects [13]. A complete listing of the sponsored projects can be found on the Energy Efficiency and Renewable Energy website [14].

4.4 Organic waste biomass in Indiana

In 2002, Indiana's total state generation of energy was 125,608 GWh. However, only 0.4% of the energy generation was renewable. Moreover, only 0.1% of the total energy generated came from biomass sources [15]. The reason for this low contribution is mainly due to the availability of low-cost fuels (coal) in the state, thus leading to generation predominantly from fossil-fueled stations [16].

Indiana has a large agricultural residue biomass resource potential, as shown in Figures 4-2, 4-3 [17] and 4-4. It is estimated that over 11 million dry tons of agricultural residues (corn stover and wheat straw) are available each year within Indiana [18]. However, there are potential problems associated with residue removal [19]. 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 [7]. However, the low cost of coal within Indiana will further tighten this bound.

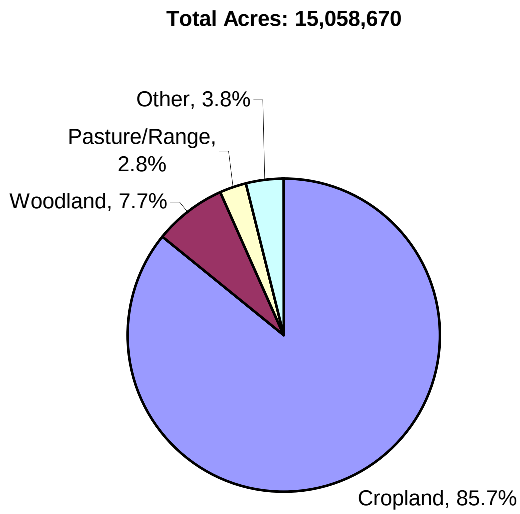

Figure 4-2: Indiana land use in 2002 (Source: USDA)

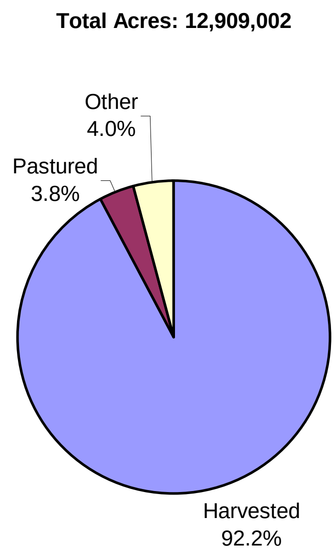

Figure 4-3: Indiana cropland use in 2002 (Source: USDA)

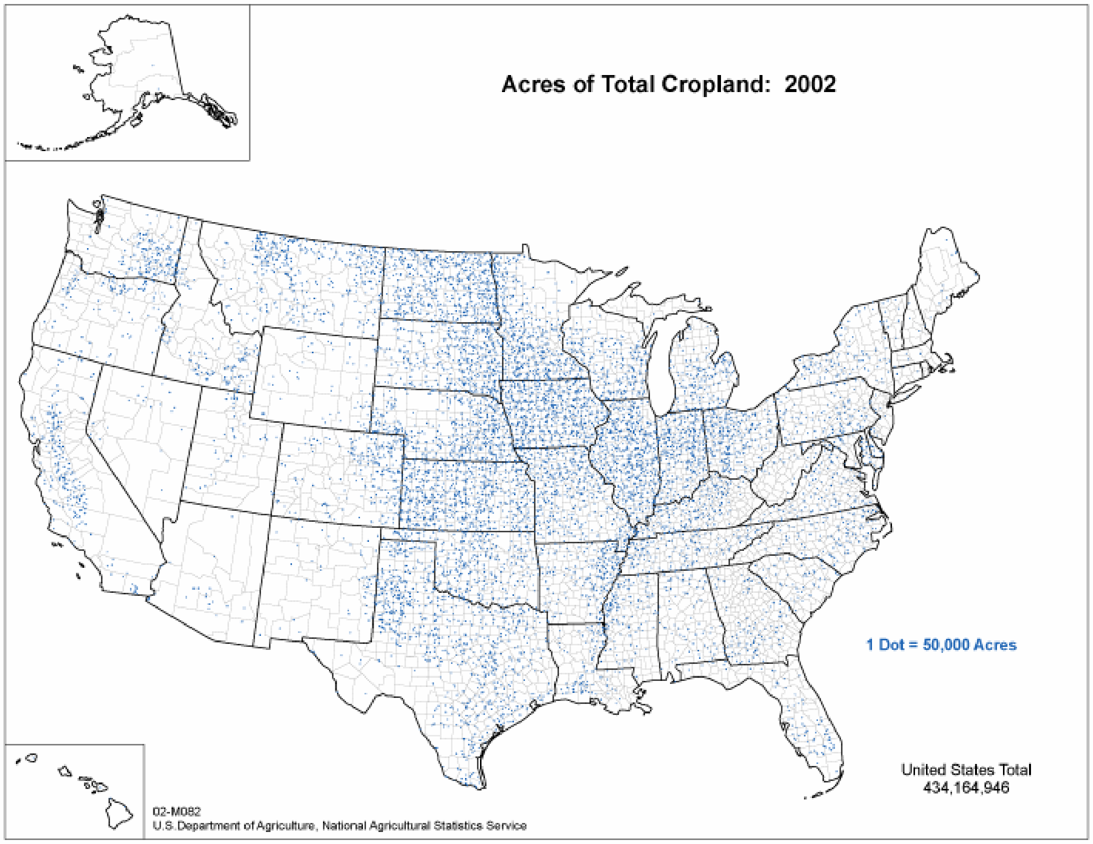

Figure 4-4: Cropland distribution in the United States (Source: NRCS [22])

An estimated 27.1 thousand GWh of electricity could be generated using renewable biomass fuels in Indiana. This is enough electricity to fully supply the annual needs of 2,706,000 average homes, or 100 percent of the residential electricity use in Indiana. 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 [18].

Wood is the most commonly used biomass fuel for heat and power while municipal solid waste (MSW) and landfill gas is the most common biomass fuel for electricity generation. The most economic sources of wood fuels are usually urban residues and mill residues. Urban residues used for power generation consist mainly of chips and grindings of clean, non-hazardous wood from construction activities, woody yard and right-of-way trimmings, and discarded wood products such as waste pallets and crates. Mill residues, such as sawdust, bark, and wood scraps from paper, lumber, and furniture manufacturing operations are typically very clean and can be used as fuel by a wide range of biomass energy systems. The estimated supplies of urban and mill residues available for energy uses in Indiana are 528,000 and 699,000 dry tons per year, respectively [18].

The other organic waste biomass resource estimates for Indiana are as follows [20]:

- Forest residues: 470,000 dry tons per year
- Biomass Processing Residues: 1,227,000 dry tons per year
- Agricultural Residues: 11,884,000 dry tons per year [18]

In a March 2004 presentation of the DOE office of the biomass program [21], the Northern Indiana Public Service Company (NIPSCO) in Hammond was reported as having 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.

As mentioned earlier, MSW/land fill gas is the main biomass fuel used for electricity generation in Indiana. The most active user of this organic waste biomass for electricity generation is Wabash Valley Power Association (WVPA). WVPA owns four landfill gas units in Hendricks, Cass, Jay and White counties and purchases the output of three other units in Indiana. WVPA has a total of 22.4 MW of waste biomass capacity. Another user of biogas for electricity generation is the Fair Oaks Dairy in northwest Indiana. A 700 kW generating facility utilizing animal manure as a fuel produces electricity to supplement the daily farms electricity needs [23].

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.

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5. Solar Energy

5.1 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 main 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 5-1.

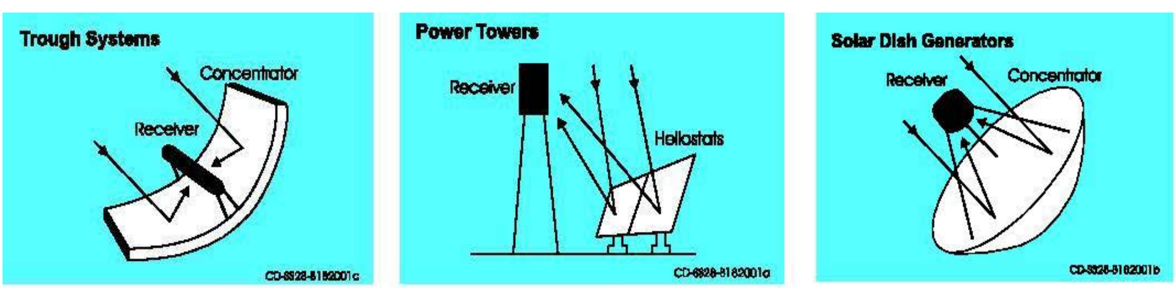

Figure 5-1: Solar thermal technologies (Source: EIA)

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[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. Solar power tower systems are unique among solar electric technologies in their ability to efficiently store solar energy and dispatch electricity to the grid when needed — even at night or during cloudy weather. [3].
- 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 5-1 illustrates further differences between the three types of solar thermal technologies [4].

	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 5-1: Characteristics of solar thermal electric power systems (Source: DOE)

Moreover, researchers are working with utilities on experimental hybrid power towers that run on solar energy and natural gas. A similar solar/fossil fuel hybrid is being developed for dish/engine systems. The advantage offered by hybrid systems is that they could run continuously independent of the weather conditions.

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.

5.2 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 [5]. Table 5-2 shows the forecast costs of energy (COE) from the solar thermal technologies in areas with high solar resources [6].

		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 5-2: Comparative costs of different solar thermal technologies (Source: Sandia National Laboratories)

Table 5-3 presents a comparison of solar electricity prices by the Solarbuzz Company [7] for the 12 month period running from July 2000 to June 2001. "*The table compares the solar electricity prices with US Government Statistics on US Electric Utility average Revenue per Kilowatt hour by Sector*."

Cents per kWhr	average electric-utility revenue	Residential Solar electricity price index	average electric-utility revenue	Commerical Solar electricity Price Index	average electric-utility revenue	Industrial solar electricity price index
	Residential		Commercial		Industrial	
2000						
July	8.63	39.85	7.58	29.62	4.76	21.50
August	8.64	39.45	7.68	29.42	4.85	21.34
September	8.5	39.41	7.49	29.3	4.69	21.26
October	8.47	39.53	7.45	29.46	4.57	21.38
November	8.19	39.26	7.15	29.18	4.37	21.18
December	7.79	40.09	7.25	29.74	4.64	21.58
2001						
January	7.73	40.57	7.6	30.02	4.96	21.74
February	8.03	40.45	7.55	29.9	5.09	21.66
March	8.19	40.45	7.51	29.86	4.9	21.62
April	8.42	40.69	7.58	30.06	4.92	21.78
May	8.57	40.57	7.48	30.02	4.93	21.74
June	8.82	40.63	7.84	30.03	5.16	21.76

Table 5-3: Solar electricity price index vs. United States electricity tariff price index (Source: Solarbuzz Company [7])

The residential price index is based upon a standard 2 kilowatt peak system, roof retrofit mounted. It is assumed to be connected to the electricity grid and has battery back up to allow it to operate during times of electricity downtime. The commercial price index is based on a 50 kilowatt ground mounted solar system, which is connected to the electricity grid. It is assumed to provide distributed energy and excludes any back up power. Finally, the industrial price index is based on a 500 kilowatt flat roof mounted solar system, suitable on large buildings. It is assumed to be connected to the electricity grid and excludes back up power [7].

5.3 State of solar energy nationally

The generation from solar energy was about 0.6 percent of the total non-hydropower renewable energy generated in 2002. The United States market showed 27 percent growth in demand for solar energy in 2004 compared to 17 percent in the previous year [8].

Figures 5-2 and 5-3 show the annual solar radiation in the U.S for different collector categories. Figure 5-2 shows the annual average solar radiation with a fixed, flat-plate, collector orientation fixed at its latitude whereas Figures 5-3 shows the annual average solar radiation for tracking, concentrating collectors [9]. 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. In addition, Figure 5-4 illustrates the solar radiation in each state [10]. The amount of solar radiation that each state is subjected to greatly impacts the cost and profit of implementing solar technologies [11].

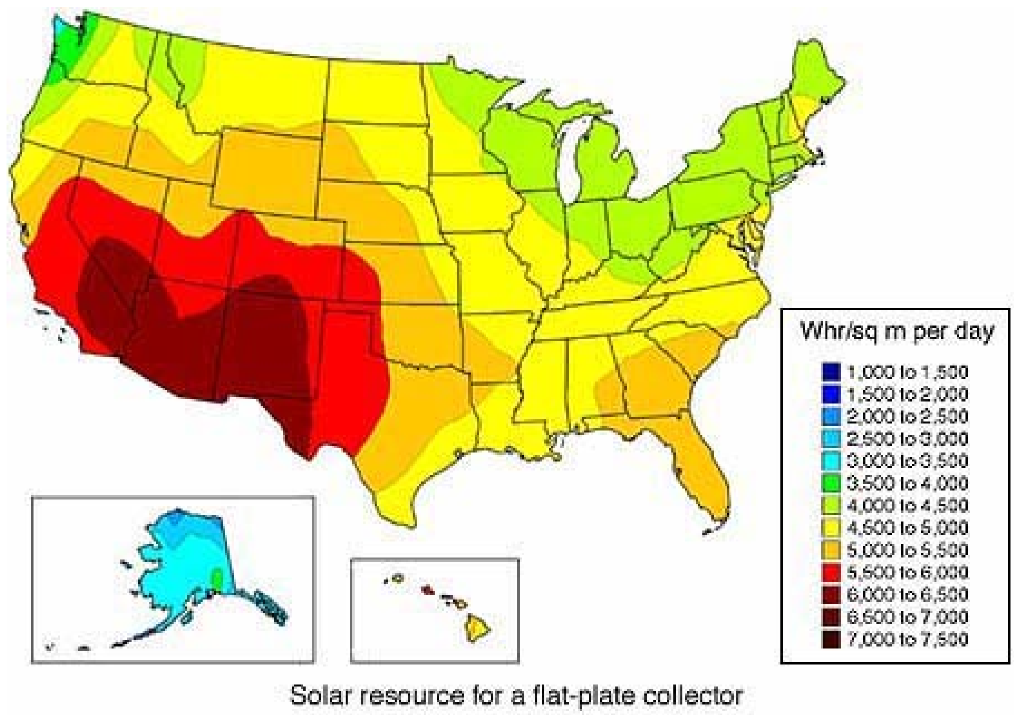

Figure 5-2: Annual average solar radiation for a flat-plate collector (Source: DOE)

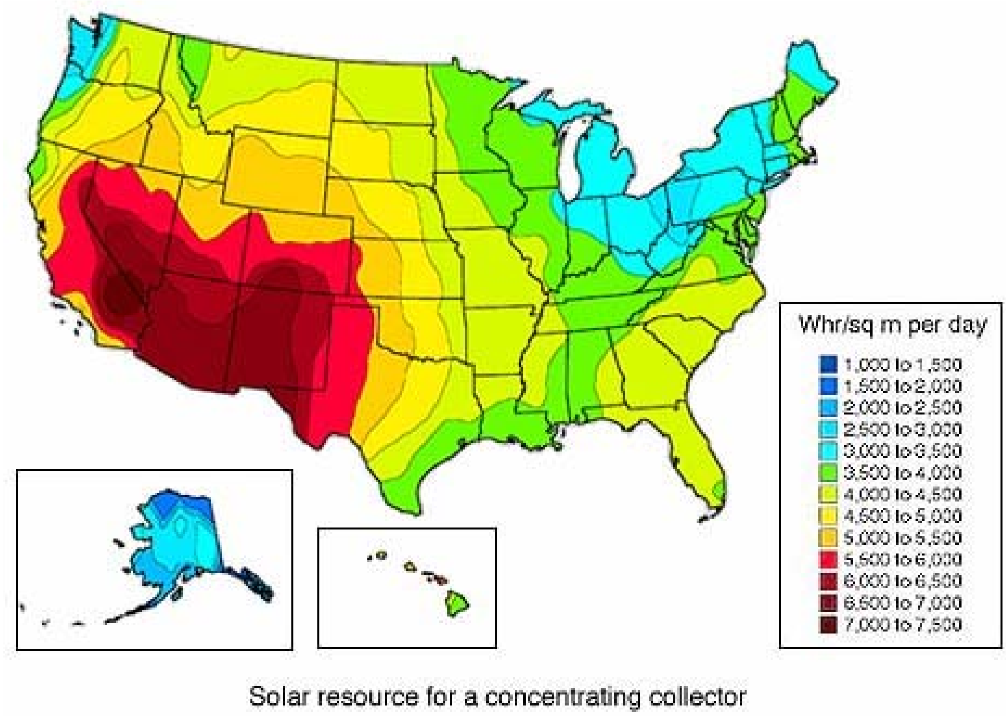

Figure 5-3: Annual average solar radiation for a concentrating collector (Source: DOE)

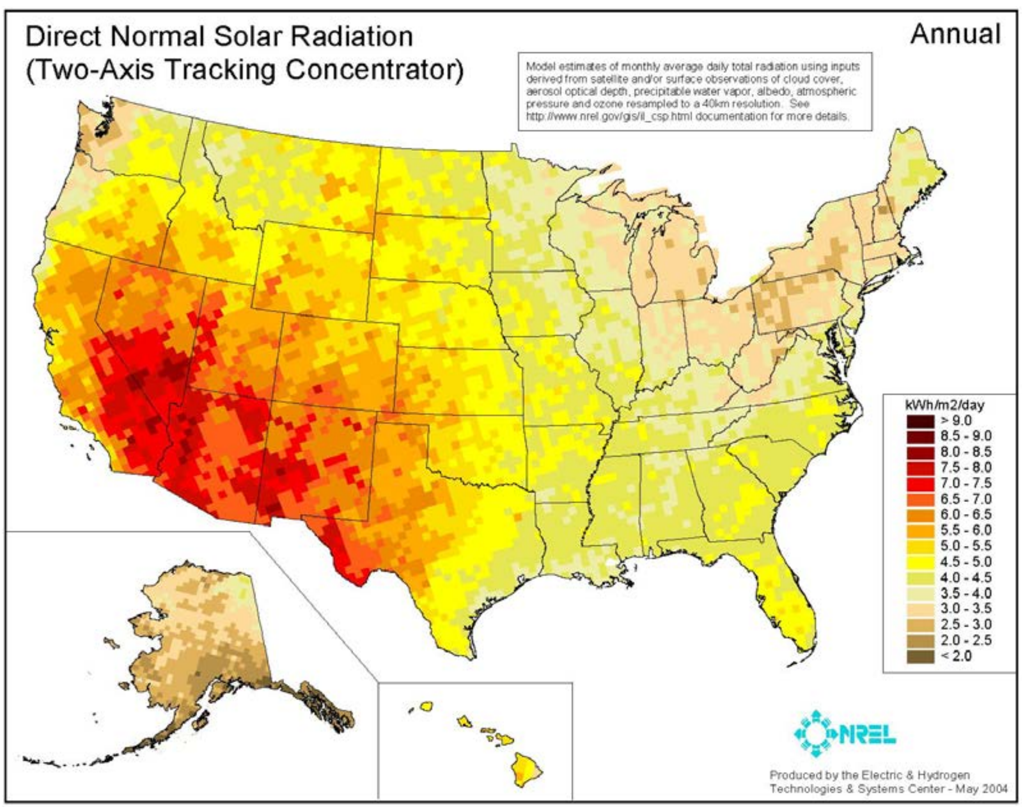

Figure 6-5: Direct normal solar radiation (two-axis solar concentrator) (Source: NREL)

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 [12]. 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. The goal of the Solar Two facility was to validate solar power generation using molten salt for thermal energy transport and storage and to show that the technology is viable for dispatchable power. The project was successful in that it met all of its objectives. Furthermore, key U.S. industry participants in the project have begun a commercial solar power tower project in Spain. They are actively seeking U.S. customers for domestic plants [10]. There are currently many projects in the Southwest investigating the long term use of solar dish systems [13].

Some projects that are currently in process include [14]:

- The 1000-MW Initiative: NREL, working through SunLab, is supporting DOE's goal to install 1,000 MW of new concentrating solar power systems in the southwestern United States by 2010. This level of deployment, combined with research and development to reduce technology component costs, could help reduce concentrating solar power electricity costs to $0.07/kilowatt-hour. At this cost, concentrating solar power can compete effectively in the Southwest's energy markets.
- USA Trough Initiative: Through the USA Trough Initiative, NREL is supporting the DOE's efforts to expand U.S. industry involvement and competitiveness in worldwide parabolic-trough development activities. This includes helping to advance the state of parabolic-trough technology from a U.S. knowledge base.
- Parabolic-Trough Solar Field Technology: NREL is working to develop less costly and more efficient parabolic-trough solar field technology. This involves improving the structure of parabolic-trough concentrators, receivers, and mirrors, and increasing the manufacturing of these components. Through NREL's development and testing, the next generation of parabolic-trough concentrators is quickly evolving. NREL is focused on optimizing the structure of the current steel/thick-glass concentrators and increasing the concentrator size.
- Advanced Optical Materials for Concentrating Solar Power: NREL is working to develop durable, low-cost optical materials for concentrating solar power systems. These optical materials-which reflect, absorb, and transmit solar energy - play a

fundamental role in the overall cost and efficiency of all concentrating solar power systems. Today, the solar collectors used in concentrating solar power systems account for approximately 50 percent of the total capital cost of power plants. The solar reflector costs for these systems represent about 30% of the collector cost. To reduce the costs of solar collectors, NREL focuses on improving the stability of selective coatings at higher temperatures for use on optical materials.

- Parabolic-Trough Systems Integration: NREL is developing system integration software tools for evaluating parabolic-trough technologies and assessing concentrating solar power program activities. This includes models for evaluating:
    - Collector optics and thermal performance
    - Plant process design and integration tools
    - Annual performance and economic assessment
    - Capital and operation and maintenance costs.
- Parabolic-Trough Solar Power Plant Technology: NREL continues to evaluate and develop opportunities for improving the cost effectiveness of parabolic-trough concentrating solar power plants. They are primarily working to integrate parabolic-trough technology into Rankine cycle power plants - the power plants of choice because of their efficiency. Their work also encompasses projects to reduce power plant and solar-field O&M costs by:
    - Scaling up plant size
    - Increasing capacity factor
    - Improving receiver and mirror reliability, and mirror-washing techniques
    - Developing improved automation and control systems
    - Developing O&M data integration and tracking systems.
- Parabolic-Trough Thermal Energy Storage Technology: NREL is working to develop efficient and lower cost thermal energy storage technologies for parabolic-trough concentrating solar power systems. Improved thermal energy storage is needed to:
    - Increase solar plant capacity factors above 25 percent
    - Increase dispatchability of solar power
    - Help reduce the cost of solar electricity.

  Parabolic-trough technology currently has one thermal energy storage option - a two-tank, indirect, molten-salt system. The system uses different heat transfer fluids for the solar field and for storage. Therefore, it requires a heat exchanger. It has a unit cost of $30-$40/kWh.

The total domestic shipments of solar thermal collectors were 11.0 million square feet in 2002 [15]. This represents an increase from 10.3 million 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 5-5 illustrates the top states for domestic shipments of solar thermal collectors in 2002.

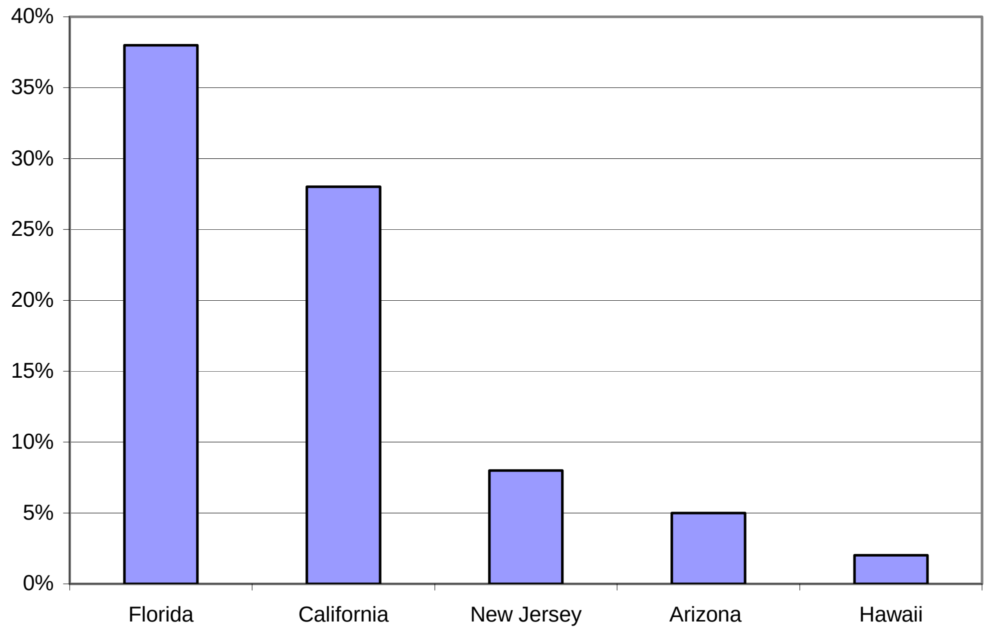

Figure 5-5: Top domestic destinations for solar thermal collectors (Source: EIA)

5.4 Solar energy in Indiana

Indiana has relatively little potential for grid-connected solar projects like those in California [9] because of the lack of annual solar radiation, as shown in Figures 5-2 and 5-3. 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. Figure 5-6 is a map made by NREL that represents

> "*the states with largest commercial solar market potential as measured by the Breakeven Turnkey Costs (BTC) using data developed by NREL. The BTC represents the cost at which investments in commercial solar equipment will breakeven over the life of the equipment. Measured this way, higher breakeven costs represent markets with the highest potential. The BTC takes into account the cost of equipment, the amount of sunlight, electricity prices, and any financial incentives available for solar equipment with the state. As shown in the map, four states (MT, HI, WI, and NJ) have the highest potential for commercial solar as measured by BTC* [16]*.*"

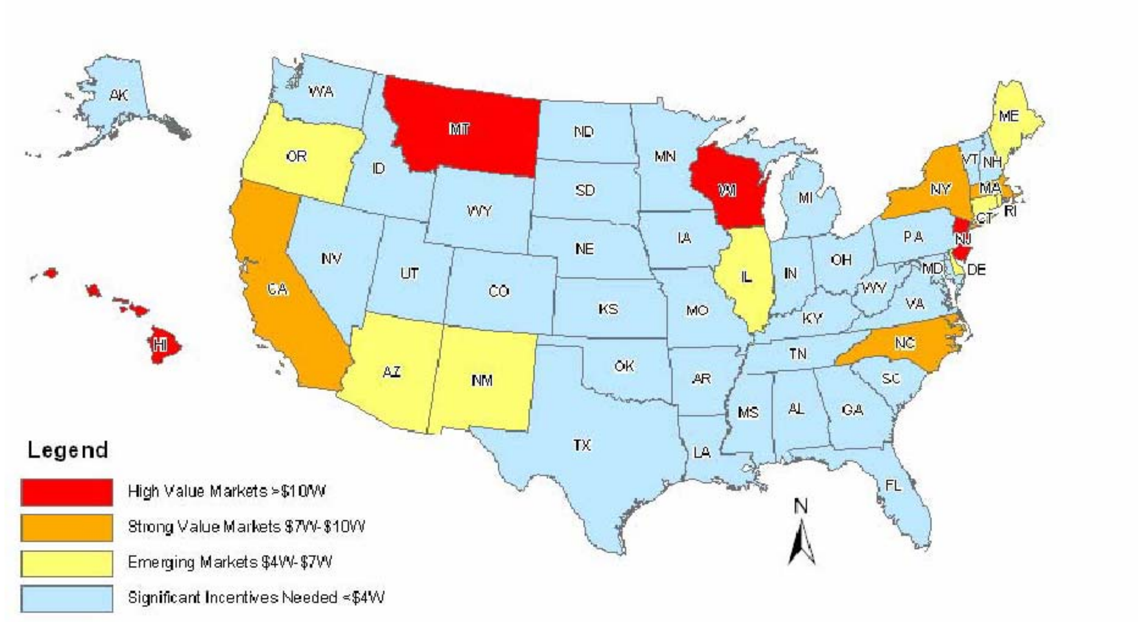

Figure 5-6: Breakeven turnkey costs for commercial solar by state (Source: NREL)

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 [17].

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 [18]. 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 [19] could help with the introduction of solar energy within Indiana:

- Million Solar Roofs Initiative DOE's Million Solar Roofs program is also aimed at increasing the number of buildings using solar power (thermal and PV) for their water and space heating and cooling needs. The goal is to have one million buildings using this technology by 2010.
- Renewable Electricity Production Credit The Renewable Electricity Production Credit (PTC) is a per kilowatt-hour tax credit for electricity generated by qualified energy resources. It provides a tax credit of 1.5 cents/kWh, adjusted annually for inflation, for wind, solar, closed-loop biomass and geothermal. The adjusted credit amount for projects in 2005 is 1.9 cents/kWh.
- 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.
- Net metering rule: Solar, wind and hydroelectric facilities with a maximum capacity of 10 kW are under this September 2004 rule qualified for net metering where the net excess generation is credited to the customer in the next billing cycle.
- 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.
- Solar and Geothermal Business Energy Tax Credit: The U.S. federal government offers a 10 percent tax credit to businesses that invest in or purchase solar or geothermal energy property in the United States. The tax credit is limited to $25,000 per year, plus 25 percent of the total tax remaining after the credit is taken. Remaining credit may be carried back to the three preceding years and then carried forward for 15 years.
- Renewable Energy Systems and Energy Efficiency Improvements Program: Solar facilities are eligible for renewable-energy grants range from $2,500 to $500,000. The grants may not exceed 25 percent of an eligible project's cost.
- Tax Exempt Financing for Green Buildings: The "American Jobs Creation Act of 2004", signed into law on October 22, 2004, authorizes $2 billion in tax-exempt bond financing for green buildings, brownfield redevelopment, and sustainable design projects.
- Residential Energy Conservation Subsidy Exclusion: According to Section 136 of the IRS Code, energy conservation subsidies provided by public utilities, either directly or indirectly, are nontaxable: "Gross income shall not include the value of any subsidy provided (directly or indirectly) by a public utility to a customer for the purchase or installation of any energy conservation measure.”
- Conservation Security Program (CSP): The 2005 CSP sign-up includes a renewable-energy component. Eligible producers will receive $2.50 per 100 kWh of electricity generated by new wind, solar, geothermal and methane-to-energy systems. Payments of up to $45,000 per year will be made using three tiers of conservation contracts, with a maximum payment period of 10 years.
- Modified Accelerated Cost-Recovery System (MACRS): Under this program, businesses can recover investments in solar, wind and geothermal property through depreciation deductions. The MACRS establishes a set of class lives for various types of property, ranging from three to 50 years, over which the property

may be depreciated. For solar, wind and geothermal property placed in service after 1986, the current MACRS property class is five years.

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.

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6. Photovoltaic Cells

6.1 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 6-1). 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].

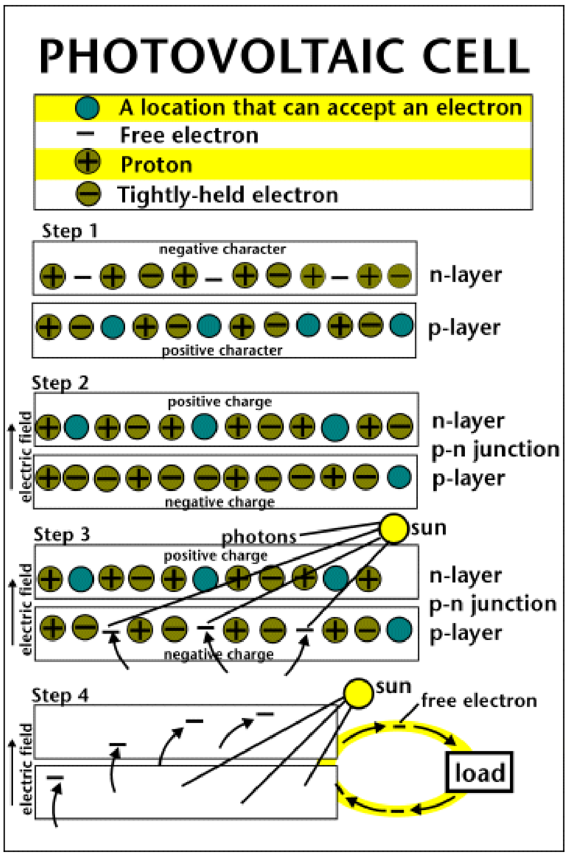

Figure 6-1: Photovoltaic cell operation (Source: EIA)

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 three major types of PV cells: crystalline silicon-based, thin film-based and concentrator 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] Concentrator cells and modules basically utilize a lens to gather and converge sunlight onto the cell or module surface [4].

"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 NREL is continuing to further research and develop concentrating photovoltaic (CPV) technology as an alternative to dish Stirling engines. According to NREL,

> *"Concentrating photovoltaic systems use lenses or mirrors to concentrate sunlight onto high-efficiency solar cells. These solar cells are typically more expensive than conventional cells used for flat-plate photovoltaic systems. However, the concentration decreases the required cell area while also increasing the cell efficiency. Concentrating photovoltaic technology offers the following advantages:*
>
> - *Potential for solar cell efficiencies greater than 40%*
> - *No moving parts*
> - *No intervening heat transfer surface*
> - *Near-ambient temperature operation*
> - *No thermal mass, fast response*
> - *Reduction in costs of cells relative to optics*
> - *Scalable to a range of sizes.*
>
> *The high cost of advanced, high-efficiency solar cells requires the use of concentrated sunlight for systems to achieve a cost-effective comparison with both*

the cost of concentrator optics and other solar power options. NREL has recently focused on the development of multi-cell packages (dense arrays) to improve overall performance, improve cooling, and install reliable prototype systems" [5].

In addition, other advanced approaches to solar cells are under investigation. For example, Dye-sensitized solar cells use a dye-impregnated layer of titanium dioxide to generate a voltage as opposed to the semiconducting materials used in most solar cells currently in the industry. Because titanium dioxide is fairly inexpensive, it offers the potential to significantly reduce the cost of solar cells. Other advanced approaches include polymer (or plastic) solar cells and photoelectrochemical cells, which produce hydrogen directly from water in the presence of sunlight [6].

The main advantages to using PV systems are [7]:

- 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.

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.

6.2 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 [8]. 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, 8]. The recent trend in PV module prices is shown in Figure 6-2 [9]. From August 2001 to April 2004, PV prices dropped by 16 percent.

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

Moreover, overall photovoltaic prices have declined on average 4 percent per annum over the past 15 years. The recent leveling of prices is believed to be due to increased demand as well as increased conversion efficiencies and manufacturing economies of scale. As production increases in response to the higher demand, prices are expected to continue to fall. In fact, The U.S. market showed 27 percent growth for solar energy demand in 2004 compared to 17 percent in the previous year. These figures serve to promote the economic viability of PV systems in the future [10].

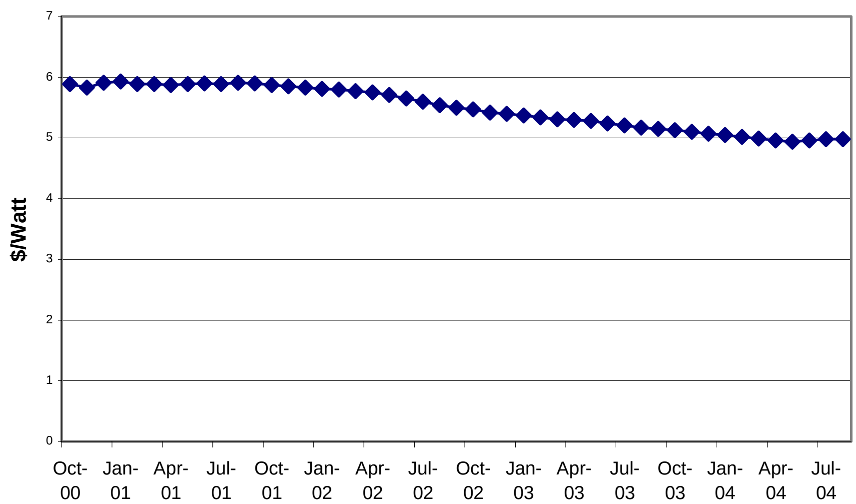

Figure 6-2: Historical PV module prices (Source: Solarbuzz)

The 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 [8, 11]. These low O&M costs lead to levelized PV energy costs ranging from about 20 cents/kWh to 50 cents/kWh [2, 8, 12]. At these prices, PV is cost effective for residential customers located farther than a quarter of a mile from the nearest utility line [12] 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 [8, 13].

Another factor affecting the economics of photovoltaic cell is the typically low conversion efficiencies. According to the NREL PV program, a typical commercial PV solar cell efficiency is 15 percent. The improvement of these efficiencies while holding down the capital cost is one of the goals of the DOE's solar energy research program [14].

6.3 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 [15], the solar resources for these two systems are different in the U.S. as shown in Figures 6-3 and 6-4. Figure 6-5 shows the direct normal solar radiation available to concentrating systems that track the sun throughout the day (two-axis concentrator) [16].

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 [17].

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 [15]. 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, 18].

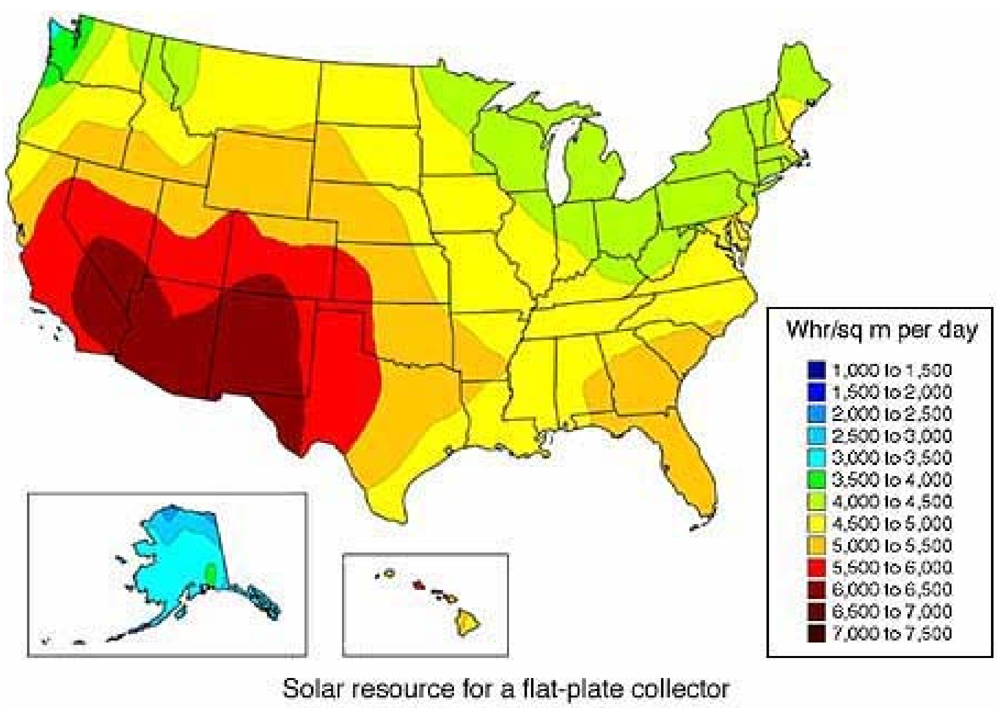

Figure 6-3: <u>Annual average solar radiation for a flat-plate collector</u> (Source: DOE)

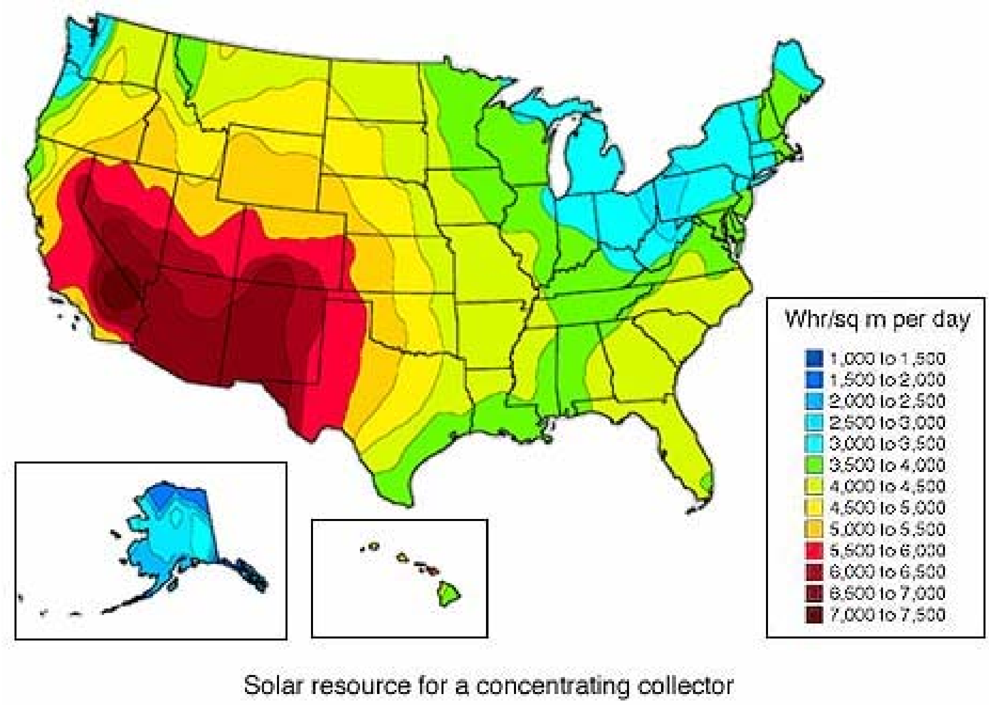

Figure 6-4: Annual average solar radiation for a concentrating collector (Source: DOE)

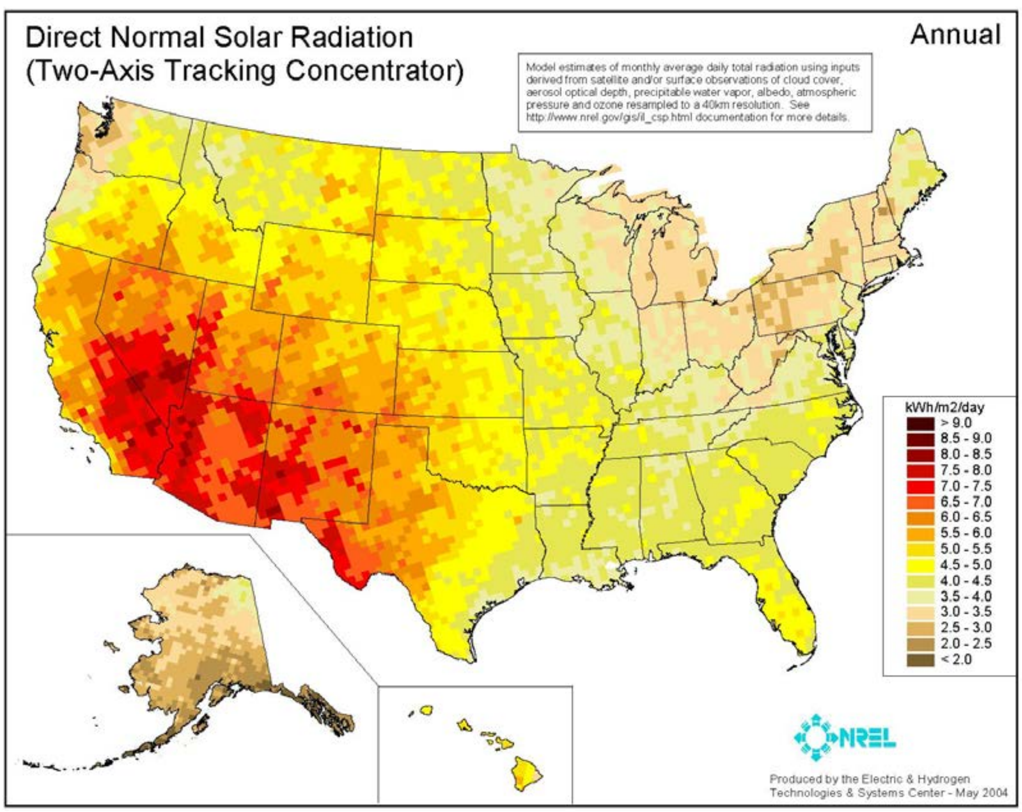

Figure 6-5: Direct normal solar radiation (two-axis solar concentrator) (Source: NREL)

In 1998, a study was carried out by EIA [19] 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 [19]:

- 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 [18]. These domestic shipments provide an indication of the status of the PV market. Table 6-1 shows the annual domestic shipments and imports of PV cells in the United States.

As can be seen from Table 6-1, 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 [18].

The following programs in the Midwest region are extracted from the International Energy Agency of major PV programs in the United States [20].

> ***"Illinois:*** *Led by the strong "Brightfields" program in Chicago (where abandoned factories (Brownfields) are converted to photovoltaic manufacturing plants (owned and operated by Spire Corporation) or installed photovoltaic*

[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. The state of Illinois passed the largest subsidy in the United States for photovoltaic systems, $6.00/W$_p$**.** Over 1 MW of photovoltaic systems was installed in Illinois in 2003.*

Ohio: *A primary objective in Ohio is support for 50 schools to have photovoltaic systems/training modules installed on public schools.*"

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 6-1: Annual domestic shipments and imports of PV cells and modules in the United States (Source: EIA)

The national PV Roadmap [21] 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) [19, 21]. The forecast end-user price in the roadmap is between $3/W and $4/W by 2010 [21].

Distributors have identified markets where photovoltaic power is cost-effective now, without subsidies [13]. 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 [22]:

> *"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 [22]. 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 [19].

Figure 6-6 shows the growth of installed PV power installations in the United States over the ten year period from 1992 to 2003 segregated by market sector [20].

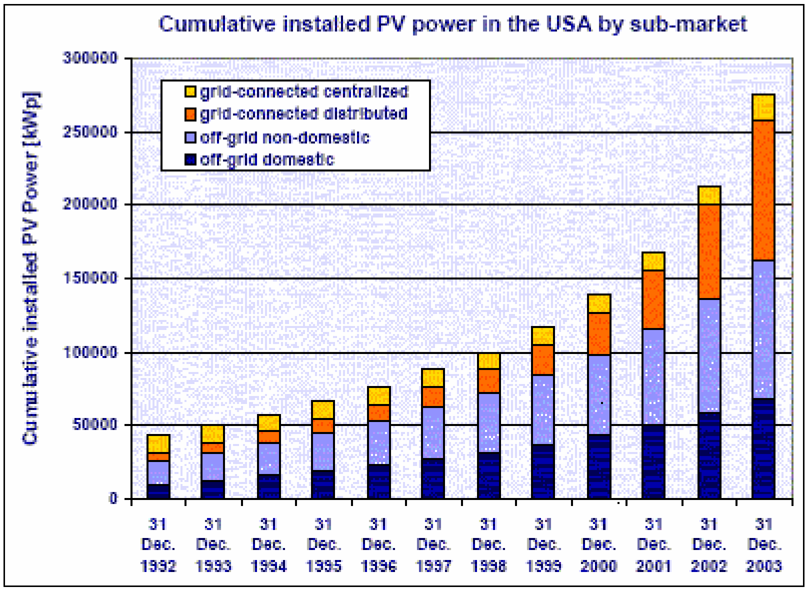

Figure 6-6: Cumulative installed PV power in the U.S. by sub-market (Source: International Energy Agency)

In 2004, 51 MW of grid-connected solar PV systems were installed in the United States. This represented a 28 percent growth over 2003 installations of approximately 37 MW. Figure 6-7 details the breakdown of nationwide PV installations in 2004 by major PV incentive program. As can be inferred from the chart, PV installations in PG&E's territory accounted for approximately 27 percent of the national market. The second largest market segment was commercialized systems into the same Northern Californian utility's territory [23].

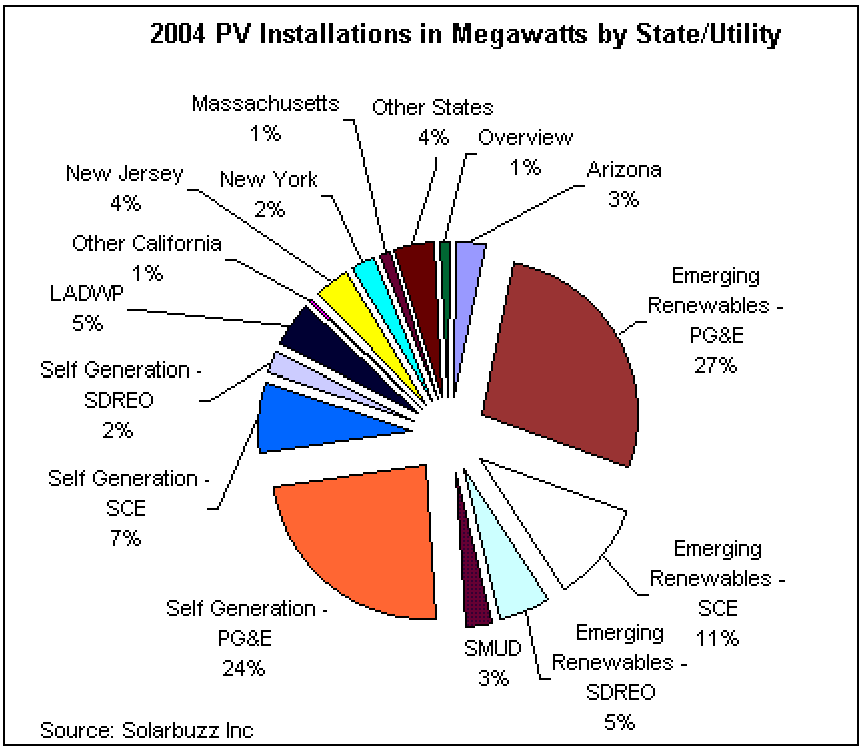

Figure 6-7: PV installations by state and utility (Source: Solarbuzz)[13]

As of May 2005, there is approximately $516M in funding lined up against prospective PV projects that have yet to be installed. Additionally, another $558 million of identified PV projects are waiting in queue to receive funding [23].

6.4 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 [17, 24], as

[13] LADWP – Los Angeles Department of Water & Power; PG&E – Pacific Gas & Electric; SDREO – San Diego Regional Energy Office; SMUD – Sacramento Municipal Utility District; SCE – Southern California Edison

shown in Table 6-2. 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 6-2: Grid-connected PV systems in Indiana (Source: DOE)

In addition, six schools installed PV systems in the Cinergy-PSI service territory in 2003 and two additional schools installed PV systems in 2004. PSI Energy has contracted with Altair Energy and the NEED Project to provide an educational program for these schools. Also, two residential homes in PSI Energy's service territory installed PV systems in 2004 in addition to four homes that installed PV systems in 2003. The eight schools currently participating in the program are [25]:

- 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
- North Manchester High School

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 [26]. In addition an 8 kW PV array has been operating at the Cinergy-PSI field office in Bloomington since September 2004 [27].

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[14] 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

[14] Besides the energy from the sun.

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 relatively low solar resource (Figures 6-3, 6-4, 6-5) in Indiana combined with the availability of low cost energy from coal results in the break-even cost being one of the lowest nationally. Figure 6-8 shows Indiana ranked thirty fifth nationally for residential PV break-even cost in a list led by such states as Hawaii, California and Arizona.

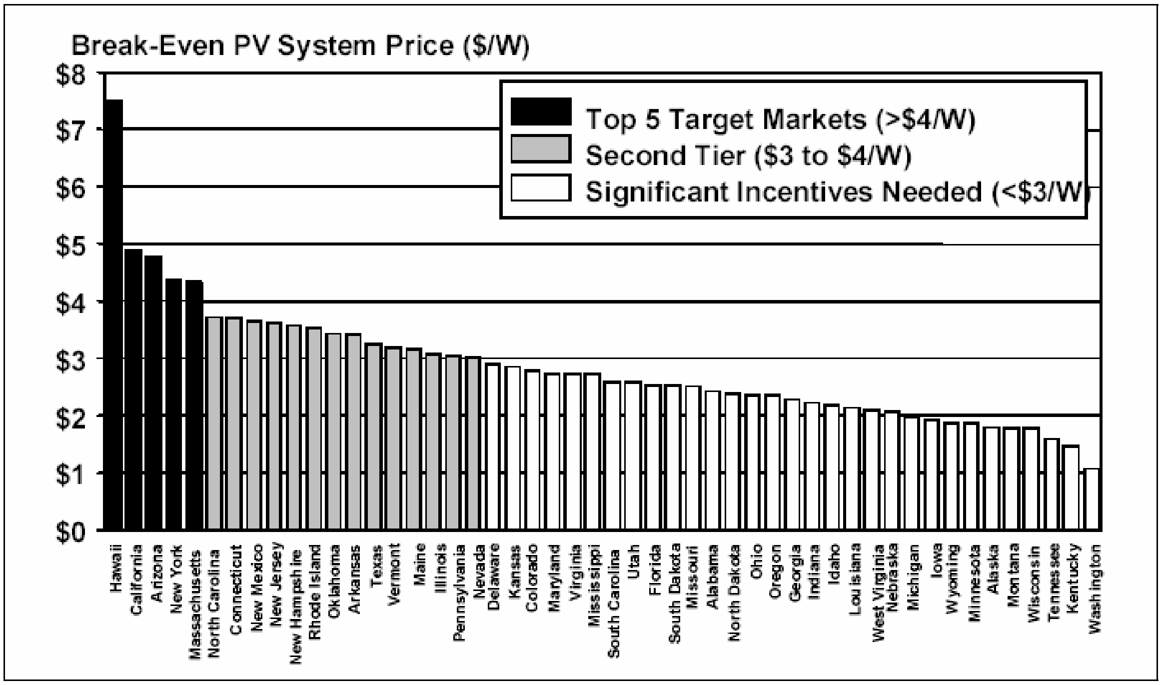

Figure 6-8: State-by-state ranking of PV residential break-even-turnkey cost (Source: NREL [28])

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 [21] but this is still above the break-even costs of entry of PV systems within Indiana. There are several Federal, State and Utility incentives available to PV systems [6]. They include[15]:

Federal Incentives:

- Million Solar Roofs Initiative: DOE's Million Solar Roofs program is aimed at increasing the number of buildings using solar power (thermal and PV) for their water and space heating and cooling needs. The goal is to have one million buildings using this technology by 2010.
- Renewable Electricity Production Credit: The Renewable Electricity Production Credit (PTC) is a per kilowatt-hour tax credit for electricity generated by qualified energy resources. It provides a tax credit of 1.5 cents/kWh, adjusted annually for

[15] These initiatives are also discussed in Section 5.4.

inflation, for wind, solar, closed-loop biomass and geothermal. The adjusted credit amount for projects in 2005 is 1.9 cents/kWh.

- Residential Energy Conservation Subsidy Exclusion: According to Section 136 of the IRS Code, energy conservation subsidies provided by public utilities, either directly or indirectly, are nontaxable: "Gross income shall not include the value of any subsidy provided (directly or indirectly) by a public utility to a customer for the purchase or installation of any energy conservation measure".
- Modified Accelerated Cost-Recovery System (MACRS): Under this program, businesses can recover investments in solar, wind and geothermal property through depreciation deductions. The MACRS establishes a set of class lives for various types of property, ranging from three to 50 years, over which the property may be depreciated. For solar, wind and geothermal property placed in service after 1986, the current MACRS property class is five years.
- Solar and Geothermal Business Energy Tax Credit: The U.S. federal government offers a 10 percent tax credit to businesses that invest in or purchase solar or geothermal energy property in the United States. The tax credit is limited to $25,000 per year, plus 25 percent of the total tax remaining after the credit is taken. Remaining credit may be carried back to the three preceding years and then carried forward for 15 years.
- Tax Exempt Financing for Green Buildings: The "American Jobs Creation Act of 2004", signed into law on October 22, 2004, authorizes $2 billion in tax-exempt bond financing for green buildings, brownfield redevelopment, and sustainable design projects.
- Renewable Energy Systems and Energy Efficiency Improvements Program: Solar Facilities are eligible for renewable-energy grants range from $2,500 to $500,000. The grants may not exceed 25% of an eligible project's cost.

State Incentives:

- 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).
- 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.
- Net Metering Rule: Solar, wind and hydroelectric facilities with a maximum capacity of 10 kW are under this September 2004 rule qualified for net metering where the net excess generation is credited to the customer in the next billing cycle.
- Energy Education and Demonstration Grant Program: This program makes small-scale grants for projects that demonstrate applications of energy efficiency and renewable energy technologies for businesses, public and non-profit institutions, schools and local governments. A maximum of $30,000 may be awarded.

- Energy Efficiency and Renewable Energy (EERE) Set-Aside: This program is a joint effort of the Indiana Energy and Recycling Office and the Indiana Office of Air Quality that offers potential financial incentives to large-scale energy-efficiency projects and renewable-energy projects that significantly reduce nitrogen-oxide emissions.
- 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 [29]. These credits can be sold on the national market.

Utility programs:

- Green Pricing Program: is an initiative offered by some utilities that give consumers the option to purchase power produced from renewable energy sources at some premium [30].

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7. Fuel Cells

7.1 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 7-1 below.

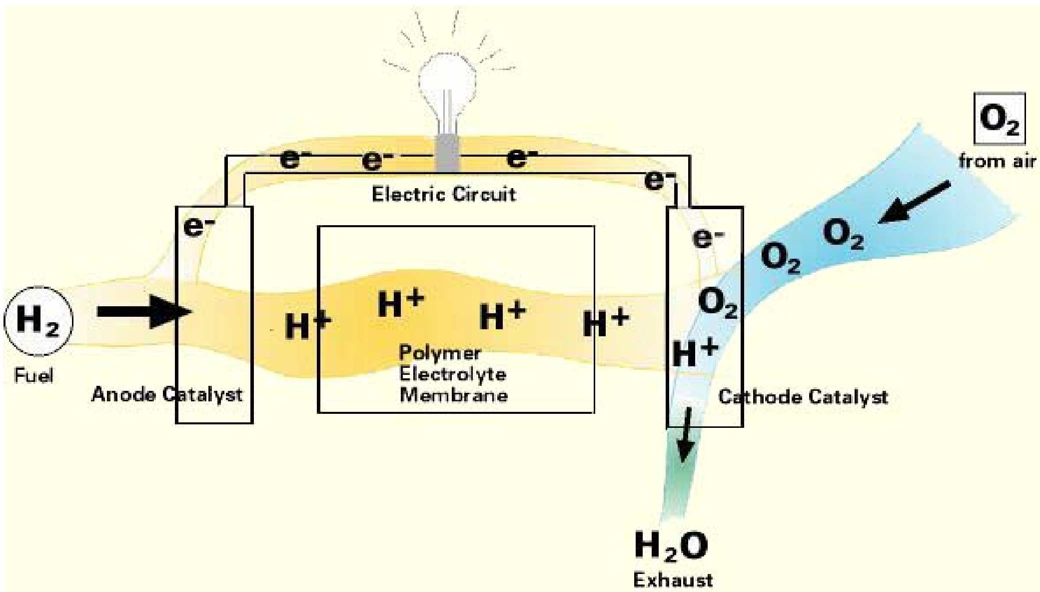


Figure 7-1: Schematic of basic fuel cell operation (Source: www.fuelcells.org)

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].

Fuel cells are classified primarily by the kind of electrolyte they employ. This in turn determines the chemical reactions that take place in the cell, the catalysts required for the chemical reaction, the temperature range in which the cell will operate, the fuel required, and a variety of other factors. Taken together, these characteristics affect the applications for which these cells are most suitable. Listed below are several types of fuel cells currently under development, each with its own advantages, limitations, and potential applications [2].

- Polymer Electrolyte Membrane Fuel Cells (PEMFCs): These fuel cells (also known as proton exchange membrane fuel cells) deliver high power density and offer advantages of low weight and volume, compared to most other fuel cells.

PEMFCs require only hydrogen, oxygen, and water to operate and are used primarily for transportation applications. However, the costs associated with utilizing a catalyst to separate the hydrogen's electrons and protons coupled with the space required for hydrogen storage prevent the use of these fuel cells in vehicles.

- Direct Methanol Fuel Cells (DMFCs): These fuel cells are powered by pure methanol, which is mixed with steam and consequently fed to the fuel cell anode. Direct methanol fuel cells do not have the fuel storage problems that are prevalent in most hydrogen-based fuel cells because methanol has a higher density than hydrogen. However, this technology is relatively new and research is still being conducted on its efficacy/economic viability.
- Alkaline Fuel Cells (AFCs): These fuel cells use potassium hydroxide and water as the electrolyte. Conventional high-temperature AFCs operate between 100°C and 250°C. However, newer designs operate between 23°C to 70°C. AFCs' performance is dependent upon the rate at which chemical reactions take place in the cell. They have demonstrated efficiencies of approximately 60 percent in space applications. In order to effectively compete in commercial markets, AFCs will have to become more cost-effective. AFC stacks have been proven to maintain stable operation for more than 8,000 operating hours. However, to be economically viable in large-scale utility applications, these fuel cells must reach operating times exceeding 40,000 hours.
- Phosphoric Acid Fuel Cells (PAFCs): These fuel cells use liquid phosphoric acid as an electrolyte and porous carbon electrodes containing a platinum catalyst. PAFCs are one of the most mature cell types and the first to be used commercially, with over 200 units currently in use. These types of fuel cells are typically used for stationary power generation, but some PAFCs have been used to power large vehicles such as city buses. In addition, they are typically 85 percent efficient when used for the cogeneration of electricity and head, but only 37-42 percent efficient at generating electricity alone. A typical phosphoric acid fuel cell costs between $4,000 and $4,500 per kilowatt.
- Molten Carbonate Fuel Cells (MCFCs): These fuel cells are being developed for natural gas and coal-based power plants for electric utility, industrial, and military applications. MCFCs utilize an electrolyte composed of a molten carbonate salt mixture and operate at temperatures of 650°C. MCFCs can reach efficiencies of approximately 60 percent. When the waste heat is captured and used, efficiency levels can reach 85 percent. The primary disadvantage of MCFC technology is durability. The high temperatures at which these cells operate and the corrosive electrolyte used reduce cell life.
- Solid Oxide Fuel Cells (SOFCs): SOFCs use a hard ceramic compound as the electrolyte. They are expected to be around 50-60 percent efficient at converting fuel to electricity. In applications designed to capture and utilize the system's waste heat (co-generation), overall fuel use efficiencies could top 80-85 percent. Moreover, SOFCs operate at temperatures of approximately 1,000°C. However, the high-temperatures at which the fuel cell operates has disadvantages as well, such as slow startups and increased thermal shielding to retain heat and protect personnel.

- Regenerative Fuel Cells (RFCs): RFCs produce electricity from hydrogen and oxygen and generate heat and water as byproducts. However, RFC systems are capable of utilizing energy from solar power or other sources to divide the excess water into oxygen and hydrogen fuel – a process known as "electrolysis." This technology is still being developed by NASA and others.

The five basic fuel cell types which are currently being pursued by manufacturers are listed in Table 7-1. 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[16] [3]. Table 7-1 and 7-2 illustrates the efficiency levels of the various fuel cell technologies [4].

Fuel Cell Type	Electrolyte	Operating Temperature	Applications	Advantages	Disadvantages
Polymer Electrolyte membrane (PEM)	Solid organic polymer poly-perfluorosulfonic acid	60–100°C 140–212°F	• electric utility • portable power • transportation	• Solid electrolyte reduces corrosion & management problems • Low temperature • Quick start-up	• Low temperature requires expensive catalysts • High sensitivity to fuel impurities
Alkaline (AFC)	Aqueous solution of potassium hydroxide soaked in a matrix	90–100°C 194–212°F	• military • space	• Cathode reaction faster in alkaline electrolyte so high performance	• Expensive removal of CO_2 from fuel and air streams required
Phosphoric Acid (PAFC)	Liquid phosphoric acid soaked in a matrix	175–200°C 347–392°F	• electric utility • transportation	• Up to 85% efficiency in cogeneration of electricity and heat • Can use impure H_2 as fuel	• Requires platinum catalyst • Low current and power • Large size/weight
Molten Carbonate (MCFC)	Liquid solution of lithium, sodium, and/or potassium carbonates, soaked in a matrix	600–1000°C 1112–1832°F	• electric utility	• High efficiency • Fuel flexibility • Can use a variety of catalysts	• High temperature enhances corrosion and breakdown of cell components
Solid Oxide (SOFC)	Solid zirconium oxide to which a small amount of yttria is added	600–1000°C 1112–1832°F	• electric utility	• High efficiency • Fuel flexibility • Can use a variety of catalysts • Solid electrolyte reduces corrosion & management problems • Low temperature • Quick start-up	• High temperature enhances breakdown of cell components

Table 7-1: Comparison of fuel cell technologies (Source: EERE)

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

Fuel Cell Type	Operating Temperature	Efficiency
PEFC/PEMFC	~80°C	~45%
PAFC	~100–220°C	~37-42%
MCFC	~600–700°C	>70%
SOFC	~600–1000°C	>70%
AFC	~200°	~60%

Table 7-2: Operating temperatures and efficiency levels for fuel cells (Source: Fuelcells.org)

There are five main attractive features of fuel cell technology [3]:

- 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
- Lack of moving parts (chemical process); therefore there is less noise and less maintenance than conventional generation technologies (turbine-generator sets); and
- Fuel cells have longer operating times than batteries. Doubling the operating time only requires the doubling of the amount of fuel, not the capacity of the unit.

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[17] (natural gas) or water. In addition, the DOE is working to achieve a $3.00 per gallon of gasoline equivalent at the station by 2008 and $1.50 per gallon of gasoline equivalent by 2010 [1]. 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. Fuel cells currently have a significant drawback in that economically viable technology and infrastructure for the production, transportation, distribution, and storage of hydrogen is not yet available [3].

[17] 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.

Fuel cells have many potential applications ranging from powering motor vehicles to providing primary (or backup) power for homes and industries (stationary applications) [5]. While there are several different types of fuel cells technologies available, the PEMFCs are most commonly found in most prototype fuel cell cars and buses. SOFCs are being tested on cars and trucks with traditional power trains as “auxiliary power units,” which will ease their transition into the automotive market. To date, more than 50 vehicles have been demonstrated using fuel cell technology [1].

Stationary fuel cells are used for backup power, power for remote locations, stand-alone power plants, distributed generation and co-generation systems. They are beneficial because they provide extremely reliable power, are modular in nature, are capable of utilizing different fuels, and are environmentally preferable to traditional power generation technologies. In fact, the first commercially available fuel cell power plants, produced by the UTC Fuel Cells, created less than 20 grams of pollutants per MWh, compared to over 11,388 grams per MWh for an average U.S. fossil fueled plant. A typical residential fuel cell system consists of three main components [1]:

- Hydrogen Fuel Reformer: This unit allows the extraction of hydrogen from the hydrogen-rich fuel, e.g., natural gas;
- Fuel Cell Stack: Converts the hydrogen and oxygen from air into electricity, water vapor and heat; and
- Power Conditioner: 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. Fuel cells operating at wastewater treatment facilities effectively reduce emissions of methane, carbon dioxide, and other pollutants that contribute to global warming. In fact, the New York Power Authority’s (NYPA) fuel cell system in Yonkers, New York generates about 1.6 million kilowatt-hours of electricity a year, and in that time releases only 72 pounds of air emissions into the environment. Average fossil fuel power plants generating the same amount of electricity generally produce more than 41,000 pounds of air pollutants [1]. The Northeast Regional Biomass program has completed a study on the feasibility of using bio-based fuels with stationary fuel cell technologies [6]. The results show that this is technically feasible for providing a source of clean, renewable electricity over the long-term.

7.2 Economics of fuel cells

The currently available PAFCs units cost around $3,000/kW [1, 3]. These units are only produced in 200 kW sizes which are suitable for larger power applications. This is in comparison to the cost for a typical automotive internal combustion engine power plant of approximately $25-$35/kW [5]. 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 [3]. 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. For transportation applications, a fuel cell system needs to cost $30/kW for the technology to be competitive [7].

7.3 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 [8]:

- 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 [5].

A variety of other projects are also currently being undertaken throughout the nation. Some of the more notable ones are referenced below [1]:

- DaimlerChrysler (California): DaimlerChrysler has provided the University of California at Los Angeles with two F-Cell fuel cell vehicles. UCL has formed the Hydrogen Engineering Research Consortium (HERC) whose goal is to accelerate the onset of the hydrogen economy through the development and demonstration of technologies for the production, storage, transportation and use of hydrogen.

- Cellex Power Products, Inc. (Missouri): Cellex Power Products, Inc. has completed its Alpha hydrogen fuel cell product field trials at the logistics subsidiary of Wal-Mart Stores, Inc. They had four fuel cell power units in operation at a Wal-Mart food distribution center demonstrating the operational benefits to Wal-Mart when powering their fleet of pallet trucks. The fuel cell units ran successfully and were capable of being refueled with compressed hydrogen in one minute.
- Sierra Nevada Brewing Company (California): California Governor Schwarzenegger dedicated a 1 MW fuel cell power plant at Sierra Nevada Brewing Company. The power plant consists of four 250 KW Direct Fuel Cell power plants from FuelCell Energy, Inc. The waste heat from the fuel cell is harvested in the form of steam and used for the brewing process as well as other heating operations.
- IdaTech, LLC: IdaTech, LLC has entered into a new contract with the U.S. Army to continue the development of a portable fuel cell system for military applications. The agreement involves research into the enhancement of its 250 watt, integrated, portable fuel cell systems for use in tactical military operations on domestic bases and to provide quiet, rechargeable power over an extended period of time during training.

As stated in Section 7.2, 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, 3]. 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 recommended that Congress should enact a tax credit program beginning in 2003 and continuing to 2007. 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 [5].

7.4 Fuel cells in Indiana

In September of 1999, Cinergy Technology Inc. installed a 250 kW stationary generator at the Crane Naval Surface Warfare Center. This was the first 250 kW PEM fuel cell generator in the world to enter field testing and provided valuable information concerning the viability of fuel cells during its two-year evaluation period. In March 2004, the US Navy installed a PEM-powered refueler at Crane [1].

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, 3]. 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 [3]. 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.

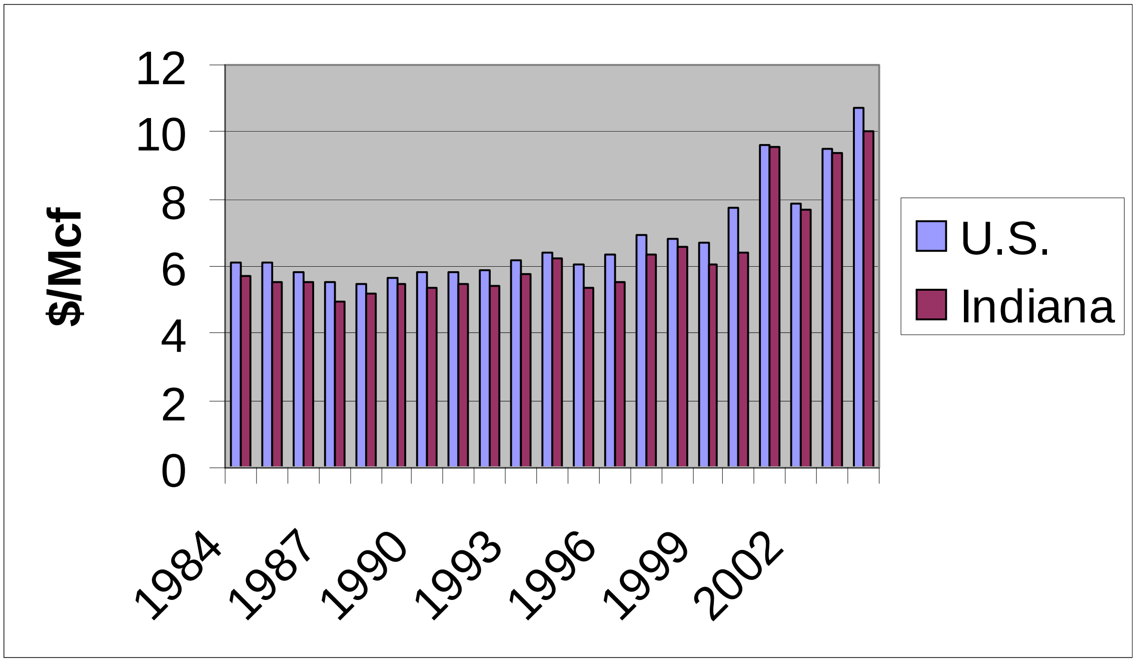
In 2003, Indiana had the fifth cheapest average retail electricity prices in the nation [9]. The low cost of electricity in Indiana might provide a barrier to entry for the emerging fuel cell technology and other renewable sources.

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 [3].

The current short-term viability of fuel cells is seen as using existing natural gas supplies to extract hydrogen for the fuel cell[18] [1, 3]. Figure 7-2 shows the average annual residential price of natural gas in the nation and within Indiana [10]. 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.

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.

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



<u>Figure 7-2:</u> <u>National and Indiana residential natural gas prices</u> (Source: EIA)

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, 5]. The tax credit proposed in [5] would help in this regard. Further state incentives could also assist the introduction of fuel cells within Indiana. These include [11]:

- <u>Distributed Generation Grant Program:</u> 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).
- <u>Alternative Power and Energy Grant Program:</u> 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).
- <u>Net Energy Credit:</u> 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.
- <u>Emissions Credits:</u> 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 [12]. These credits can be sold on the national market.
- <u>Energy Efficiency and Renewable Energy Set-Aside:</u> This program is a joint effort of the Indiana Energy and Recycling Office and the Indiana Office of Air Quality that offers potential financial incentives to large-scale energy-efficiency projects and renewable-energy projects that significantly reduce nitrogen-oxide emissions.

- Renewable Energy Systems and Energy Efficiency Improvement Program: The USDA has implemented this program through a Notice of Funds Availability (NOFA) for each of the last three years. The latest round of funding, totaling $22.8 million, was made available in March 2005. Half ($11.4 million) of this sum is available immediately for competitive grants. Renewable-energy grants range from $2,500 to $500,000 and may not exceed 25% of an eligible project's cost.
- Tax-Exempt Financing for Green Buildings, Renewable Energy and Brownfield Redevelopment: The American Jobs Creation Act of 2004" (HR 4520), signed into law on October 22, 2004, authorizes $2 billion in tax-exempt bond financing for green buildings, brownfield redevelopment, and sustainable design projects. Tax-exempt financing allows a project developer to borrow money at a lower interest rate because the buyers of the bonds will not have to pay federal income taxes on interest earned. The savings from tax-exempt financing must then be used to offset the costs of sustainable design and/or renewable energy technologies.

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.

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8. Hydropower from Existing Dams

8.1 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 8-1 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.

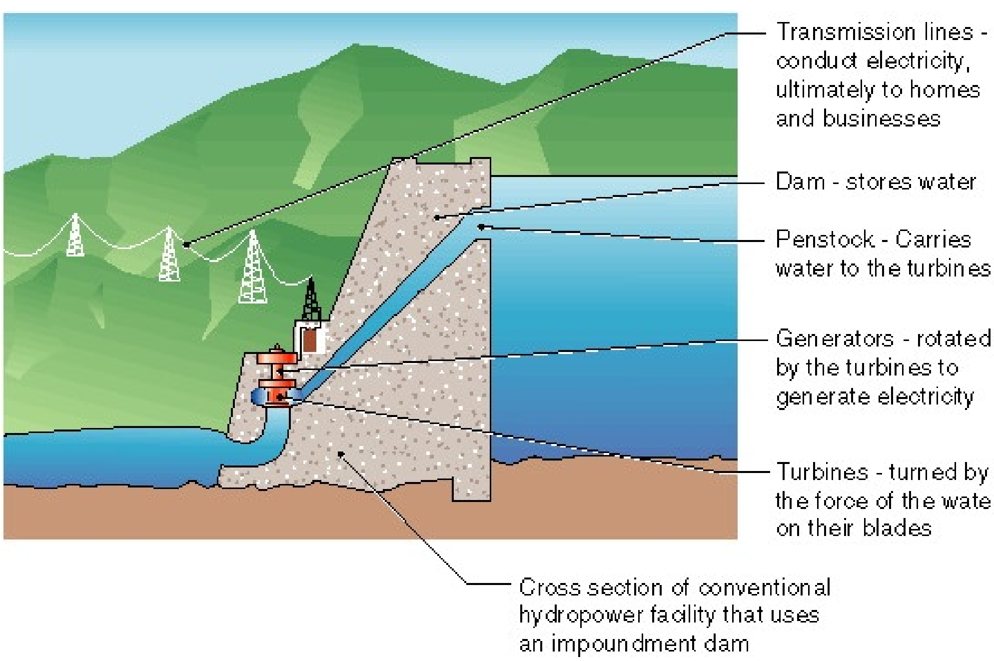

Figure 8-1: Schematic of impoundment hydropower facility (Source: INEL)

In addition, there are a variety of turbine technologies that are utilized for hydropower. The turbines utilized are chosen based on their particular application and the height of standing water. The turning part of the turbine is called the runner, and the most common types of turbines are listed below [4]:

- Pelton Turbines: The Pelton turbine has multiple jets of water impinging on the buckets of a runner that looks like a water wheel. These turbines are used for high-head sites (50 feet to 6,000 feet) and can be as large as 200 MW.
- Francis Turbines: These turbines have a runner with fixed vanes (usually 9). The water enters the turbine in a radial direction with respect to the shaft, and is discharged in an axial direction. Francis turbines usually operate from 10 feet to 2,000 feet of head and can be as large as 800 MW.
- Propeller Turbines: These turbines have a runner with three to six fixed blades, much like a boat propeller. The water passes through the runner and provides a force that drives the blades. These turbines can operate from 10 feet to 300 feet of head and can be as large as 100 WM.

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 [5]:

- 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.

8.2 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 8-2 and 8-3 illustrate the competitiveness of hydropower with respect to other generator plant types.

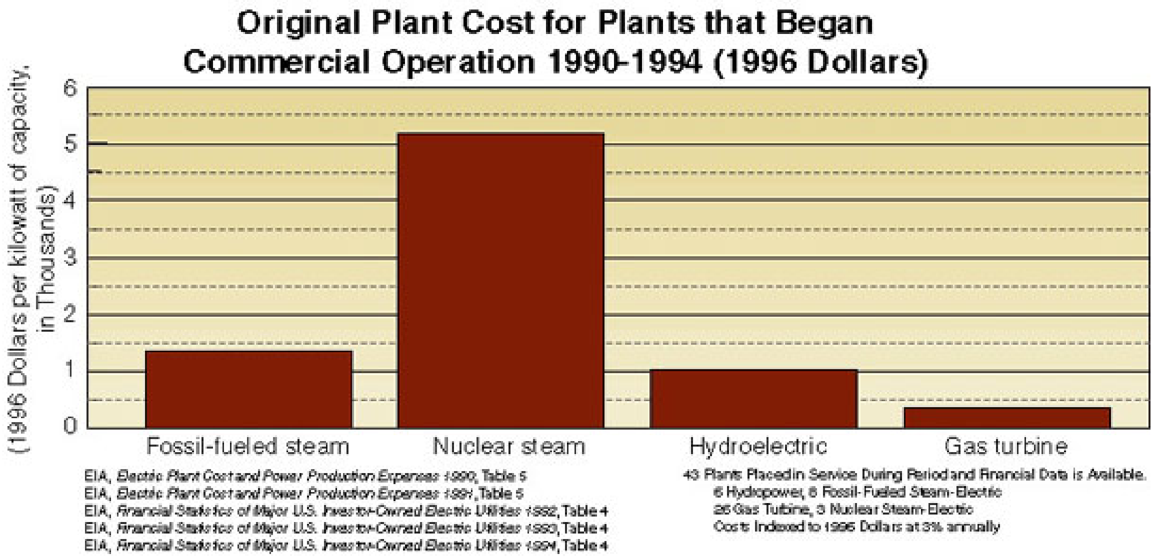

Figure 8-2: <u>Plant costs per unit installed capacity</u> (Source: INEL)

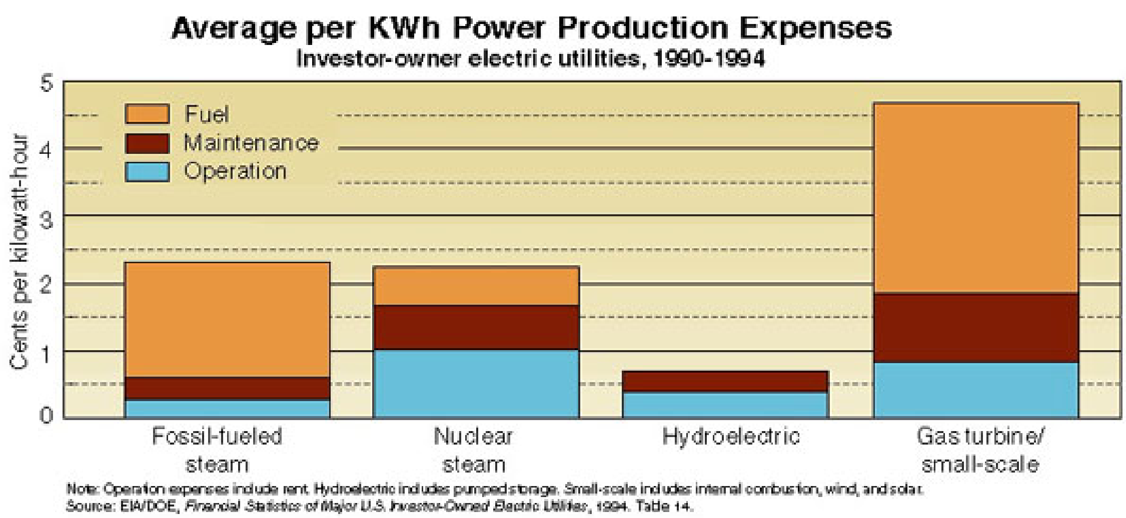

Figure 8-3: <u>Average production costs of various types of generating plants</u> (Source: INEL)

8.3 State of hydropower nationally

The total U.S. hydropower capacity—including pumped storage facilities—is about 95,000 MW. Researchers are currently working on advanced turbine technologies that will not only help maximize the use of hydropower but also minimize adverse environmental effects [6].

In 2003, the United States consumed 6.131 quadrillion Btu of renewable energy. Of this, 2.779 quadrillion Btu (45.3 percent) was from conventional hydroelectric energy [7].

Hydroelectric generation capacity[19] constitutes (in 2003) about 8 percent of the total generation capacity [7]. The total (including pumped storage) installed hydroelectric generation capacity in the U.S. is 103.8 GW [1]. Figure 8-4 illustrates the other production energy sources that are prevalent throughout the U.S. [6]. 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 [8]. Figure 8-5 shows the operational hydroelectric capacity by state in 2002 [9].

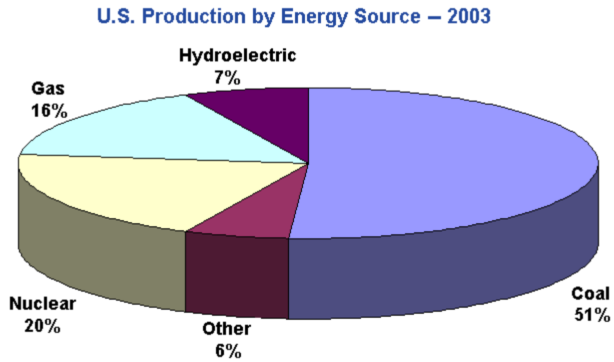

Figure 8-4: U.S. electricity production by energy source (Source: USBR)

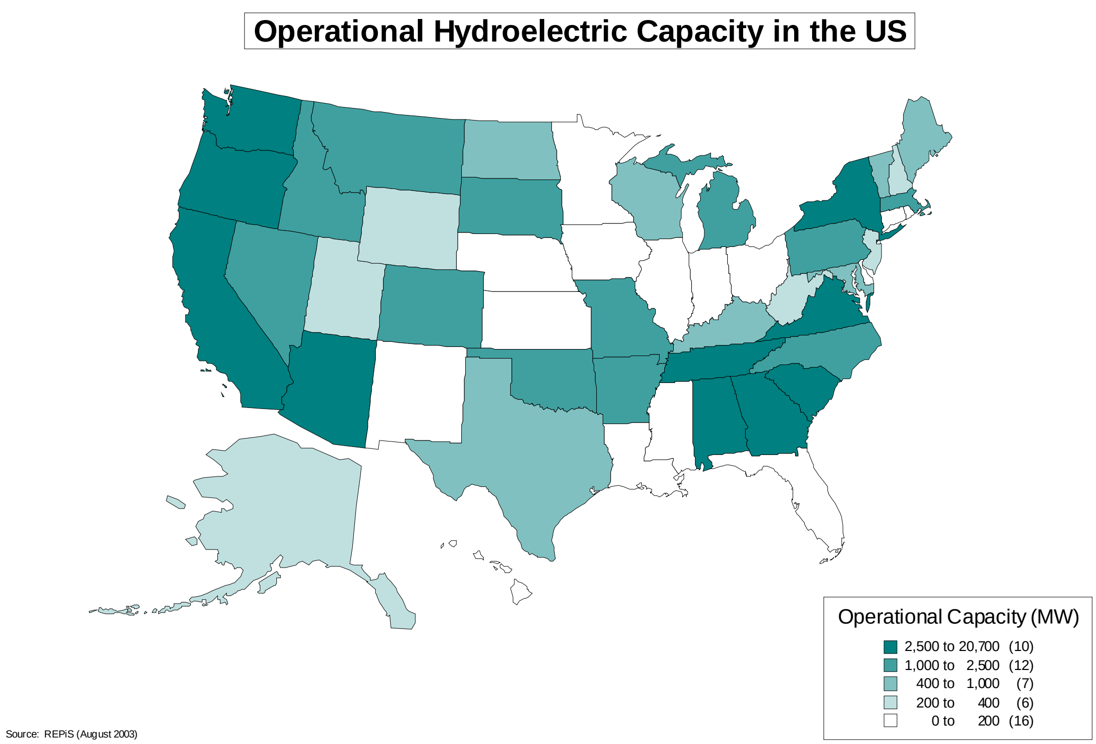

Figure 8-5: Operational hydroelectric capacity in the U.S. (Source: NREL)

[19] This is excluding pump storage schemes.

In 1998 DOE published a report assessing the resources for hydropower in the country [10]. 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 [10]. 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 8-6.

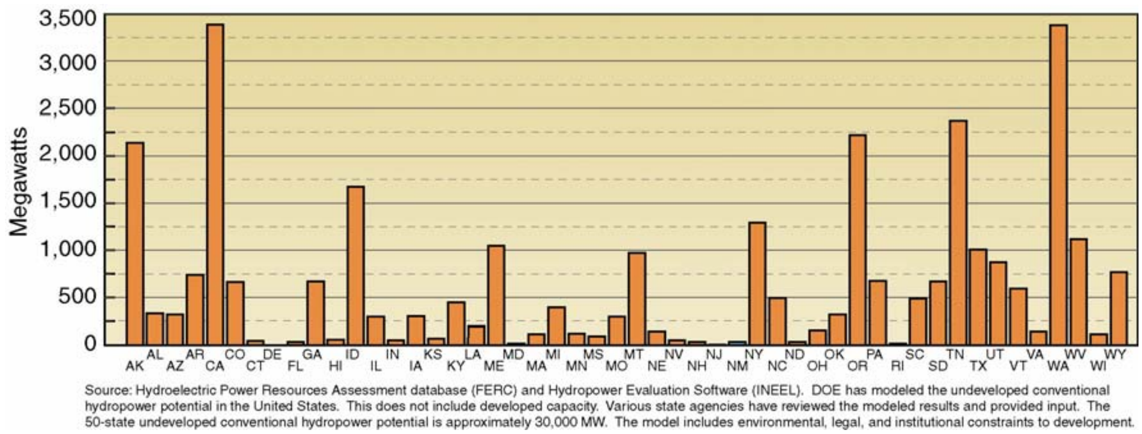

Figure 8-6: State breakdown of potential hydropower capacity (Source: INEL)

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 [5]. The reason for this is due to a combination of environmental issues, regulatory complexities and pressures, and changes in economics [5]. 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.

Currently, the DOE is conducting research into technologies that will enable existing hydropower projects to generate more electricity with less environmental impact. Their main objectives are to develop new turbine systems that have improved overall performance, develop new methods to optimize hydropower operations, and to conduct research to improve the effectiveness of the environmental mitigation practices required at hydropower projects. Taken together, these advances in hydropower technology will serve to reduce the cost of implementation and help smooth the hydropower integration process [11].

8.4 Hydropower from existing dams in Indiana

Hydroelectric energy contributed only 0.3 percent (411 GWh) of the total electricity generated in the Indiana in 2002, as shown in Figure 8-7. Indiana has 91.4 MW of hydroelectric generation capacity, which makes up about 0.3 percent of the state's total generation capacity [12, 13]. In 2001, the total hydroelectric generation in Indiana was 571 GWh (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.

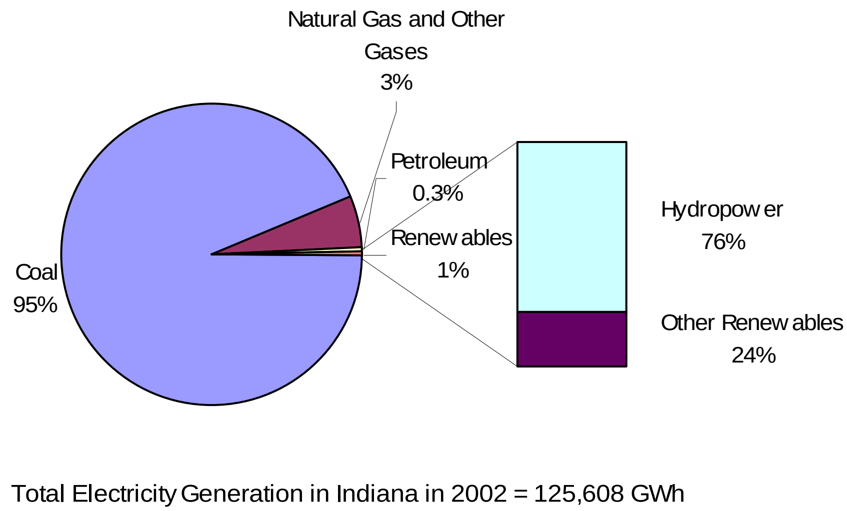

Figure 8-7: Contribution of various generation sources to total electricity generated in Indiana (Source: EIA)

In 1995 a report was published for DOE which assessed the potential hydropower resources[20] available in Indiana [14]. 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 8-1 shows a breakdown of these identified sites.

The following key[22] was used to indicate the status of the potential hydropower site [14]:

- 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.

[20] Undeveloped pumped-storage hydropower potential was not included.
[21] A complete list of these projects is given in [14].
[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.

- Undeveloped: This site does not have power generating capability nor any impoundment or diversion structure.

	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 8-1: Undeveloped hydropower potential in Indiana (Source: Francfort)

From Table 8-1 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 [14]. 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 [14].

The viability of these projects could be increased with Federal and State government incentives. The current incentives for hydropower within Indiana include the following [9]:

- 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.
- Net metering rule: Solar, wind and hydroelectric facilities with a maximum capacity of 10 kW are under this September 2004 rule qualified for net metering where the net excess generation is credited to the customer in the next billing cycle.
- Energy Efficiency and Renewable Energy Set-Aside: This program is a join effort of the Indiana Energy and Recycling Office (ERO) and the Indiana Office of Air Quality (OAQ) that offers potential financial incentives to large-scale energy-efficiency projects and renewable-energy projects that significantly reduce nitrogen-oxide emissions.

- Renewable Electricity Production Tax Credit: This program is a per kilowatt-hour tax credit for electricity generated by qualified energy sources. The initiative was recently renewed in August of 2005 and provides a tax credit of 0.9 cents/kWh for electricity generated from hydropower.
- Renewable Energy Systems and Energy Efficiency Improvements: The USDA makes direct loans and grants to agricultural producers that purchase renewable-energy systems and make energy-efficiency improvements. The USDA has implemented this program through a Notice of Funds Availability (NOFA) for each of the last three years. The latest round of funding, totaling $22.8 million was made available in March 2005.
- Value Added Producer Grant Program: The USDA awards grants to support the development of value-added agriculture business ventures. A total of $14.3 million in grants was allocated for the fiscal year 2005.

Indiana has marginal potential hydropower from existing dams (about 41.7 MW) as illustrated in Figure 8-6. Most of these projects were below 1 MW in capacity and would therefore typically be microhydro-type projects. Even with the realization of this potential, hydropower would not significantly impact the generation mix within Indiana.

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