PURDUE UNIVERSITY Discovery Park Energy Center

2008 Indiana Renewable Energy Resources Study

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State Utility Forecasting Group | Energy Center at Discovery Park | Purdue University | West Lafayette, Indiana

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Acronyms and Abbreviations

AEP	American Electric Power Corporation
AFC	Alkaline Fuel Cell
ASD	Agricultural Statistical District
AWEA	American Wind Energy Association
BIPV	Building Integrated Photovoltaics
BPA	Bonneville Power Administration
BTC	Breakeven Turnkey Cost
Btu	British Thermal Unit
CPV	Concentrating Photovoltaic
CREB	Clean Renewable Energy Bonds
CRP	Conservation Reserve Program
CSP	Concentrating Solar Power
DMFC	Direct Methanol Fuel Cell
DOE	U.S. Department of Energy
DSIRE	Database of State Incentives for Renewables and Efficiency
EERE	Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy
EIA	Energy Information Administration, U.S. Department of Energy
ELCC	Effective Load Carrying Capability
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
ESA	Electrical Storage Association
GWh	Gigawatthour
H_2	Hydrogen
IEA	International Energy Agency
INEL	Idaho National Engineering and Environmental Laboratory, U.S. Department of Energy
IREC	Interstate Renewable Energy Council

ISDA	Indiana State Department of Agriculture
kW	Kilowatt
kWh	Kilowatthour
LEED	Leadership in Energy and Environmental Design, U.S. Green Building Council
LMOP	Landfill Methane Outreach Program, Energy Information Administration, U.S. Department of Energy
m/s	Meters Per Second
MACRS	Modified Accelerated Cost-Recovery System
MCFC	Molten Carbonate Fuel Cell
MGY	Million Gallons per Year
MISO	Midwest Independent System Operator
mph	Miles Per Hour
MSW	Municipal Solid Waste
MW	Megawatt
MWh	Megawatthour
NaS	Sodium Sulfur Battery
NIPSCO	Northern Indiana Public Service Company
NO_x	Nitrogen Oxide
NRCS	Natural Resources Conservation Service, U.S. Department of Agriculture
NREL	National Renewable Energy Laboratory, U.S. Department of Energy
O&M	Operation and Maintenance
OEDD	Indiana Office of Energy and Defense Development
ORNL	Oak Ridge National Laboratory, U.S. Department of Energy
PAFC	Phosphoric Acid Fuel Cell
PEM	Polymer Electrolyte Membrane
PEMFC	Polymer Electrolyte Membrane Fuel Cells
PHES	Pumped Hydroelectric Energy Storage
POLYSYS	Policy Analysis System
PTC	Production Tax Credit

PV	Photovoltaic
REAP	Rural Energy for America Program, U.S. Department of Agriculture
REPI	Renewable Energy Production Incentive
RES	Regulatory and Economic Studies Department, Midwest Independent System Operator
RFA	Renewable Fuels Association
RFC	Regenerative Fuel Cell
RFS	Renewable Fuel Standard
SAI	Solar America Initiative
SEGS	Solar Electric Generation System, California
SEDS	State Energy Data System, Energy Information Administration, U.S. Department of Energy
SOFC	Solid Oxide Fuel Cell
SMES	Superconducting Magnetic Energy Storage
SUFG	State Utility Forecasting Group
USDA	U.S. Department of Agriculture
VEETC	Volumetric Ethanol Excise Tax Credit
W/m^2	Watts Per Meter Squared
WAPA	Western Area Power Administration
WVPA	Wabash Valley Power Association

Foreword

This report represents the sixth annual study of renewable resources in Indiana performed by the State Utility Forecasting Group. 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 and one appendix. 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. 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:

- <u>Introduction:</u> This section gives an overview of the technology and briefly explains how the technology works.
- <u>Economics of the renewable resource technology:</u> This section covers the capital and operating costs of the technology.
- <u>State of the renewable resource technology nationally:</u> This section reviews the general level of usage of the technology throughout the country and the potential for increased usage.
- <u>Renewable resource technology in Indiana:</u> This section examines the existing and potential future usage for the technology in Indiana in terms of economics and availability of the resource.
- <u>Incentives for the renewable resource technology:</u> This section 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.
- <u>References:</u> This section contains references that can be used for a more detailed examination of the particular renewable resource.

The appendix looks at the operational and planning challenges that intermittent resources create. It examines methods for dealing with these challenges, including those presently being used and others under development for the future. Finally, examples of intermittent resources in Indiana are provided.

While there are significant amounts of new renewable resources under development in Indiana, particularly in wind power, the new generators have not been in operation long enough to appear in the annual energy numbers. A compilation of recently completed, approved, and proposed wind projects has been included.

This report was prepared by the State Utility Forecasting Group. The information contained in it should not be construed as advocating or reflecting any other organization's views or policy position. For further information, contact SUFG at:

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1. Overview

This first section of the 2008 Indiana Renewable Energy Resources Report presents an overview of the trends in renewable energy consumption in the U.S. and in Indiana.

1.1 Trends in renewable energy consumption in the United States

Based on data from the Energy Information Administration's (EIA) 2007 *Annual Energy Review* [1], Figure 1-1 shows the trends in renewable energy consumption in the U.S. from 1949 to 2007. As can be seen in the figure, the increase in renewable energy consumption from the mid 1950s to mid 1970s is accounted for by an approximate doubling of hydroelectric energy. After that big jump, hydroelectric energy levels have remained relatively stable, only exhibiting swings arising from varying levels of precipitation in the catchment basins. Starting with the 1970s' energy crisis through the mid 1980s there was a similar surge in the level of biomass energy, primarily wood, in the U.S. energy consumption mix. Energy from biomass remained level from the mid 1980s until recently when another increase has occurred. This increase in biomass consumption is due mainly to the increased use of ethanol with gasoline, first as a replacement for the oxygenating chemical MTBE and more recently as a blending mix as mandated by the federal Renewable Fuel Standard authorized in the Energy Policy Act of 2005.

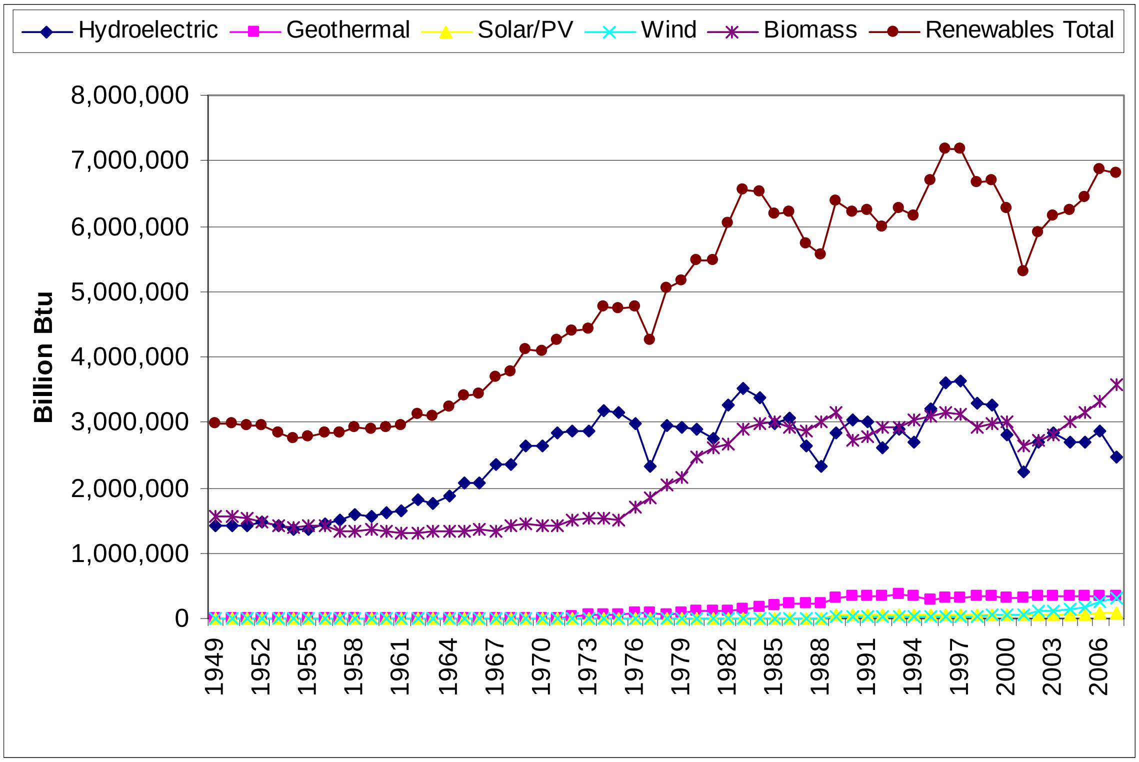

Figure 1-1: Renewable energy consumption in U.S. (1949-2007) (Source: EIA [1])

Although Figure 1-1 shows a steady increase in the quantity of renewable energy, its contribution relative to the total energy supply has not increased substantially; it has remained approximately at the current level of 7 percent. Figure 1-2 shows the trend in total energy consumption in the U.S. from 1949 to 2007.

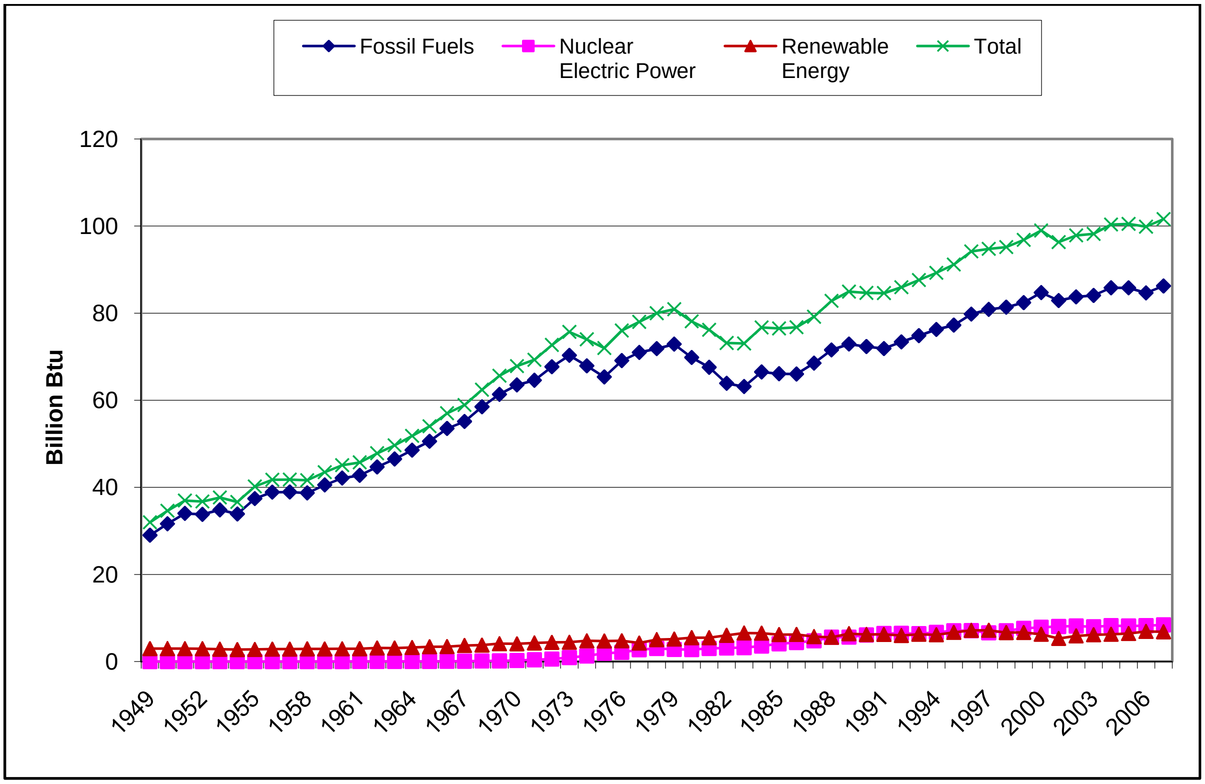

Figure 1-2: U.S. energy consumption by source (1949-2007) (Data source: EIA [1])

Figure 1-3 shows the energy mix for 2007. Petroleum continues to be the dominant energy source supplying 39 percent of total U.S. consumption followed by natural gas and coal at 22 and 23 percent, respectively. Among the renewable resources, biomass supplies over half of the renewable energy consumed, followed by hydroelectricity at 36 percent.

When one considers renewable resources in electricity generation (Figure 1-4), hydroelectricity plays a dominant role, exceeding all the other renewable resources combined. Hydroelectricity makes up 76 percent of the renewable electricity sources, compared to 14 percent by biomass resources. Wind energy is third in share with 7 percent, ahead of geothermal's 4 percent and solar energy's 0.1 percent. As can be seen in Figure 1-4, pumped hydroelectricity's net energy contribution was negative (- 1.7 percent of total energy). Pumped hydroelectric generators are typically used as peaking generators, using electricity from the grid to pump water to an uphill reservoir during periods of low demand so as to be available to generate electricity during the high demand periods. The negative –1.7 percent shows that over the space of the year pumped hydroelectricity plants consumed more energy than they generated.

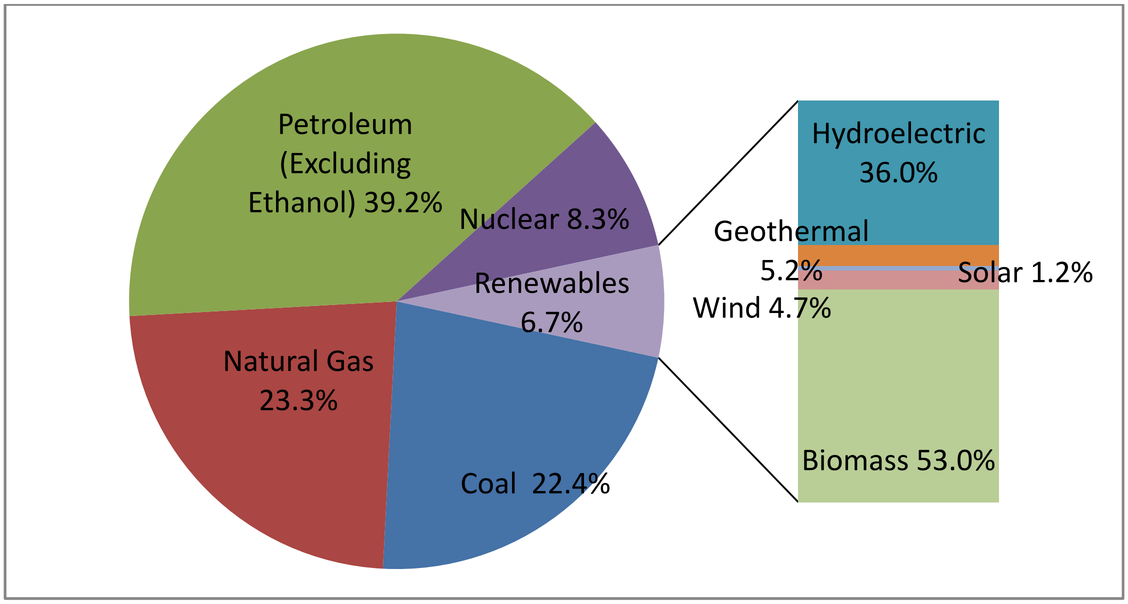

Figure 1-3: U.S. total energy consumption by energy source in 2007 (Source: EIA [2])

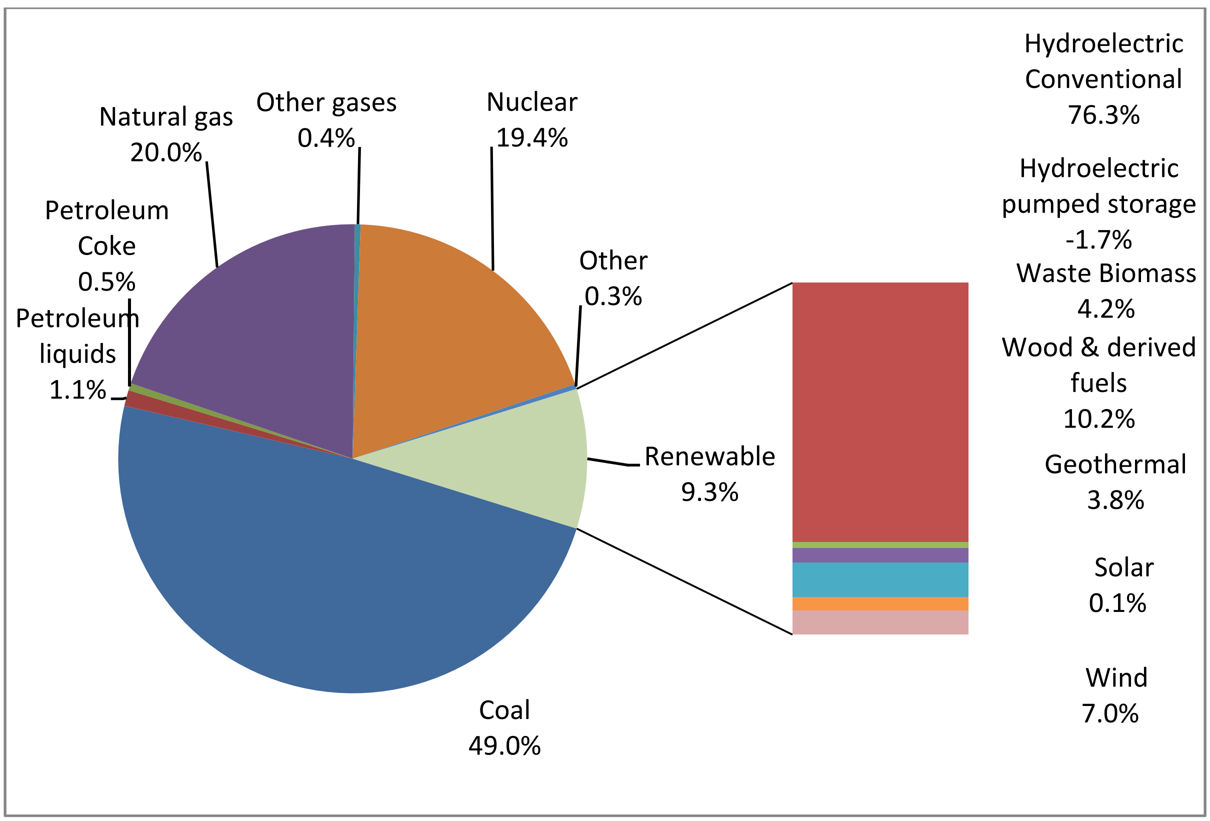

Figure 1-4: Net U.S. electricity generation by energy source in 2006 (Data source: EIA [2, 3])

1.2 Trends in renewable energy consumption in Indiana

Figure 1-5 shows renewable energy consumption in Indiana from 1960 to 2005. At their peak in the 1980s, renewable resources contributed over 2.5 percent of total energy consumed in Indiana. Since the early 1990s this share has fallen to its current level of 1.5 percent. The rise and fall in renewable energy consumption in 1990s is accounted for by biomass resources.

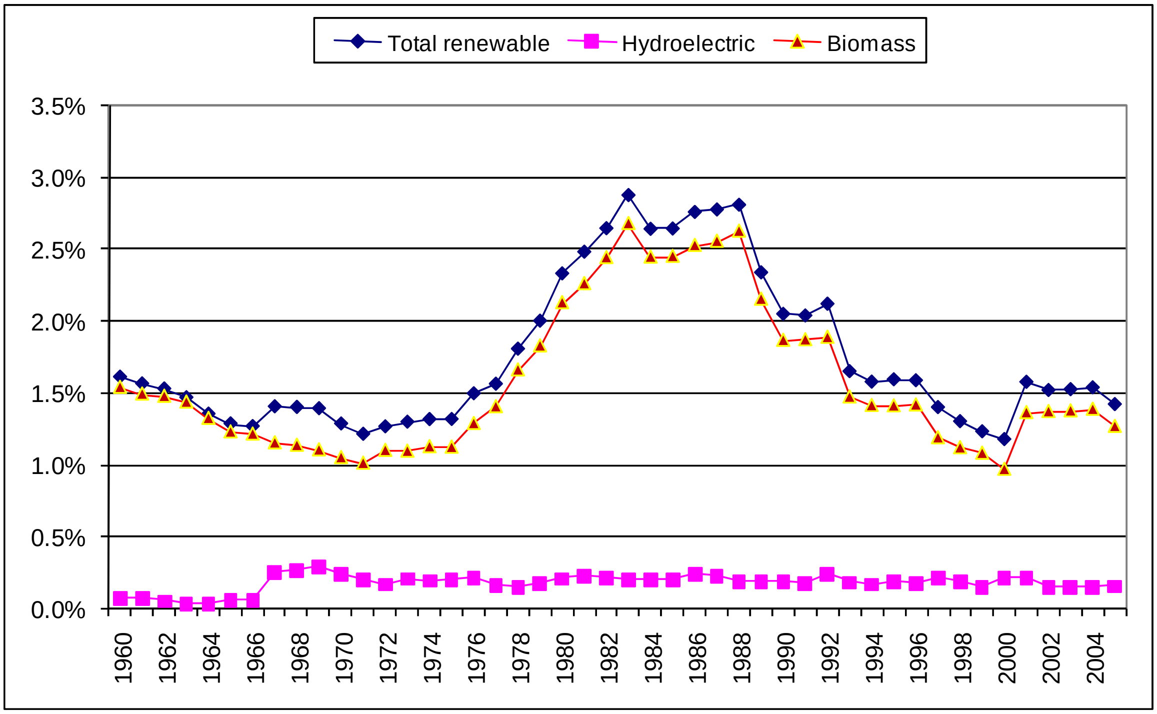

Figure 1-5: Renewables share in Indiana total energy consumption (1960 – 2005) (Data source: EIA [4])

When one considers only the renewable resources in electricity generation in Indiana, the role of biomass is diminished and hydroelectricity plays the dominant role. Figure 1-6 shows Indiana electricity generation from renewable resources from 1990 to 2006. While renewable resources have contributed about 1.5 percent of Indiana's total energy consumption in the 2000s, they have contributed less than 0.6 percent of electric energy.

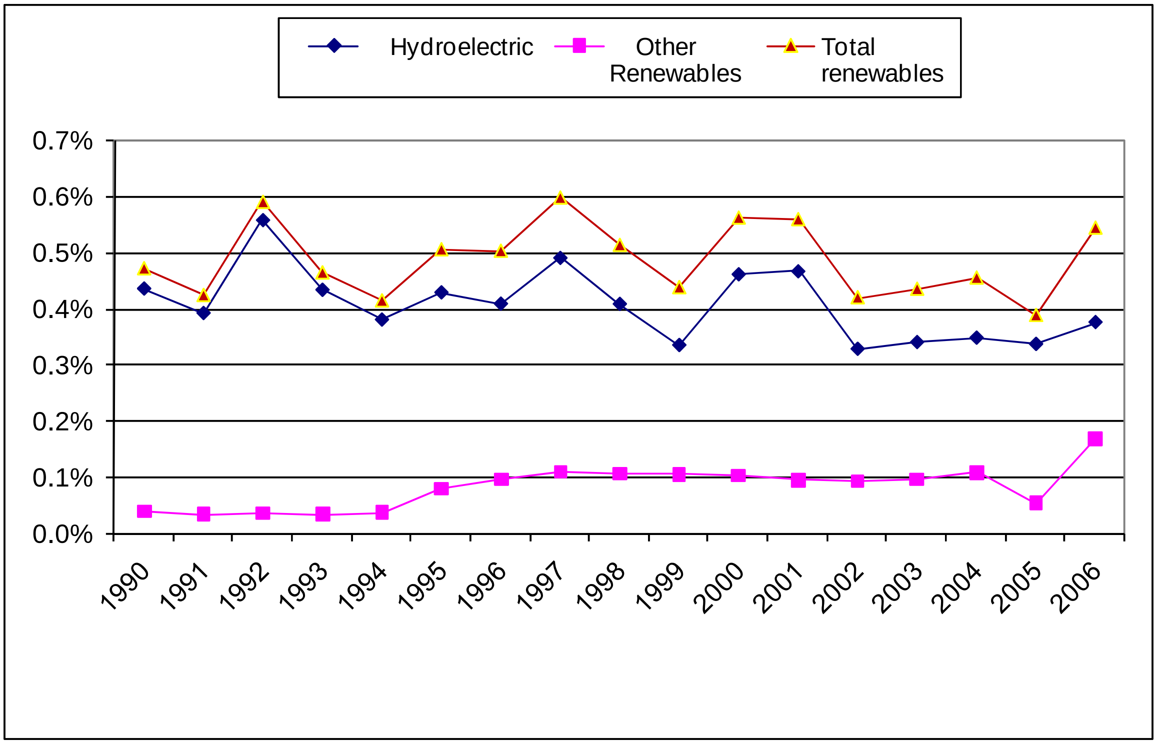

Figure 1-6: Renewables share of Indiana net electricity generation (1990-2006) (Data source: EIA [5])

One of the main reasons that renewable energy resources play a much smaller role in Indiana compared to the rest of the nation is the relatively low cost of electricity in Indiana. Table 1-1 shows average retail electricity prices for Indiana and the U.S. by sector and for all sectors combined. It also shows where Indiana stands in terms of the ranking of states with the least expensive electricity.

	Indiana (cents/kWh)	*U.S. (cents/kWh)*	*Indiana Rank*
Residential	8.22	10.40	13
Commercial	7.21	9.46	17
Industrial	4.95	6.16	16
All Sectors	6.46	8.90	10

Table 1-1: Indiana's retail prices comparison and ranking

With the successful commissioning of the 130 MW Benton County Wind Farm in the spring of 2008, wind energy is poised to have a substantial impact on the energy mix in Indiana's electricity industry. Wind farms with over 2,800 MW of name plate capacity have been proposed in various counties in Indiana. Table 1-2 shows the status of the various projects.

Project Name	**Counties**	**Developer**	**Rated Capacity (MW)**	**Construction Schedule**	**Status**
Benton County Wind Farm	Benton	Orion Energy	130	Completed Spring 2008	Completed
Fowler Ridge Phase 1	Benton	BP Alternative Energy & Dominion	400	To be completed by end of 2008	Under construction
Hoosier Wind Project	Benton	enXco	100	2009	Pending
Fowler Ridge Phase 2	Benton	BP Alternative Energy & Dominion	350	Begin early 2009	Approved
Tri-County Wind Energy Center	Tippecanoe, Montgomery, Fountain	Invenergy	300-500	Begin 2010	Proposed
Meadow Lake Wind Farm	Benton, White	Horizon Energy	600-1,000	Begin 2010	Proposed
	Randolph	Horizon Energy	100-200		Proposed
	Howard	Horizon Energy	200		Proposed

Table 1-2: Status of wind generation projects in Indiana

Indiana utilities have signed agreements with many of the developers to purchase electricity from these wind projects. They include 100 MW and 30 MW agreements by Duke and Vectren respectively to purchase power from the Benton County Wind farm, Indiana Michigan's agreement to purchase 100 MW from the Fowler Ridge Wind Farm and Indianapolis Power & Light's agreement to purchase 100 MW from the Hoosier Wind project proposed Benton County. Two of Indiana's utilities have signed agreements to purchase electricity from out of state wind farms. NIPSCO has two purchase agreements totaling 100 MW: 50 MW from a wind farm in South Dakota and 50 MW from a wind farm in Iowa, while Wabash Valley Power Association has an 8 MW power purchase agreement with the AgriWind project in Illinois. Table 1-3 lists the purchase agreements that Indiana utilities have to purchase wind power.

In addition to the utility-scale wind farms, two small scale distribution level wind turbines were reported at the Indiana wind energy conference held in Indianapolis in June 2008 (WIndiana 2008) [6]. They are a 50 kW turbine owned by The Time Factory, a publishing company located in Indianapolis and a 15 kW wind turbine owned and operated by Hoosier Energy. Prior to these projects, which were commissioned this year, SUFG was only aware of a total of 20 kW of wind energy projects operating in Indiana.

Utility	Project	State	Power Purchase Agreement (MW)	Status
Duke Energy	Benton County Wind Farm	Indiana	100	Operational
SIGECO	Benton County Wind Farm	Indiana	30	Operational
WVPA	AgriWind	Illinois	8	Operational
Indiana Michigan	Fowler Ridge	Indiana	100	Approved
NIPSCO	Buffalo Ridge	South Dakota	50	Approved
NIPSCO	Barton Windpower	Iowa	50	Approved
IPALCO	Hoosier Wind	Indiana	100	Pending

Table 1-3: Wind energy purchase agreements by Indiana utilities

Another renewable resource that is having a significant impact on the Indiana renewable energy industry is corn-based ethanol. Unlike the other renewable resources in this report, ethanol is mainly used as a blend in gasoline for the transportation industry. According to the Renewable Fuels Association [7], Indiana's ethanol production capacity has grown tremendously in the last four years from the modest start of one 102 million gallon per year (MGY) plant in 2005, to the current 460 MGY with another 330 MGY of capacity proposed. The amount of the proposed capacity that will actually be built is uncertain given the recent sharp increase in the price of corn.

1.3 References

1. Energy Information Administration (EIA). 2007 Annual Energy Review, June 2008. http://www.eia.doe.gov/emeu/aer/contents.html
2. EIA. Renewable Energy Trends, 2006 Edition, July 2008. http://www.eia.doe.gov/cneaf/solar.renewables/page/trends/rentrends.html
3. EIA. Electric Power Monthly, June 2008. http://www.eia.doe.gov/cneaf/electricity/epm/epm_sum.html
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5. EIA. Indiana Electricity Profile Table 5, November 2007. http://www.eia.doe.gov/cneaf/electricity/st_profiles/indiana.html
6. Indiana Office of Energy and Defense Development. WIndiana 2008, Conference notes and presentations. http://www.in.gov/oed/2552.htm
7. Renewable Fuels Association (RFA). Ethanol biorefinery locations, July 2008. http://www.ethanolrfa.org/industry/locations/

2. Energy from Wind

2.1 Introduction

Although utility-scale multi-megawatt wind farms are a relatively new phenomenon, the use of some form of windmill to harness energy from wind has been around for thousands of years. Windmills were used by early American colonists to grind grain and pump water and cut wood at sawmills [1]. There are two main types of wind turbines, vertical and horizontal axis. The horizontal axis turbine with three blades facing into the wind is the most common configuration in modern wind turbines. Figure 2-1 shows the basic parts of a modern wind turbine used for electricity generation and the layout of the two types of wind turbine configurations.

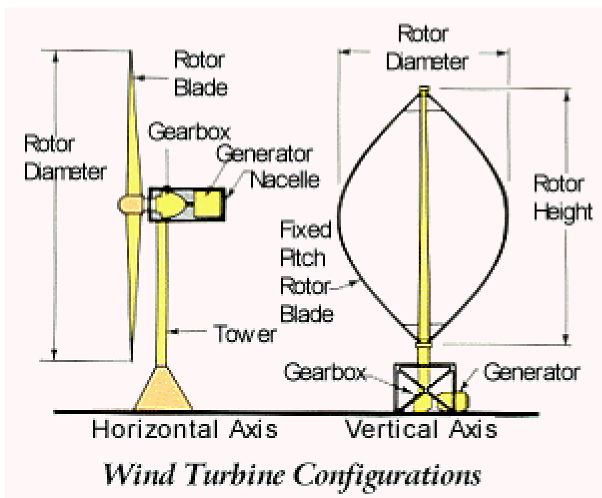

Figure 2-1: Horizontal and vertical wind turbine configurations (Source: AWEA [2])

Since the beginning of utility scale wind farms in California in the 1980s, the size and power output of wind turbines have been increasing dramatically. In the 1980s wind turbines were on the order of 50 – 100 kilowatt (kW) of rated capacity. This has grown steadily to the point where the 1.5 megawatt (MW) wind turbine is common in modern day wind farms [3]. Despite this dramatic increase in size and capacity, a wind farm's generating capacity is still small compared to coal and nuclear power plants. The largest wind farm in the U.S. is the Horse Hollow Wind Farm in Texas with a name plate capacity of 736 MW [4] while the largest coal power plant in Indiana is composed of five 600 MW units adding up to a plant capacity of 3,000 MW. Furthermore the capacity factor[1] of a wind farm is typically far less than that of a baseload power plant. A baseload coal or nuclear power plant in the U.S. will typically have annual capacity factor of over 80 percent while the capacity factors of wind farms are estimated to range between 20 and 40 percent, depending on the average annual wind speeds at their location [2].

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 plants require a minimum wind speed of 6 to 7 m/s (13-16 mph) at an elevation of 50 meters [5]. The power available to drive wind turbines is proportional to the cube of the speed of the wind. This implies that a doubling in wind speed leads to an eight-fold increase in power output. A measurement called the wind power density measured in watts per meter squared (W/m^2), calculated from annual observed wind speeds and the density of air, is used to classify sites into "wind power classes" [6]. Table 2-1 lists the class distinctions currently used.

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

Table 2-1: Wind resource classification (Source: AWEA [6])

The major advantages of wind energy include:

- It is a virtually inexhaustible renewable resource.
- It is a modular and scalable technology.

The main disadvantages include:

- Wind is an intermittent source of energy and is not always available when it is needed. Unlike conventional generators, a wind farm cannot be dispatched to match demand.

[1] $\text{Annual capacity factor} = \dfrac{\text{Actual amount of energy produced in an year}}{\text{Energy that would have been produced if plant operated at full rated capacity all year}}$

- Good wind sites are usually located far from the main load centers, and therefore transmission system expansion may be required to connect the load centers with the wind-rich sites.
- There are concerns regarding the death of birds that fly into the turbine blades.
- Wind turbine blades can cause radar interference [7].

2.2 Economics of wind energy

Figure 2-2 shows the trend in the cost of wind farm construction projects per unit of electricity capacity over the last 25 years [8]. As one can see from the figure, after a steady decline in project capital cost from the 1980s to the early 2000s, costs have been showing a recent upward trend. Installed project costs dropped by approximately $2700/kW from the early 1980s to the early 2000s and showed an average $370/kW increase in 2007 compared to the early 2000s. It should be noted that the construction costs of conventional generation technologies have also increased significantly recently, largely due to increases in steel and concrete prices [9].

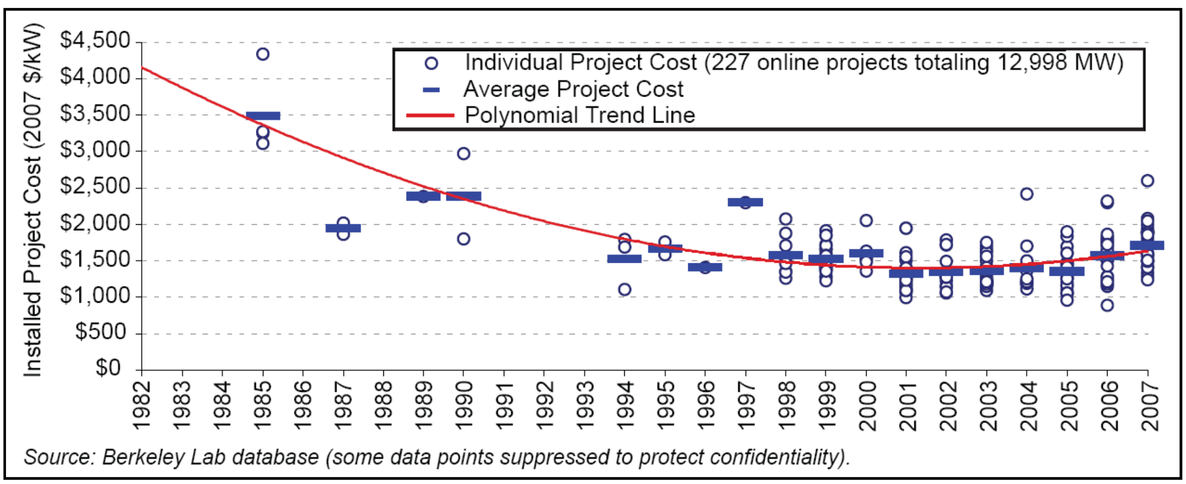

Figure 2-2: Installed wind project costs over time (Source: EERE [8])

Although there are many local factors influencing construction costs at each site, the main factor driving the increase in costs has been the price of turbines. Figure 2-3 shows wind turbine costs over time, as calculated in a report from the Lawrence Berkeley National Laboratory [8]. As illustrated in the diagram, turbine prices were in a steady, rapid decline up to 2000 and have since been increasing. Since 2000, turbine prices have increased by more than $600/kW (85 percent).

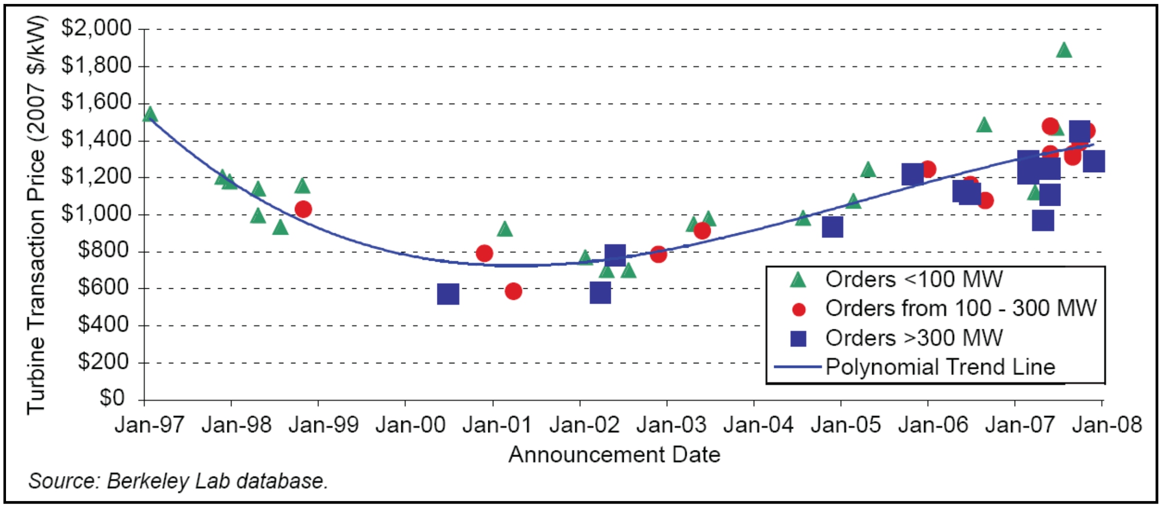

Figure 2-3: Reported U.S. wind turbine prices over time (Source: EERE [8])

Because wind farm projects coming online in 2007 had locked in lower turbine prices 1-2 years in advance, the recent increase in turbine costs are not fully reflected in the cost of the 2007 projects. As such, construction costs for wind farm projects are expected to continue to rise in the near future. In tandem with increasing turbine costs and installed project costs, the cost of electricity produced by wind projects coming online in recent years has increased as well.

Figure 2-4 shows the cumulative capacity-weighted average power prices paid to the owners of the 128 wind turbines in the database maintained by the Lawrence Berkeley National Laboratory that were built from 1997 through 2007 [8]. The 8,303 MW in this database represent approximately 55 percent of the wind generating capacity built in the period. The cumulative capacity-weighted average wind price of the 7 projects in built in 1997 and 1998 was $63/MWh (expressed in 2007 dollars) as shown by the height of column marked 1999 in Figure 2-4. The red bar at the top of the column indicated the range of prices within one standard deviation of the average. The cumulative average price exhibited a steady decline through 2005 and then showed a slight increase in 2006 and 2007. The average price for the 128 projects built from 1997 through 2007 was $40/MWh with a one standard range extending from $24/MWh to $55/MWh. The prices in the Berkeley Lab's database include all available state and federal subsidies such as the Production Tax Credit; therefore they would be higher if these subsidies were not included.

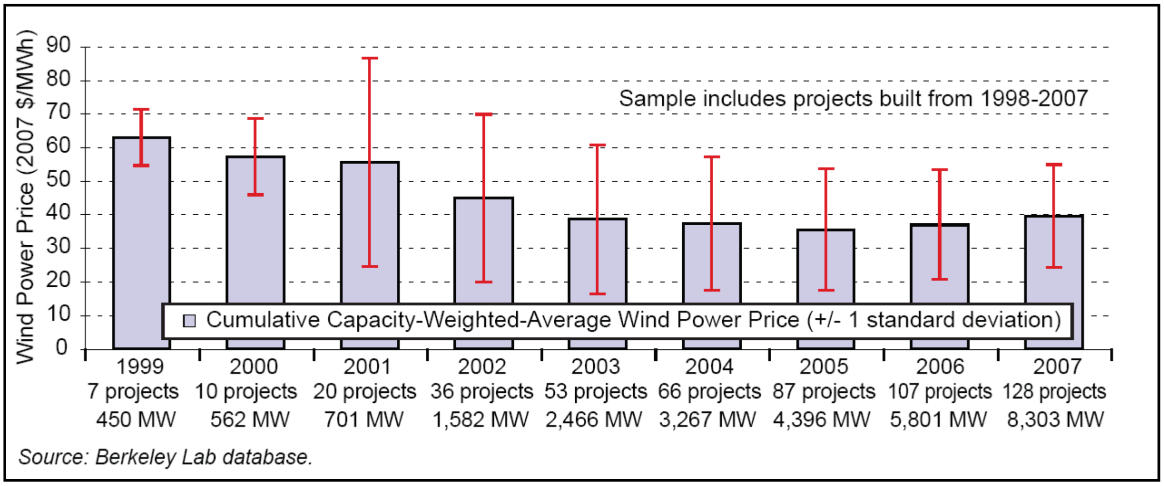

Figure 2-4: Reported U.S. wind power prices over time (Source: EERE [8])

Despite the incremental increase in the price of electricity produced by wind in recent years, wind-produced electricity remains competitive with the price of electricity produced from other sources. Figure 2-5 shows a comparison between the average cumulative wind prices and wholesale electricity prices by U.S. region. The blue columns in Figure 2-5 show the average whole sale price of electricity in 2007 $/MWh in 8 regions of the U.S. The red bars show the capacity-weighted average price received by the owners of the 128 wind projects in the Berkeley Lab's database in each of these regions, while the yellow dots show the average prices received by individual projects in each of the eight regions of the U.S. The last column in Figure 2-5 shows similar comparison of average wind prices and average wholesale electricity prices at the national level.

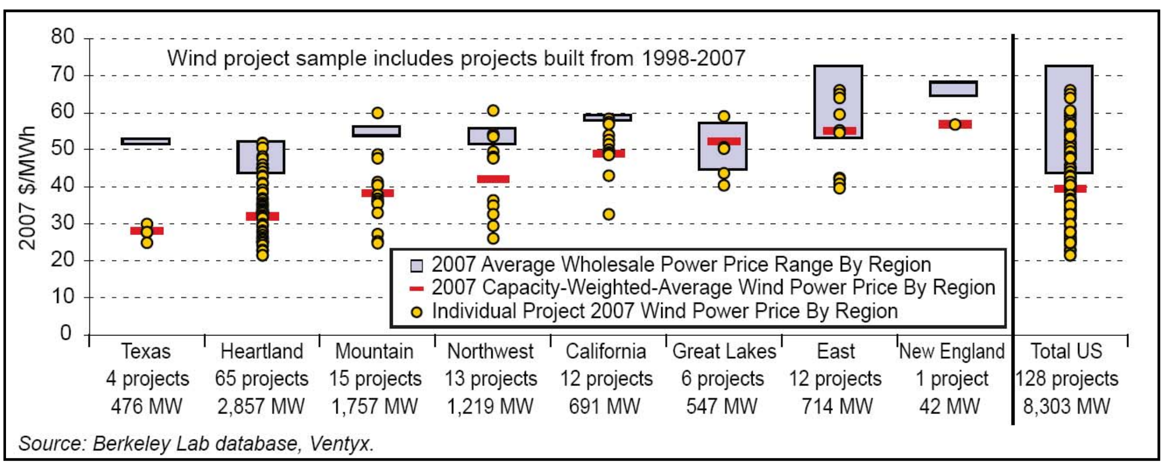

Figure 2-5: Average cumulative wind and wholesale power prices by region (Source: EERE [8])

2.3 State of wind energy nationally

Wind resources are prevalent throughout the U.S., with class 4 or higher winds concentrated in the Mountain West and the Heartland, as shown in the national wind resource map in Figure 2-6 [10]. Although this map shows annual average wind power, for many locations there can be large seasonal variation. In addition to land-based wind projects, interest is growing in the U.S. for construction of off-shore wind projects. Wind speeds are usually higher, more constant, and unidirectional over water instead of land.

Wind capacity has been expanding rapidly in the U.S. over the past 25 years, as seen in Figure 2-7; by the end of 2007, there was over 16,900 MW of installed capacity. The primary drivers behind the rapid expansion of wind production are the federally financed Renewable Electricity Production Tax Credit (PTC), the Renewable Energy Portfolio Standards found in 26 states, and the expectation of some form of carbon regulation in the future. The PTC, established by the Energy Policy Act of 1992, credits renewable electricity producers with 2.0 cents/kWh during the first ten years of operation. As shown in Figure 2-7, the installation of wind farms has paralleled the several expiration and renewal cycles of the PTC. The substantial drops in installations in 2000, 2002 and 2004 reflect the expiration of the production tax credit in 1999, 2001 and 2003, respectively. The PTC was extended to December 2008, resulting in the 5,300 MW of wind capacity added in 2007. This added capacity totaled 35 percent of all new electricity generation in the U.S. and was second only behind natural gas as a source for new electricity generation [8].

The Renewable Energy Portfolio Standards, now in place across 26 states and the District of Columbia [8], require that a minimum proportion of electricity be supplied from renewable sources. In addition, several states have non-binding goals for renewable energy content for their electricity mix. Figure 2-8 shows the status of Renewable Energy Portfolio Standards across the nation [11].

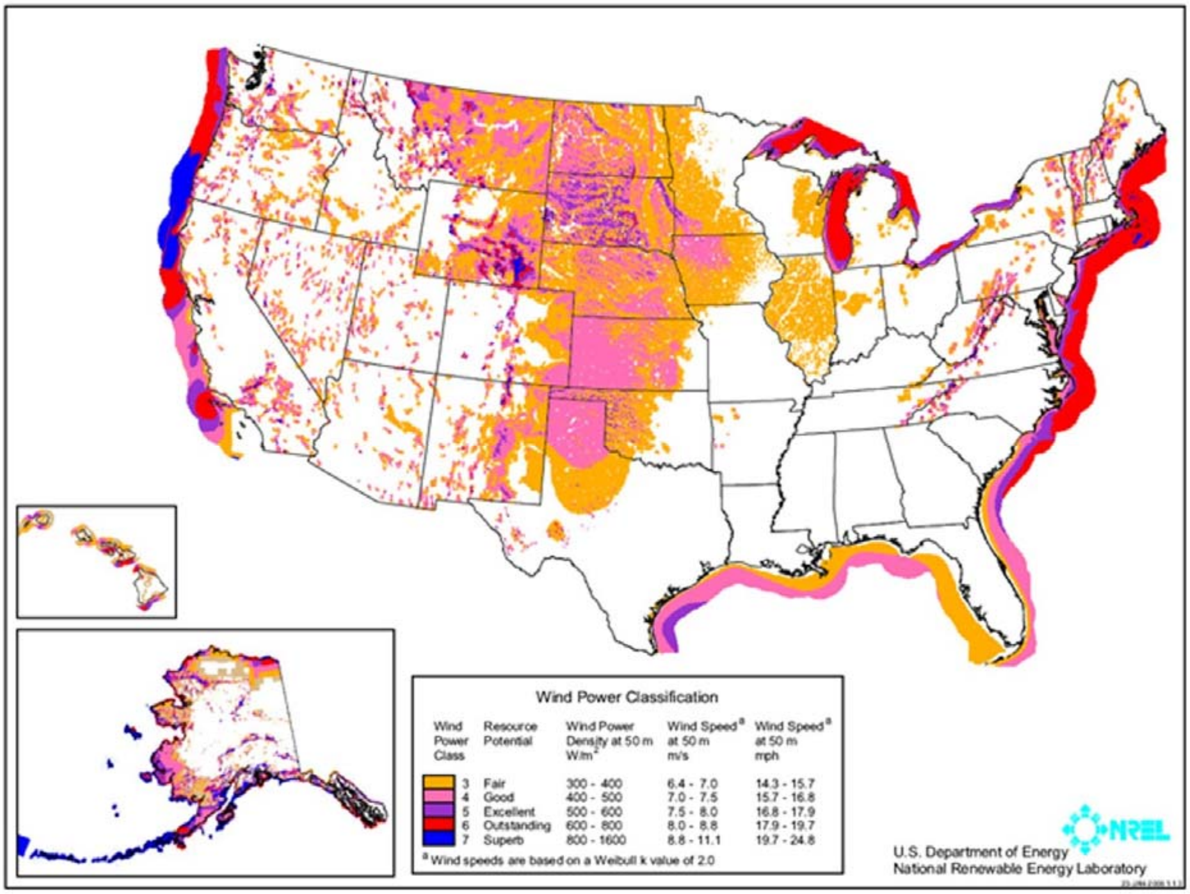

Figure 2-6: National wind energy resource map (Source: EERE [10])

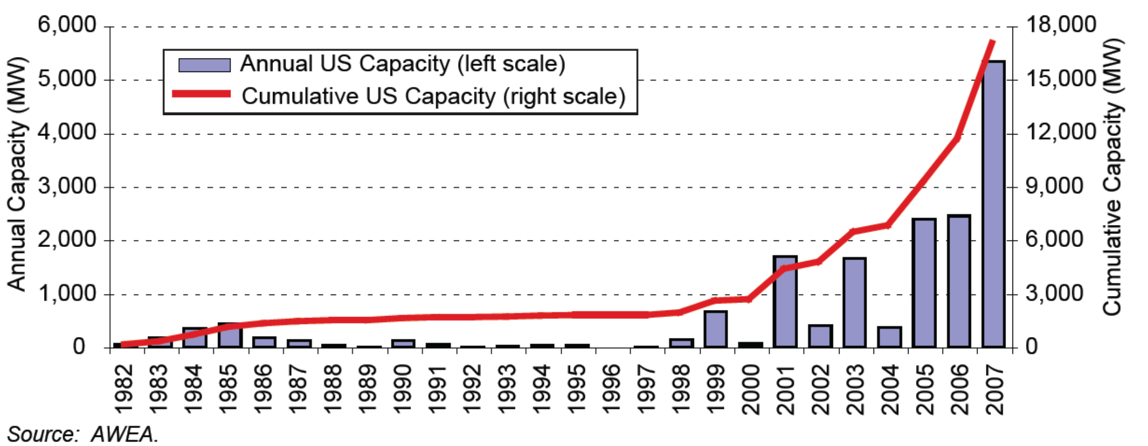

Figure 2-7: Annual and cumulative growth in U.S. wind power capacity (Source: EERE [8])

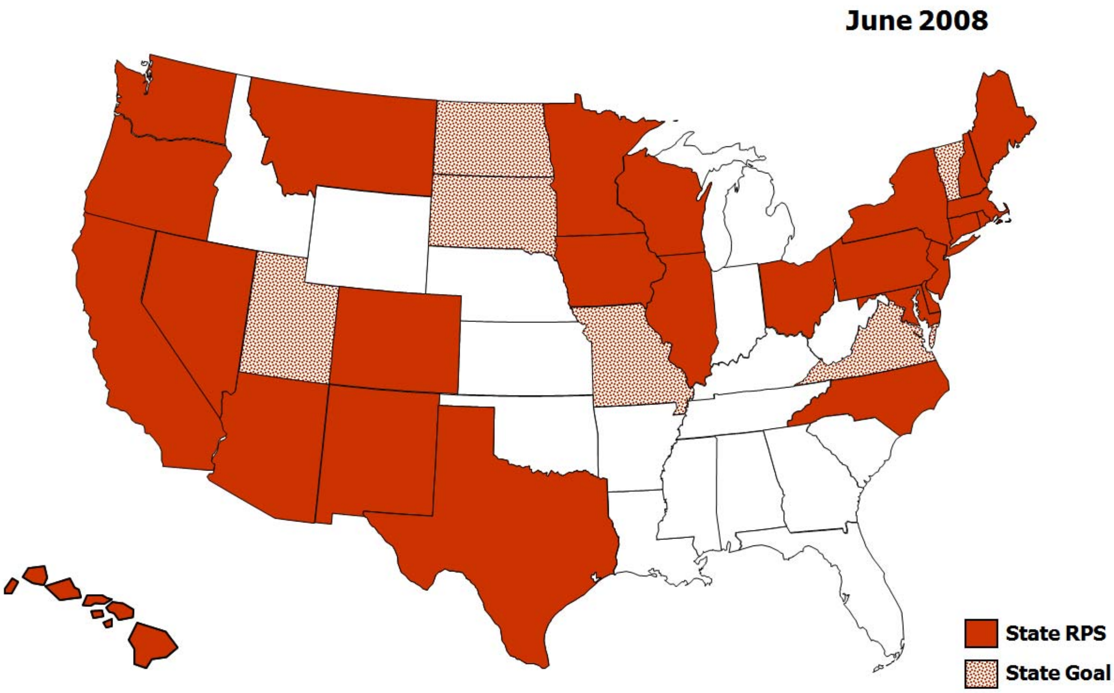

Figure 2-8: Renewable portfolio standards across the U.S. (Source: EERE [10])

As shown in Figure 2-9, the leading wind capacity states at the end of 2007 are (in MW): Texas – 4,446; California – 2,439; Minnesota – 1,298; Iowa – 1,271; Washington – 1,163. Table 2-2 also provides data compiled by the American Wind Energy Association, listing the largest wind farm operations, the companies which produce the most wind-generated electricity, and the utilities which buy the most wind-generated electricity [4].

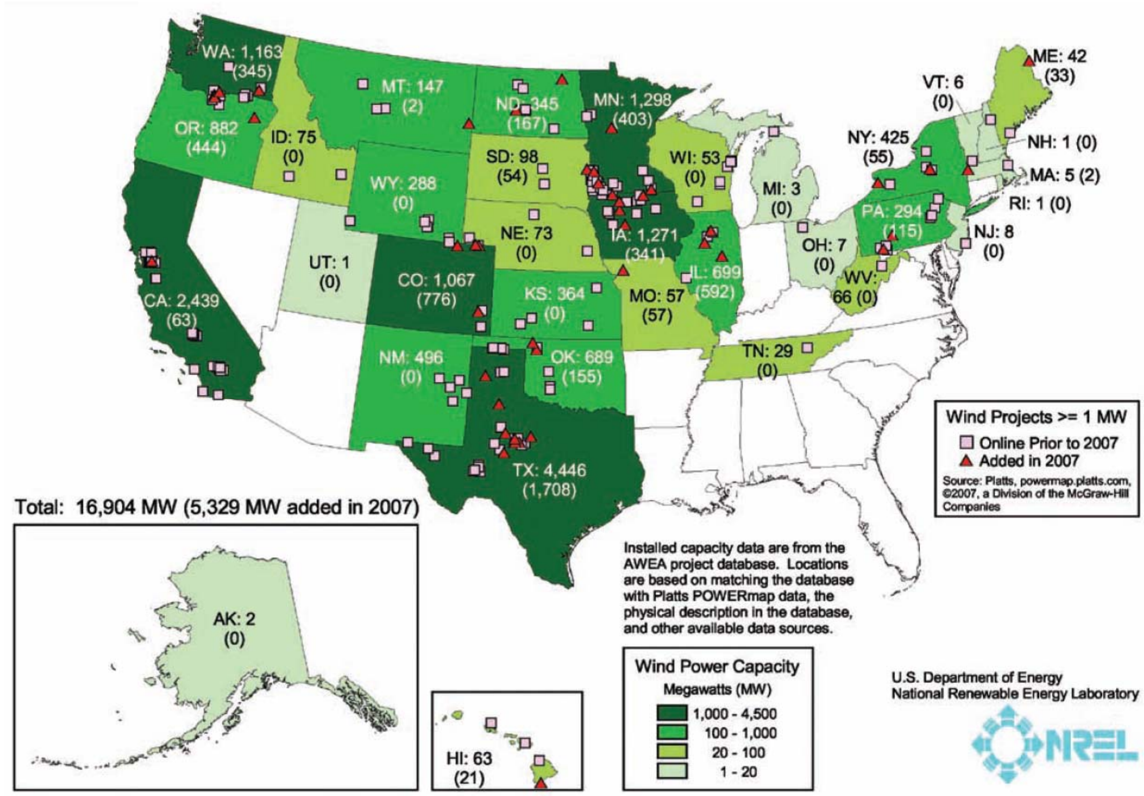

Figure 2-9: Size and location of wind power development in the U.S. (Source: EERE [8])

	Largest Wind Farms		Largest Wind Producers		Largest Utilities*	
Rank	**Name**	**MW**	**Name**	**MW**	**Name**	**MW**
1	Horse Hollow, Texas	736	FPL Energy	4,016	Xcel Energy	2,635
2	Sweetwater, Texas	505	PPM Energy	1,058	MidAmerican	1,201
3	Buffalo Gap, Texas	353	MidAmerican Energy	593	Southern California Edison	1,026
4	Maple Ridge, New York	322	Babcock & Brown	559	Portland General Electric	878
5	Stateline, Oregon/Washington	300	Horizon/Goldman Sachs	452	Luminant	704

* Utilities data from [8]

Table 2-2: Largest wind operations in the U.S. (Source: AWEA [4])

Table 2-3 shows the installed wind capacity by state as of the end of 2007 [8]. Of the states in the Midwest, Minnesota and Iowa have moved to the lead in installed wind energy capacity and in the proportion of statewide electricity generated by wind. This is due for the most part to Minnesota and Iowa's favorable wind patterns.

Incremental Capacity (2007, MW)		Cumulative Capacity (end of 2007, MW)		Estimated Percentage of In-State Generation	
Texas	1,708	Texas	4,446	Minnesota	7.5%
Colorado	776	California	2,439	Iowa	7.5%
Illinois	592	Minnesota	1,298	Colorado	6.1%
Oregon	444	Iowa	1,271	South Dakota	6.0%
Minnesota	403	Washington	1,163	Oregon	4.4%
Washington	345	Colorado	1,067	New Mexico	4.0%
Iowa	341	Oregon	882	North Dakota	3.8%
North Dakota	167	Illinois	699	Oklahoma	3.0%
Oklahoma	155	Oklahoma	689	Texas	3.0%
Pennsylvania	115	New Mexico	496	Washington	2.8%
California	63	New York	425	California	2.8%
Missouri	57	Kansas	364	Kansas	2.3%
New York	55	North Dakota	345	Hawaii	2.3%
South Dakota	54	Pennsylvania	294	Montana	1.9%
Maine	33	Wyoming	288	Wyoming	1.7%
Hawaii	21	Montana	147	Idaho	1.5%
Massachusetts	2	South Dakota	98	Illinois	0.8%
Montana	2	Idaho	75	Maine	0.8%
		Nebraska	73	New York	0.7%
		West Virginia	66	Nebraska	0.7%
Rest of U.S.	0	*Rest of U.S.*	277	*Rest of U.S.*	0.05%
TOTAL	**5,329**	**TOTAL**	**16,904**	**TOTAL**	**1.1%**

Source: AWEA project database, EIA, Berkeley Lab estimates.

Table 2-3: U.S. wind power rankings: Top 20 states (Source: EERE [8])

The U.S. Department of Energy (DOE) recently launched an ambitious project to expand wind production, called the Advanced Energy Initiative. The initiative is designed to increase the share of wind-generated electricity in the U.S. from approximately 1 percent today to 20 percent by 2030 [12].

2.4 Wind energy in Indiana

With the successful commissioning of the 130 MW Benton County Wind Farm in the spring of 2008, wind energy is poised to have a substantial impact on the energy mix in Indiana's electricity industry. Wind farms with over 2,800 MW of name plate capacity have been proposed in various counties in Indiana. Table 2-4 shows the status of the various projects.

Project Name	Counties	Developer	Rated Capacity (MW)	Construction Schedule	Status
Benton County Wind Farm	Benton	Orion Energy	130	Completed Spring 2008	Completed
Fowler Ridge Phase 1	Benton	BP Alternative Energy & Dominion	400	To be completed by end of 2008	Under construction
Hoosier Wind Project	Benton	enXco	100	2009	Pending w/ PPA
Fowler Ridge Phase 2	Benton	BP Alternative Energy & Dominion	350	Begin early 2009	Approved
Tri-County Wind Energy Center	Tippecanoe, Montgomery, Fountain	Invenergy	300-500	Begin 2010	Proposed
Meadow Lake Wind Farm	Benton, White	Horizon Energy	600-1000	Begin 2010	Proposed
	Randolph	Horizon Energy	100-200		Proposed
	Howard	Horizon Energy	200		Proposed

Table 2-4: Status of wind generation projects in Indiana

Indiana utilities have signed agreements with the developers to purchase electricity from these wind projects. They include 100 MW and 30 MW agreements by Duke and Vectren respectively to purchase power from the Benton County Wind farm; Indiana Michigan's agreement to purchase 100 MW from the Fowler Ridge Wind Farm; and Indianapolis Power & Light's agreement to purchase 100 MW from the Hoosier Wind project proposed Benton County. Two of Indiana's utilities have signed agreements to purchase electricity from out of state wind farms. NIPSCO has two purchase agreements totaling 100 MW; 50 MW from a wind farm in South Dakota and 50 MW from a wind farm in Iowa. Table 2-5 lists the purchase agreements that Indiana utilities have to purchase wind power.

Utility	Project	State	Power Purchase Agreement (MW)	Status
Duke Energy	Benton County Wind Farm	Indiana	100	Operational
SIGECO	Benton County Wind Farm	Indiana	30	Operational
WVPA	AgriWind	Illinois	8	Operational
Indiana Michigan	Fowler Ridge	Indiana	100	Approved
NIPSCO	Buffalo Ridge	South Dakota	50	Approved
NIPSCO	Barton Windpower	Iowa	50	Approved
IPALCO	Hoosier Wind	Indiana	100	Pending

Table 2-5 Wind energy purchase agreements by Indiana utilities

In addition to the utility-scale wind farms, two small scale distribution level wind turbines were reported at the Indiana wind energy conference held in Indianapolis in June 2008 (WIndiana 2008). They are a 50 kW turbine owned by The Time Factory, a publishing company located in Indianapolis and a 15 kW wind turbine owned and operated Hoosier Energy. Prior to these projects commissioned this year, SUFG was only aware of a total of 20 kW of wind energy projects operating in Indiana. This comprised of a 10kW wind turbine in Fort Wayne owned by American Electric Power, and a 10 kW wind turbine owned by Duke Energy at a rest stop on I-65 in White county.

Indiana has roughly two wind regions, with the northern half having class 2 winds (12.5 – 14.3 mph at a height of 50 meters) and the southern half having class 1 winds (0 – 12.5 mph). Figures 2-10, 2-11 and 2-12 show the wind energy distribution in Indiana at 50, 70 and 100 meters, respectively [13]. The higher altitude wind maps indicate that wind speeds are significantly higher farther up. For instance, much of northern Indiana experiences class 4 or better winds at 100 meters.

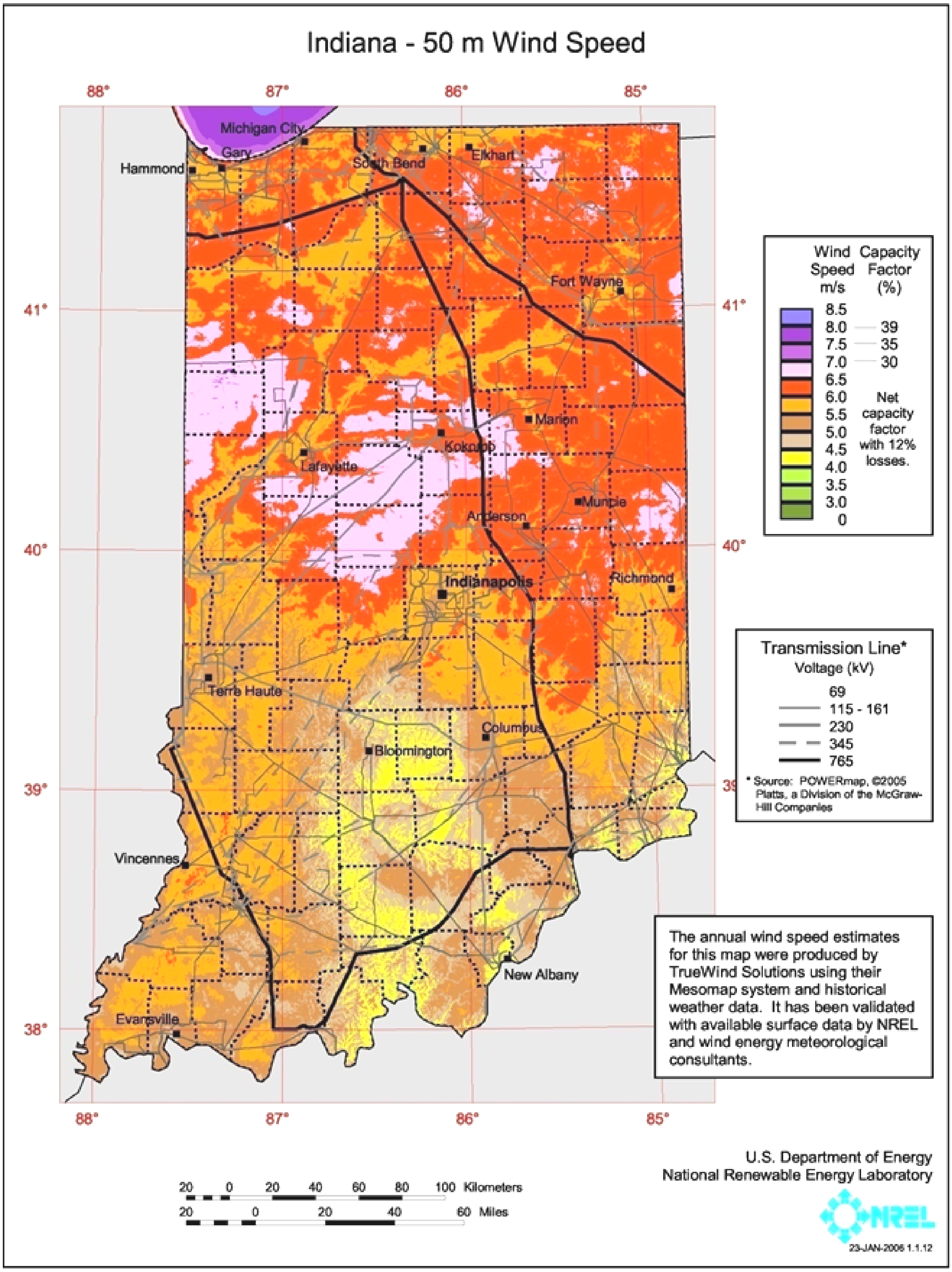

Figure 2-10: Indiana wind speed at 50 meters height (Source: OEDD [13])

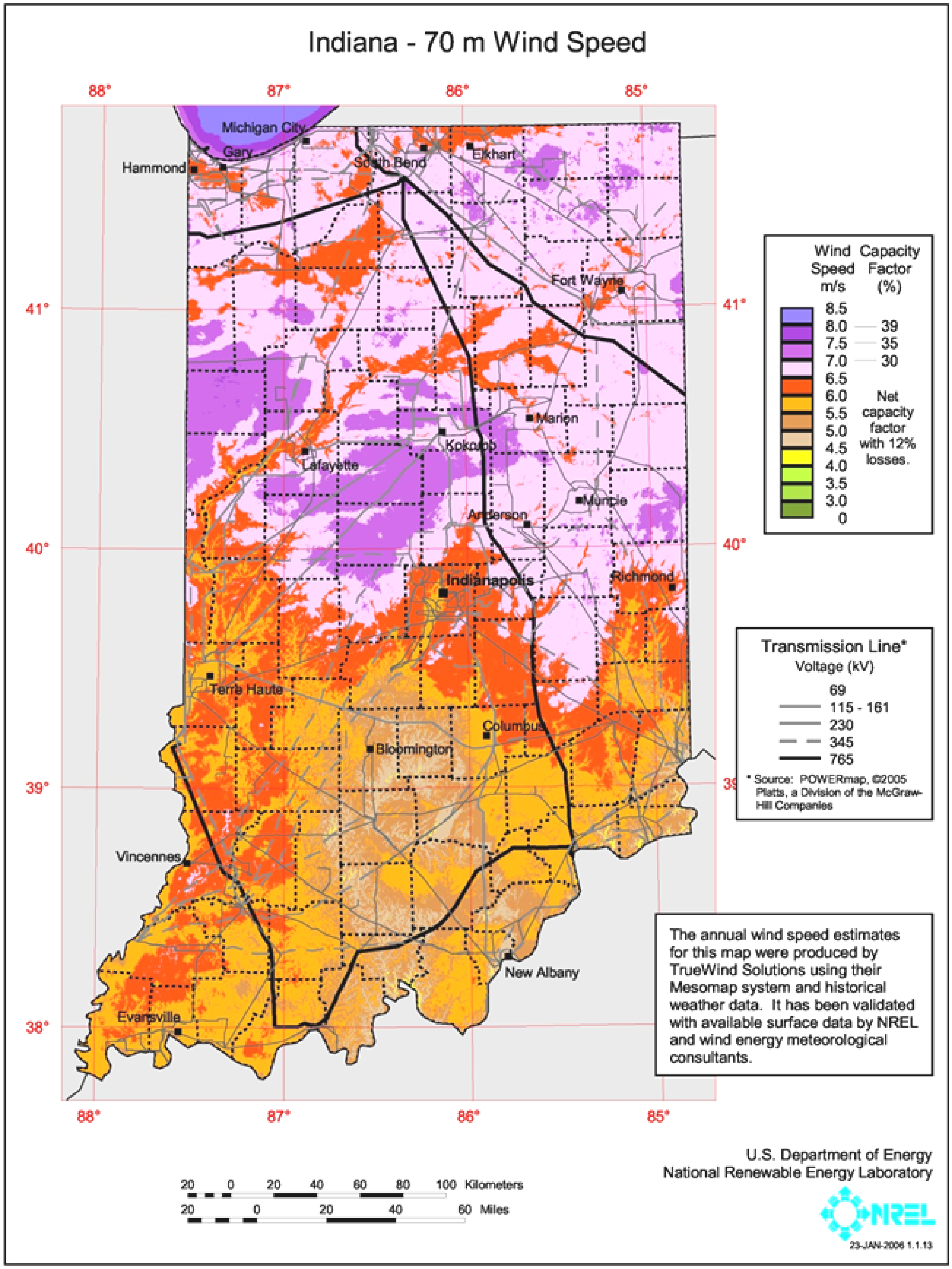

Figure 2-11: Indiana wind speed at 70 meters height (Source: OEDD [13])

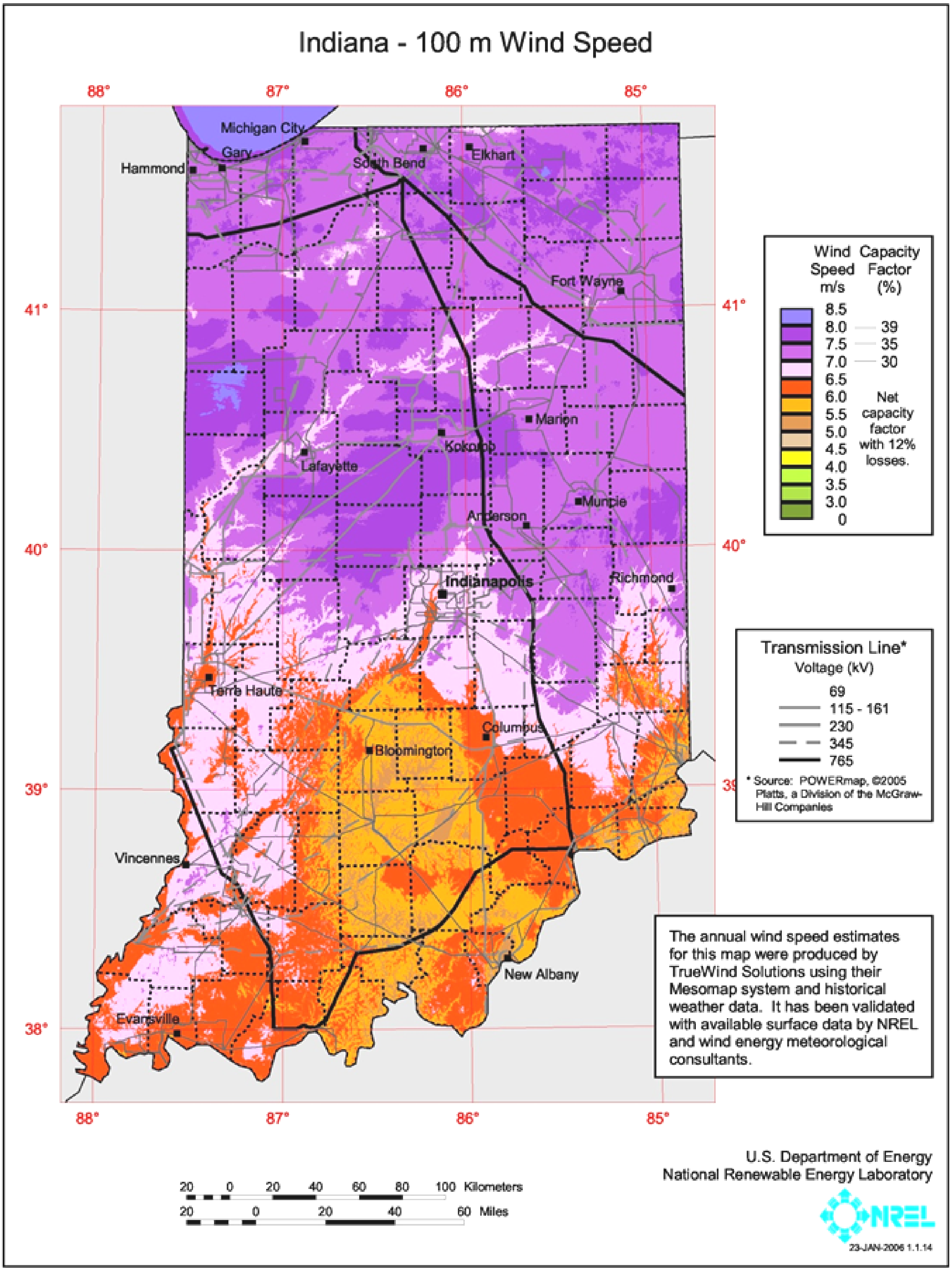

Figure 2-12: Indiana wind speed at 100 meters height (Source: OEDD [13])

2.5 Incentives for wind energy

The following federal and state incentives are available for wind energy projects [14].

Federal Incentives

- Renewable Electricity Production Tax Credit (PTC) credits wind energy producers with 2.0 cents/kWh during the first ten years of operation. The PTC expires in December 2008 [14].
- Renewable Energy Production Incentive (REPI) provides financial incentive similar to the production tax credit to wind generators owned by not-for-profit groups, public-owned utilities and other such organizations who do not qualify for the PTC. Qualifying facilities are eligible for annual incentive payments of 1.5 cents/kWh indexed for inflation for the first ten years of production, subject to the availability of annual appropriations in each federal fiscal year of operation. The Energy Policy Act of 2005 expanded the list of eligible technologies and facilities owners, as well as reauthorizing the program through the year 2026 [14]
- Conservation Security Program 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).
- Modified Accelerated Cost-Recovery System (MACRS): This program allows businesses to recover investments in solar, wind and geothermal property through depreciation deductions.
- Clean Renewable Energy Bonds (CREBs): This program, authorized by the Energy Policy Act of 2005, makes available a total of $1.2 billion in 0 percent bonds for non-profit organizations, public utilities, and state and local governments to pursue renewable energy projects. The program has currently not been extended past 2008 and is set to close at the end of the year. In February, 312 projects were announced that would receive CREBs funding [14].
- Energy Efficiency Mortgage can be used by homeowners to finance a variety of energy efficiency measures, including renewable energy technologies, in a new or existing home. The federal government supports these loans by insuring them through FHA or VA programs. This allows borrowers who might otherwise be denied loans to pursue energy efficient improvements, and it secures lenders against loan default and provides them with confidence in lending to customers whom they would usually deny [14].
- Value-Added Producer Grant Program: The application period for year 2008 closed on March 31, 2008. Funding decisions were scheduled to be made by August 31,

2008. In 2008, a total of $18.4 million in grants is available 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 2006 supported energy generated on-farm through the use of agricultural commodities, wind power, water power, or solar power. The maximum award per grant was $300,000. Matching funds of at least 50 percent were required [16].

Indiana Incentives

- Alternative Power and Energy Grant Program: offers grants of up to $25,000 to Indiana public, non-profit, and business sectors for the purchase of alternative energy systems, including solar hot water and photovoltaic systems [16].
- Energy Project Feasibility Study Program: This grant program offers cost share grants to public, non-profit, or business groups in Indiana to explore the feasibility of renewable energy [16].
- Net metering rule: Solar, wind and hydroelectric facilities with a maximum capacity of 10 kW are qualified for net metering. The net excess generation is credited to the customer in the next billing cycle.
- Renewable Energy Systems Property Tax Exemption provides property tax exemptions for the entire renewable energy device and affiliated equipment [14].
- 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 [17]. These credits can be sold on the national market.

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3. Dedicated Energy Crops

3.1 Introduction

Dedicated energy crops represent one of three types of biomass or organic matter that can be converted into energy. The other two types are dual use food crops, such as corn and soybeans, and organic waste such as forest residues, agricultural residues and municipal solid waste. The use of organic waste biomass as a source of energy is the subject of the next section (Section 4) of this report.

Dedicated energy crops can be divided into two broad categories: herbaceous grasses such as switchgrass, sorghum, and energy cane, and short rotation woody crops such as hybrid poplars and hybrid willows. Unlike dual use food crops and organic waste biomass, the dedicated energy crop industry is still in its infancy. According to a report by Marie Walsh of the Oak Ridge National Laboratory (ORNL) as of 2000 there was no commercial production of dedicated energy crops anywhere in the U.S. [1]. One advantage of biomass over other renewable resources is that, as a source of energy, biomass is not intermittent like wind and solar. Another unique feature about biomass among other renewable resources is that it can be readily converted into liquid fuels for the transportation industry [2].

Production of energy from biomass can be done in the following ways [3]:

- Direct combustion: This is the simplest conversion process and translates biomass energy into heat energy. The heat can be used to produce steam, which in turn can be used to generate electricity. Direct combustion, however, leads to high levels of ash production and may not be the most efficient way of extracting energy from biomass.
- Co-firing: This conversion process involves mixing a biomass source with existing fossil fuels (typically coal or oil) prior to combustion. The mixing of biomass with fossil fuels could either take place inside or outside the boiler. Co-firing is the most popular method used to generate electricity from biomass. This is because the biomass supply reduces nitrogen oxide, sulfur dioxide, and carbon dioxide emissions without reducing energy efficiency—co-firing allows the energy in biomass to be converted to electricity with the high efficiency (33 to 37 percent) of a modern coal-fired power plant. In co-firing, typically 5 to 15 percent of the input fuel is biomass.
- Chemical and biochemical conversion: Biomass can be used to produce liquid fuels (biofuels) such as ethanol and biodiesel. While ethanol and biodiesel can be used directly in some vehicles, both are more frequently used as additives to conventional fuels to reduce toxic air emissions and improve performance.
- Gasification: This involves a two-step thermochemical process of converting biomass or coal into either a gaseous or liquid fuel in high temperature reactors. Thermal

gasification converts approximately 60 percent of available energy in biomass into gases that may 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 the above methods, this technology is not yet in the marketplace. Challenges with this technology include "bio-oil cleanup," which is the filtering of the pyrolysis oil to remove impurities. [4].

Bioenergy constituted 3.6 percent of the total energy consumed, and 53 percent of the total renewable energy consumed, in the U.S. in 2007 [5]. Of the 3.374 quadrillion British thermal units (quads) of energy supplied by biomass in 2006, 58 percent was consumed in the industrial sector, 12 percent was consumed in the electricity sector, and 12 percent was consumed in the residential sector [6]. Another 14 percent was consumed in the transportation sector in the form of ethanol and biodiesel. The majority of biomass consumption in the industrial sector comes from cogeneration of wood wastes at pulp and paper plants. Here the wood residues from the manufacturing process are combusted to produce steam and electricity [7]. Residential consumption occurs primarily in the form of wood burning fireplaces and stoves.

NREL is conducting research on cost-effective biorefinery platforms. The biorefinery concept involves integrating biomass conversion processes and equipment to produce fuels, power and chemicals from biomass. The NREL biorefinery concept, shown in Figure 3.1 is built on two different platforms: the sugar platform based on biochemical conversion processes (fermentation of sugar) and syngas platform based on thermochemical conversion processes (gasification of biomass).

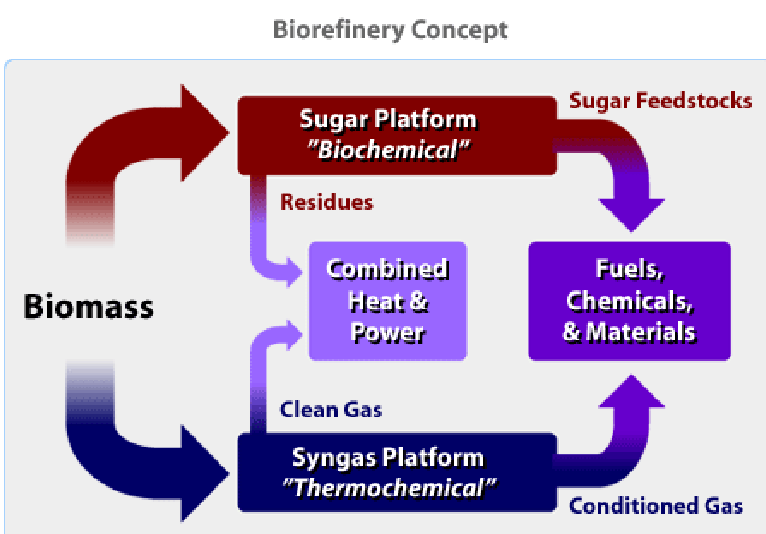

Figure 3-1: NREL biorefinery platforms (Source: NREL [8])

The value-added of a biorefinery lies in the advantage of maximizing the value derived from the different biomass stocks. The NREL Biomass Program is currently working on six major biorefinery projects [8].

The primary sources of biomass for electricity generation are landfill gas and municipal solid waste, which account for approximately 90 percent of biomass electricity generation [6]. 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 [9]. Energy crops are not being commercially grown in the U.S. at present, although demonstration projects have been funded by DOE in Iowa and New York [7]. The Bioenergy Feedstock Development Program at ORNL has identified hybrid poplars, hybrid willows, and switchgrass as having the greatest potential as dedicated energy crops over a wide geographic range [9].

Switchgrass falls under the category of herbaceous energy crops. These energy crops are perennials that are harvested annually after taking an initial two to three years to reach full productivity. A 2005 study by McLaughlin and Kszos reported a current average annual yield of switchgrass clones of 4.2 - 10.2 dry tons/acre in the U.S. [10]. The hybrid poplar and hybrid willow are short rotation, fast growing hardwood trees. They are harvested within five to eight years after planting. The comparative chemical characteristics between relevant energy crops and conventional fossil fuels are shown in Table 3-1 [11].

Fuel Source	Heating Value (gigajoule/ton)	Ash (%)	Sulfur (%)
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 [11])

In today's co-fired power plants, generation costs are equivalent to or lower than that of coal, about 2.1 cents/kWh depending on the cost of the biomass inputs. In the future, advanced technologies such as gasification-based systems could generate electricity for 5 cents/kWh. The cost of modifying existing coal-fired power plants and converting them into co-firing plants may be recouped in 2-3 years if low-cost biomass is used [12].

3.2 Economics of energy crops

According to ORNL [1], there was no dedicated energy crop production in the U.S. as of the year 2000. This is because the low price of fossil fuels meant that the price of energy crops would be too low for farmers to profitably grow them in place of current traditional food crops, such as corn and soybeans.

In a report titled *Biomass for Energy Generation* by Zia Haq at the Energy Information Administration (EIA) [7], biomass supply for energy production would grow dramatically given higher prices for biomass. Dr. Haq utilized an agricultural sector model called POLYSYS (Policy Analysis System), which was developed by ORNL to estimate possible future supplies of agricultural crops. Traditionally this software has been used for estimating commodity crops' supply; thus, to evaluate the economic potential of energy crops, several modifications to the POLYSYS model were made [13]. The estimated national supply curve for biomass and energy crops produced by POLYSYS for the year 2020 is shown in Figure 3-2. Other modeling tools used for estimating feedstock supplies developed by ORNL are ORIBAS, BIOCOST, and the database ORRECL [14].

Figure 3-2 indicates that energy crops will be supplied to the market when the average price (in 2000 dollars) paid for biomass exceeds $2.10/million Btu. In comparison, the average price of coal to electric utilities in 2007 was $1.48/million Btu (in 2000 dollars) [15]. Therefore, the use of energy crops is not yet economical.

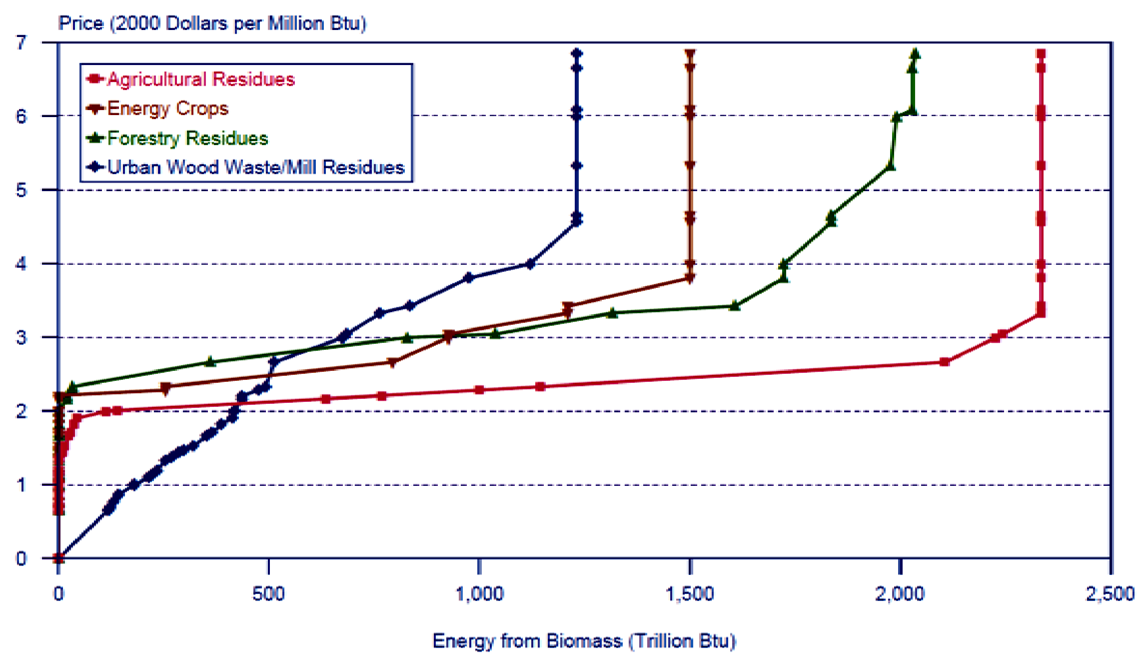

Figure 3-2: POLYSYS estimated biomass supply curve for year 2020 (Source: EIA)

Corn use for ethanol production

Although corn does not meet the strict definition of a dedicated energy crop, its rapid rise as a feedstock for ethanol plants has had a significant effect on the renewable energy industry and agriculture in Indiana. Unlike most other renewable fuels in this report, the main use of ethanol is in the transportation sector as an additive to motor gasoline. According to the Renewable Fuels Association [16], Indiana's ethanol plant capacity has grown tremendously over the last few years. Today, 11 plants are in operation or under construction in Indiana, with over 460 MGY (million gallons per year) of current ethanol production capacity, and another 330 MGY of capacity under construction. The amount of the proposed capacity that will actually be built is uncertain, given the recent sharp increase in the price of corn.

The following factors account for the rapid increase in ethanol production nationwide.

- Substitution of ethanol as a gasoline oxygenating additive in place of the chemical additive MTBE, which has been associated with ground water pollution. The shift from MTBE to ethanol was driven by states and the 2005 Energy Policy Act [17].
- The renewable fuel standard (RFS) included in the 2005 Energy Policy Act. The RFS mandates the use of renewable fuels, beginning with 4 billion gallons of ethanol per year in 2006, and expanding to 7.5 billion gallons by 2012 [18].
- The streamlining of the volumetric ethanol excise tax credit (VEETC) process and the raising of the cutoff level for the small producer's tax credit from 30 million gallons per year to 60 million gallons per year. The streamlined VEETC allows for a 51 cents/gallon tax credit to be refunded within 20 days of blending the ethanol with gasoline [19].

In 2006 Indiana also introduced the following incentives for ethanol and biodiesel production and blending:

- Increased the maximum allowed tax credit for biodiesel production, biodiesel blending and ethanol production from $20 million to $50 million,
- Allowed a $0.10 per gallon sales tax deduction for retail sales of the ethanol blended fuel E85 until July 2008 or up to $2 million., and
- Extended the tax credit for retail sale of blended biodiesel to 2010. [20]

Table 3-2 shows the ethanol plants existing and under construction in Indiana.

Plant Existing before 2005			
Company	Location	Current Capacity (MGY*)	Capacity under Construction (MGY*)
New Energy Corp	South Bend	102	
Plants Recently Constructed			
Central Indiana Ethanol	Marion	40	
Iroquois Bio-Energy Co.	Rensselaer	40	
POET Energy	Portland	68	
The Andersons Clymers	Clymers	110	
VeraSun Energy Co.	Linden	110	
POET Energy	Alexandria	60	
Plants Under Construction			
Aventine Renewable Energy	Mt. Vernon		220
Cardinal Ethanol	Harrisville		100
Indiana Bio-Energy	Bluffton		101
POET Energy	North Manchester		68

*MGY is million gallons per year.

Table 3-2: Ethanol plants in Indiana (Source: RFA [16], ISDA [21])

3.3 State of energy crops nationally

Energy crops can be grown on most of the land classified as cropland in the U.S. [9]. Overall, the nation's cropland acreage declined from 420 million acres in 1982 to 368 million acres in 2003, a decrease of about 12 percent [22]. Figure 3-3 shows estimated biomass production potential nationally [23]. A subset of these lands is defined as prime farmland – those lands with the best combination of physical and chemical characteristics for growing crops. However, while traditional crops may be best grown on prime farmland, energy crops can also be grown on erosive lands or lands that are otherwise limited for conventional crop production.

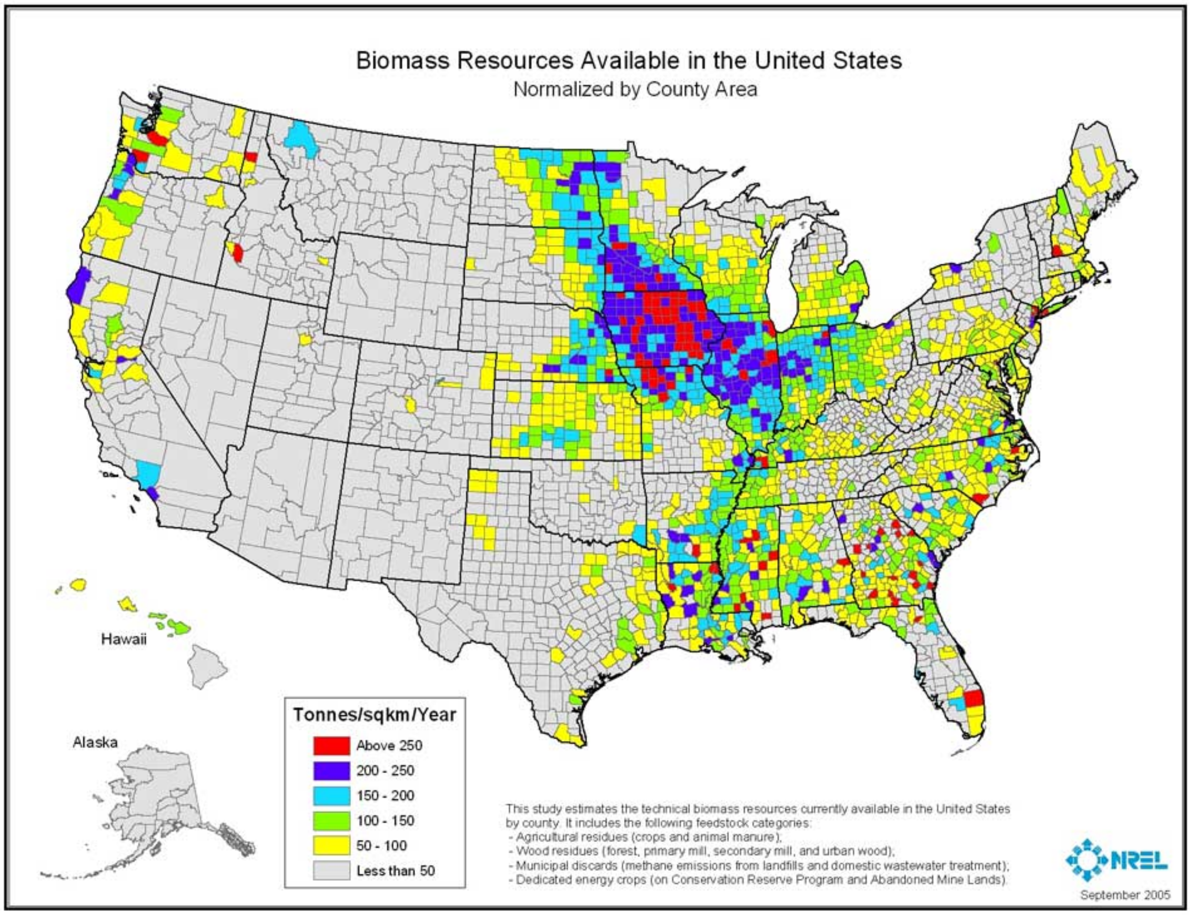

Figure 3-3: Biomass resources available in the U.S. (Source: NREL [23])

The Oak Ridge National Laboratory, which houses the national Biomass Feedstock Development Program, uses the POLYSYS modeling system referred to in Section 3.2 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 economically and environmentally unfeasible, and thus excludes the Western Plains due to the natural rain gradient in the U.S. 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, including Indiana [7, 24]. Hybrid poplar production was assumed to occur in the Pacific Northwest, Southern and Northern regions, while willow production was centered on the northern Great Lakes and the Northeast. The production assumptions used by ORNL are shown in Figure 3-4. The final panel in Figure 3-4 shows the acreage in the Conservation Reserve Program (CRP) that may be available for bioenergy crop production. These and further assumptions that ORNL used with the POLYSYS model are discussed in *The Economic Impacts of Bioenergy Crop Production on U.S. Agriculture* [13].

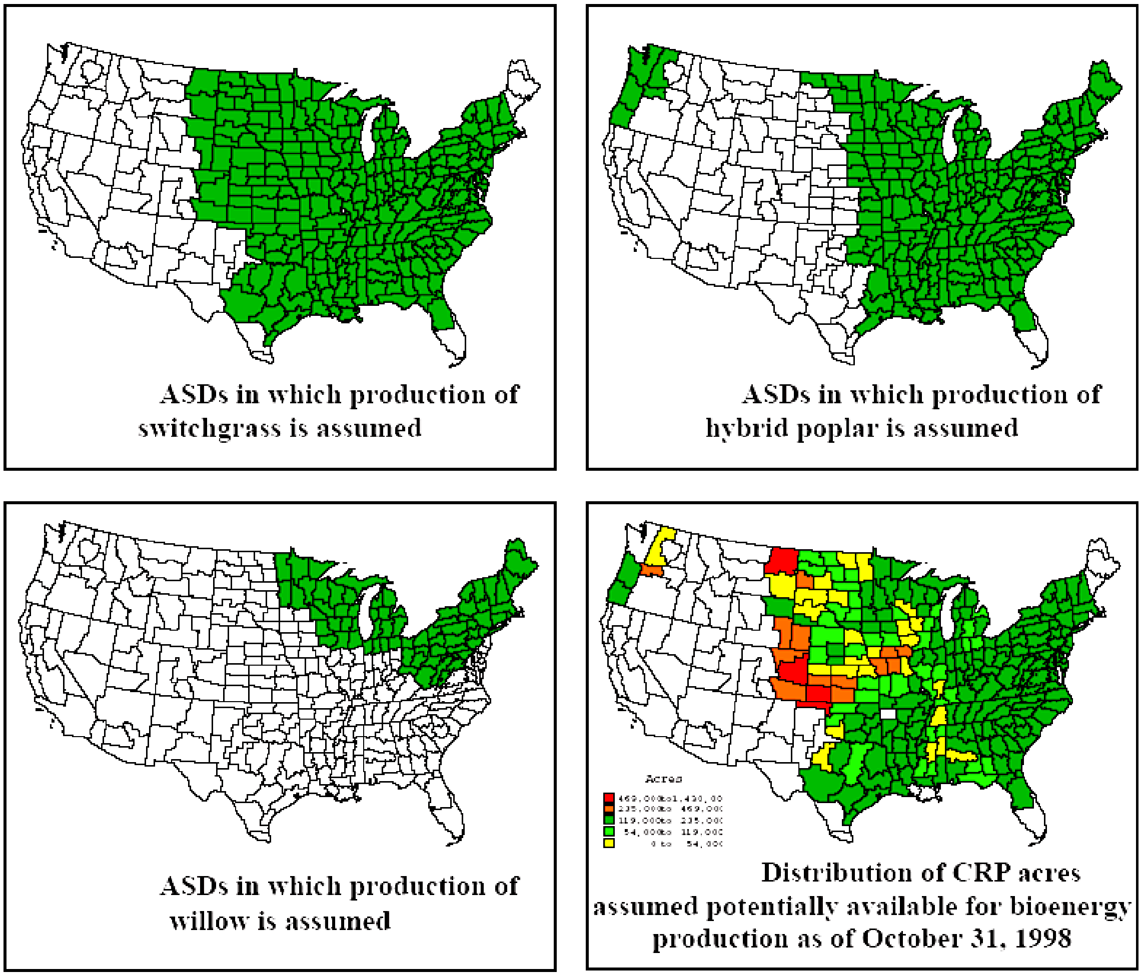

Figure 3-4: POLYSYS assumed Agricultural Statistical Districts (ASDs) for energy crop production (Source: University of Tennessee [13])

The energy crop yield assumptions that have been used for the POLYSYS model are displayed in Table 3-3. According to Haq's *Biomass for Electricity Generation* [7], the variation in yields for energy crops is due to differing soil conditions and weather patterns across the country. Also, different varieties of the energy crops are suited for different parts of the country, and these have variable growth rates. Haq's projections indicate that the lower costs and higher yields of switchgrass would make switchgrass the preferred energy crop of farmers. Also, for end users, switchgrass is advantageous because it has much lower moisture content than wood chips from hybrid poplars or willows. Another advantage of switchgrass is that the same plant will produce new stalks every year indefinitely. Thus, there is very low cost of maintenance—once a farmer plants his switchgrass, he can harvest it for years to come. Haq indicates that, through genetic modification and breeding, the yield and quality of switchgrass will continually improve. Thus, farmers may plow under their fields and plant new varieties of switchgrass periodically, such as every 10 years.

Hybrid poplars would be planted at 545 trees/acre. Based on geographic location, the trees would be harvested every 6-10 years of growth. The trees are distributed to customers as wood chips. Willows would be grown in a short rotation woodland management system and would be replanted every 22 years. Willows can be planted at 6,200 trees/acre, and would be harvested a total of 7 times over a 22 year time frame. The trees would also be distributed as wood chips.

Energy Crop	Currently Cultivated Lands	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/acre/year) (Source: EIA [7])

The USDA and DOE conducted another study using the POLYSYS model, to determine the potential of producing biomass energy crops [1]. The results indicated that an estimated 188 million dry tons (2.9 quads) of biomass could be available annually at prices of less than $2.88/million Btu by the year 2008. The cost is still too high, however, to compete with other sources of energy like coal. The analysis includes all cropland suitable for the production of energy crops that is currently planted with 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 16.9 million CRP acres.

The study indicates that CRP acres could become a significant source of biomass crops, decreasing the impact of competition with traditional crops [13]. Harvest of CRP acres will require a significant change in the current laws, however, and must be structured in a way that maintains the environmental benefits of the program.

Energy crop yields will increase over time, as will yields for traditional crops. The interplay of demand for food, feed, and fiber; yields of traditional crops; 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 coming years.

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 various years according to the National Resources Inventory by NRCS [22]. Note that the CRP did not exist until 1985.

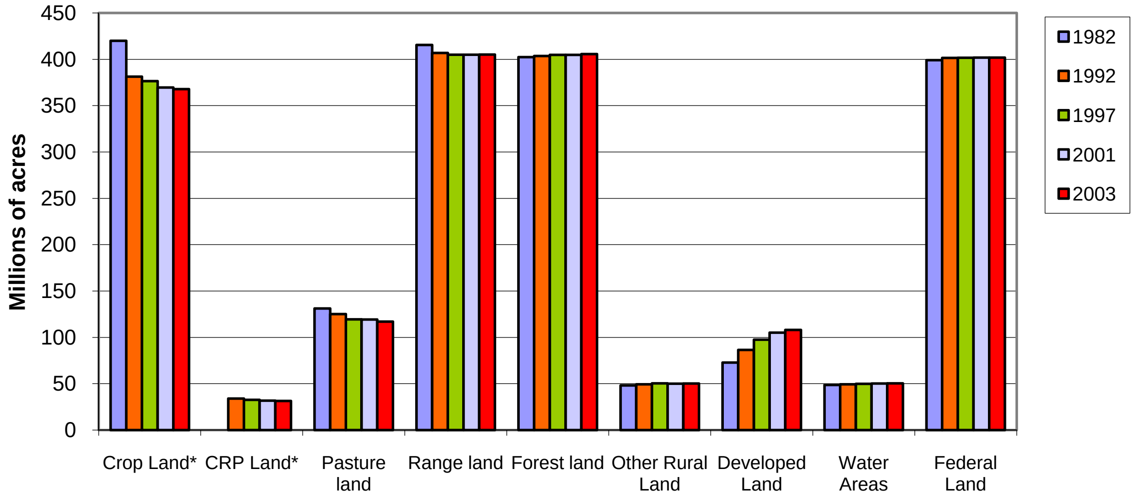

Figure 3-5: Land use in the contiguous U.S. (Source: USDA [22])

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. Potential quantities of energy crops could increase in the near future, but increases may be due more to increasing yields per acre than from an increasing number of acres under cultivation.

3.4 Energy crops in Indiana

A 2002 study at Ball State University estimated that there was potential to produce 90 million tons per year of switchgrass in Indiana if all the crop land was converted to the production of this energy crop. These 90 million tons of switchgrass would produce 450,000 GWh of energy, which is approximately four times Indiana's annual electrical energy consumption. According to this study, switchgrass is viable as an energy crop in Indiana because of the following factors.

- Switchgrass is native to most of the Midwest;
- It does not require much input after planting, resulting in less soil disturbance and erosion;
- Harvest usually occurs from September to October, prior to the harvest of corn and soybeans; and
- The machinery required for harvesting switchgrass is similar to that used for hay or silage [3].

Figure 3-6 shows the levels of energy crops that would be produced in Indiana at three different bioimass price levels used in a 1998/1999 USDA/USDOE study using the POLYSYS model. As the figure shows energy crops do not begin to be competitive with traditional food crops until the biomass price approaches $40 per dry ton. At $50 per ton, the biomass production jumps to 5 million tons [1, 25]. The biomass price levels needed to achieve the production levels shown in Figure 3-6 will be higher today given that food crop price levels are much higher than they were in 1999.

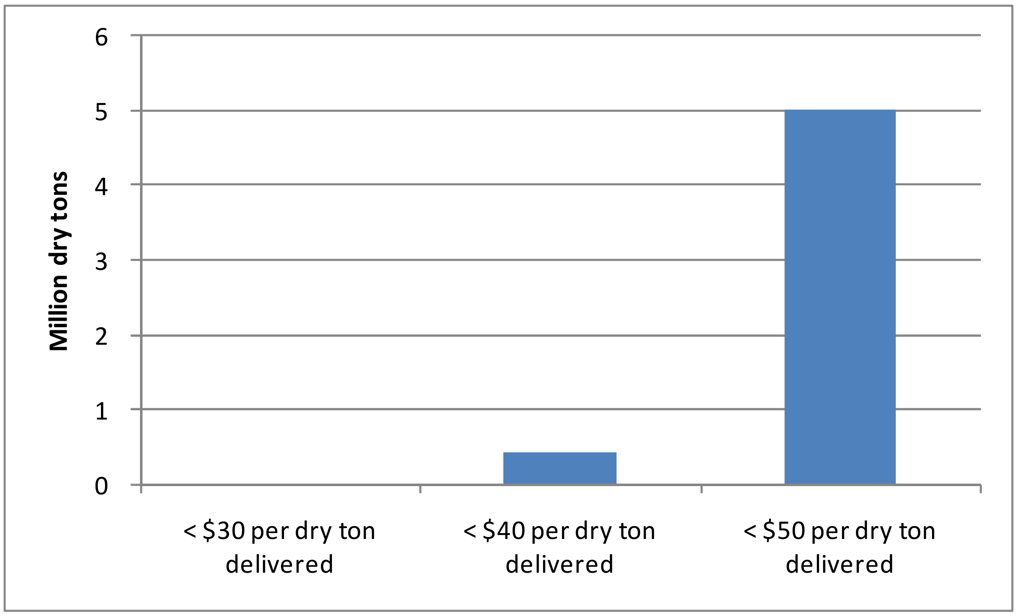

Figure 3-6: Estimated annual cumulative energy crop quantities (dry tons), by delivered price (1997 dollars) for Indiana. (Data source: ORNL [1])

The estimates of switchgrass and poplar production in a 2006 ORNL [26] study are shown in Figure 3-7. The study used the same agricultural sector model (POYSYS) referred to previously. As can be seen in Figure 3-7, central Indiana has the highest potential for switchgrass production while the northeast and southeast regions of Indiana have the highest potential for hybrid poplar production. Figure 3-8 shows the location of the Indiana regions in Figure 3-7.

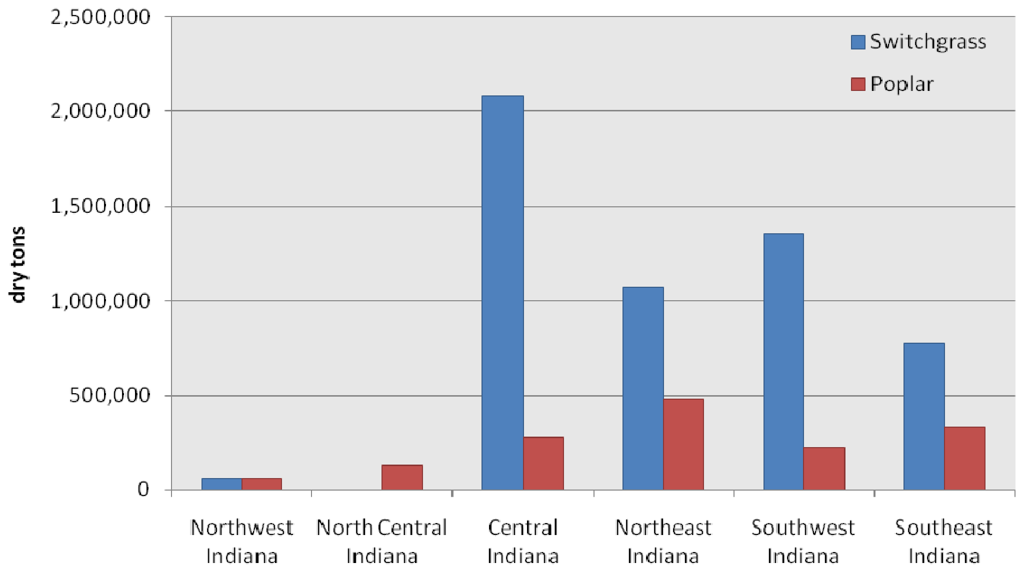

Figure 3-7: Estimated annual potential production of switchgrass and hybrid poplar (dry tons) for Indiana, USDA baseline 2001 (Source: ORNL [26])

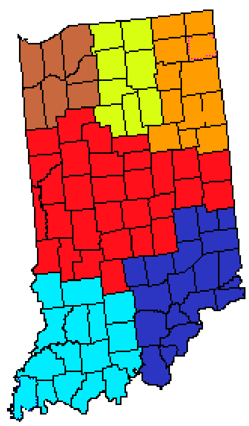

Figure 3-8: Regions of Indiana used in Figure 3-6 (SOURCE: EPA [27])

In an April 2008 working paper, Brechbill and Tyner of Purdue's Agricultural Economics Department did an extensive study of the cost of producing switchgrass and harvesting corn stover for the energy industry. Table 3-4 shows the average cost of producing switchgrass given in this study [28]. The table includes the farmer's choice to either purchase and own the harvesting equipment or to hire the services of a specialized custom operator.

	500 acre farm	1,000 acre farm	1,500 Acre farm	2,000 acre farm
Custom hired equipment	$53.23	$53.23	$53.23	$53.23
Owned equipment	$54.54	$52.43	$51.73	$51.38

Table 3-4: Average cost ($/ton) for producing switchgrass in Indiana (Source: Brechbill & Tyner [28])

3.5 Incentives for dedicated energy crops

The following incentives have been available to assist in the use of energy crops.

Federal Incentives

- Renewable Electricity Production Tax Credit (PTC) which credits renewable energy producers 2 cents/kWh during the first ten years of operation. The PTC originally covered wind and biomass, and was expanded and extended in the Energy Policy Act of 2005. It has been further extended to December 2008 by Section 207 of the Tax Relief and Health Care Act of 2006 [29].
- Renewable Energy Production Incentive (REPI) provides financial incentive payments for electricity produced and sold by new qualifying renewable energy generation facilities. Qualifying facilities are eligible for annual incentive payments of 1.5 cents/kWh for the first ten years of production, subject to the availability of annual appropriations in each federal fiscal year of operation. The Energy Policy Act of 2005 expanded the list of eligible technologies and facilities owners, and reauthorized the payment for fiscal years 2006 through 2026 [29].
- Value-Added Producer Grant Program: In 2006, a total of $21.2 million in grants was allocated 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. Grant awards for fiscal year 2006 supported energy generated on-farm through the use of agricultural commodities, wind power, water power, or solar power. The maximum award per grant was $300,000. Matching funds of at least 50 percent were required [30].

Indiana Incentives

- Energy Project Feasibility Study program: Provides grants for production of feasibility studies investigating renewable energy. These studies may be used as a foundation for application for funding from the USDA's Renewable Energy Systems and Energy Efficiency Improvements (2002 Farm Bill Section 9006) grant program [31].

- Emissions Credits: Electricity generators that do not emit NO_x and that displace utility generation are eligible to receive NO_x emissions credits under the Indiana Clean Energy Credit Program [32]. These credits can be sold on the national market.

Government aid could also assist in offsetting the renovation costs in converting conventional fossil-fueled generating stations to co-firing stations. Converting a coal-fired station to co-fire with biomass can result in an incremental cost of approximately 1 to 2 cents/kWh, and conversion to gasification can result in an incremental cost of 7 cents/kWh [33]. Further biotechnology developments in energy crops and improvements in energy conversion technology would also assist in the development of energy crops within Indiana and the use of biomass in electricity generation. Overall, farmers could earn up to $8 billion more per year if biomass were more widely utilized in the U.S. [33].

3.6 References

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4. Organic Waste Biomass

4.1 Introduction

Organic biomass waste with potential to be used as a source of energy includes:

- Residues from the forestry products industry:
    - Forest residues - Includes material left after the logging or harvesting of trees or as a result of thinning during forest management activities
    - Paper and pulping industry residues - leftover lignin and pulping liquor from paper-making processes. Many paper mills use leftover lignin to produce their own electricity.
- Municipal solid waste (MSW): Residential, commercial, and institutional post-consumer wastes contain a significant proportion of plant-derived organic material. They include such things as waste paper, cardboard, wood waste and yard cuttings.
- Residues from food and other biomass processing industries: All processing of biomass yields byproducts and waste streams which have significant energy potential.
- Animal wastes: Farms and animal processing operations create animal wastes that constitute a complex source of organic materials convertible into energy.
- Agriculture crop residues: Stalks, leaves and other material not harvested and typically not removed from the field during harvest have significant energy potential.

Biomass is one of the largest sources of renewable energy in the U.S. Historically it has ranked second to hydroelectric power, but has recently become the leading source of renewable energy. In 2007 renewable energy constituted 6.7 percent of the total energy consumed in the U.S. [1]. Of that, 53 percent was from biomass, making biomass the single largest source of renewable energy (Figure 4-1). More than 70 percent of this biomass was black liquor, a byproduct of papermaking and residue wood from the forest products industry [2]. The primary sources of biomass for non-cogeneration electricity are landfill gas and municipal solid waste [2]. Together, they accounted for over 53 percent of biomass electricity generation in the U.S. in 2006. During 2007, biomass accounted for approximately 12 percent of renewably generated electricity, 99 percent of industrial renewable energy use, 83 percent of residential renewable energy use, and 87 percent of commercial renewable energy use [1].

According to the *Billion Ton Biomass Study* by DOE and USDA [3], the U.S. has more than enough capacity to produce 1 billion tons of organic waste biomass every year, without affecting the availability of food. Production at this scale would allow the U.S. to meet the goal of replacing 30 percent of expected petroleum demand in 2030 with organic waste biomass[2]. Such organic waste biomass would come from a mix of forestland and agricultural land. Certain future technological advances and other changes would have to occur for this quantity of biomass to be produced, however, including increased crop yields, better harvesting technology, and changes to harvesting methods.

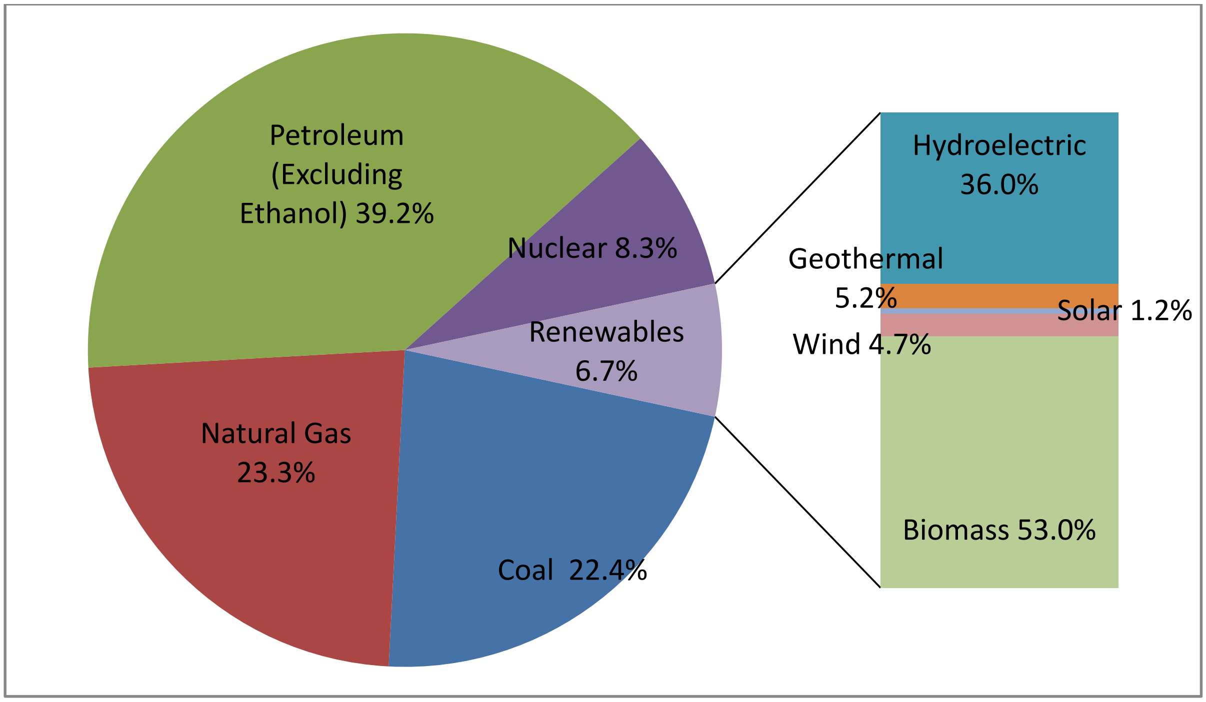

Figure 4-1: Summary of U.S. energy consumption in 2007 (Data source: EIA [1])

According to EIA's *2006 Annual Energy Outlook* [4] biomass is projected to be the largest source of renewable energy for electricity generation among the non-hydroelectric renewable. The contribution of biomass to the total electricity generation in the U.S. is projected to increase from 0.9 percent in 2004 to 1.7 percent in 2030. The increase will come from both co-firing and dedicated biomass power plants. Figure 4.2 shows EIA's projected electrical energy generation, in billion kilowatthours (kWh), from the various non-hydroelectric renewable resources through the year 2030 nationally.

[2] This goal is similar to the "20 percent by 2030" goal for wind power discussed in Section 2. The difference, however, is that wind power is solely used for electricity, while petroleum and biomass are used in a wide variety of fields, including electricity, transportation, and heating.

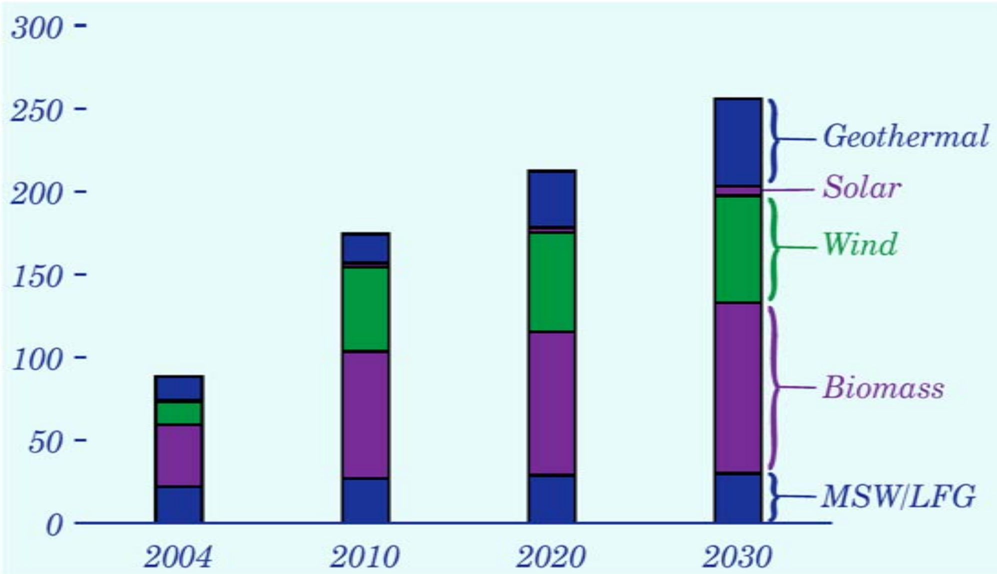

Figure 4-2: Non-hydroelectric renewable electricity generation by energy source (2004-2030) (billion kWh) (Source: EIA [4])

Biomass can be converted into energy in one of the following ways[3]: direct combustion, co-firing in conventional coal power plants, chemical conversion, and gasification.

Direct combustion and co-firing are the two most common methods used in converting biomass into energy. In direct combustion the biomass material is burned to produce heat. This heat can either be used directly or can be used to produce steam which is then passed through a turbine to produce electrical energy. According to the March 2003 report by NREL *Biopower Technical Assessment: State of the Industry and Technology*, direct combustion to raise steam was in use in all 7,000 MW of biomass-driven electricity generation plants existing in the U.S. at that time. A big hindrance to the co-firing of biomass in coal power plants is the presence of alkali metals such as sodium, potassium and calcium. The combustion products of these metals have a tendency to corrode or form deposits on heat transfer surfaces that would tend to reduce overall plant efficiency and increase the plant's maintenance costs [5].

Gasification is the technology that holds the greatest promise for future use in the conversion of biomass into energy because it is able to achieve much higher recovery efficiencies than other energy conversion methods. Typical efficiencies range from 20-24 percent for direct combustion, 33-37 percent for biomass co-firing, and up to 60 percent for gasification [6]. Although gasification technologies have been successfully tested in demonstration projects, they still have some technical barriers before they can be widely deployed at a commercial scale. They include:

[3] These terms are explained fully in Section 3.

- scaling up the technology,
- development of commercial scale technologies to integrate the gasification systems with turbines for electricity generation, and
- development of technologies to remove tars and condensate organics.

The energy content in various organic waste biomass fuels vary, as shown in Table 4-1 [2].

Fuel Type	Heat Content	Units
Agricultural Byproducts	8.248	Million Btu/Short Ton
Biodiesel	5.359	Million Btu/Barrel
Black Liquor	11.758	Million Btu/Short Ton
Digester Gas	0.619	Million Btu/Thousand Cubic Feet
Ethanol	3.539	Million Btu/Barrel
Landfill Gas	0.490	Million Btu/Thousand Cubic Feet
MSW Biogenic	9.696	Million Btu/Short Ton
Methane	0.841	Million Btu/Thousand Cubic Feet
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	12.720	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

Table 4-1: Average heat content of selected biomass materials (Source: EIA [2])

4.2 Economics of organic waste biomass

Co-firing with biomass fuels utilizes existing power plant infrastructure to minimize costs while maximizing environmental and economic benefits [7]. Typical co-firing applications utilize up to 15 percent biomass as the input fuel mix. To allow for co-firing, some low-cost conversion of the existing fuel supply system in the plant is required. The payback period for this capital investment can be as few as two years if low-cost biomass fuel is used [6].

The economics and benefits of biomass co-firing are strong, especially in a region like Indiana with high biomass availability. When 15 percent biomass is used as input in a coal-fired power plant, carbon dioxide emissions are reduced roughly 18 percent [7]. Moreover, depending on the cost of biomass, the cost of electricity production can fall. On average, coal-fired power plants produce electricity at a cost of 2.3 cents/kWh. Low-cost biomass will result in cost savings, with production at 2.1 cents/kWh. In contrast, biomass gasification plants can produce electricity at 9 cents/kWh; even with technology improvement, gasification is not expected to be cheaper than 5 cents/kWh. Thus, biomass co-firing may be economical today, while gasification is not [6].

The economics of biomass energy production are driven in a large part by geography. If the biomass source is within a close radius—a feasible distance is roughly 100 miles—then the use of biomass may make economic sense. Most of Indiana would fall in this category. Transporting biomass a further distance, however, would increase costs. Certain industries, such as papermaking and forestry products, produce much organic waste. New, small-scale generators are now becoming available that allow on-site electricity generation from biomass for these industries [6].

Biomass gasification is a technology that is still under development and is not completely deployed on a large commercial scale. According to the DOE Biomass Program, biomass gasification technology has the following technical barriers to be overcome before wide-scale commercial deployment [8]:

- A reliable feed system to supply uniform characteristic (size, moisture, etc.) feed to the gasifier has not been developed. Since biomass comes in such a wide variety of sizes and other physical characteristics, designing a system that will function across the whole range of characteristics presents a challenge.
- Gasifier systems suitable for integration with fuels synthesis technologies are not yet commercially available.
- Gas cleanup and conditioning systems available are not cheap or effective enough to achieve commercial deployment.
- The process control systems needed to maintain gasifier plant performance and emission targets are not yet commercially available.
- Process integration at a large enough scale to make gasification commercially viable is not yet available. This is especially true for gasifiers in black liquor mills, where the gasifier is already attached to an existing commercial process.
- The reactions in black liquor gasifiers are difficult to contain and the necessary approaches are yet to be developed.

4.3 State of organic waste biomass nationally

In 2007, the total biomass-based generation capacity in the U.S. was 10,313 MW [9]. Of this installed capacity, 6,432 MW was dedicated to generation from wood and wood wastes, 3,238 MW was attributed to generation capacity from municipal solid waste (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 [6]. This translates to about 7,500 MW of additional generation capacity. Figure 4-3 shows the current biomass availability in the U.S.

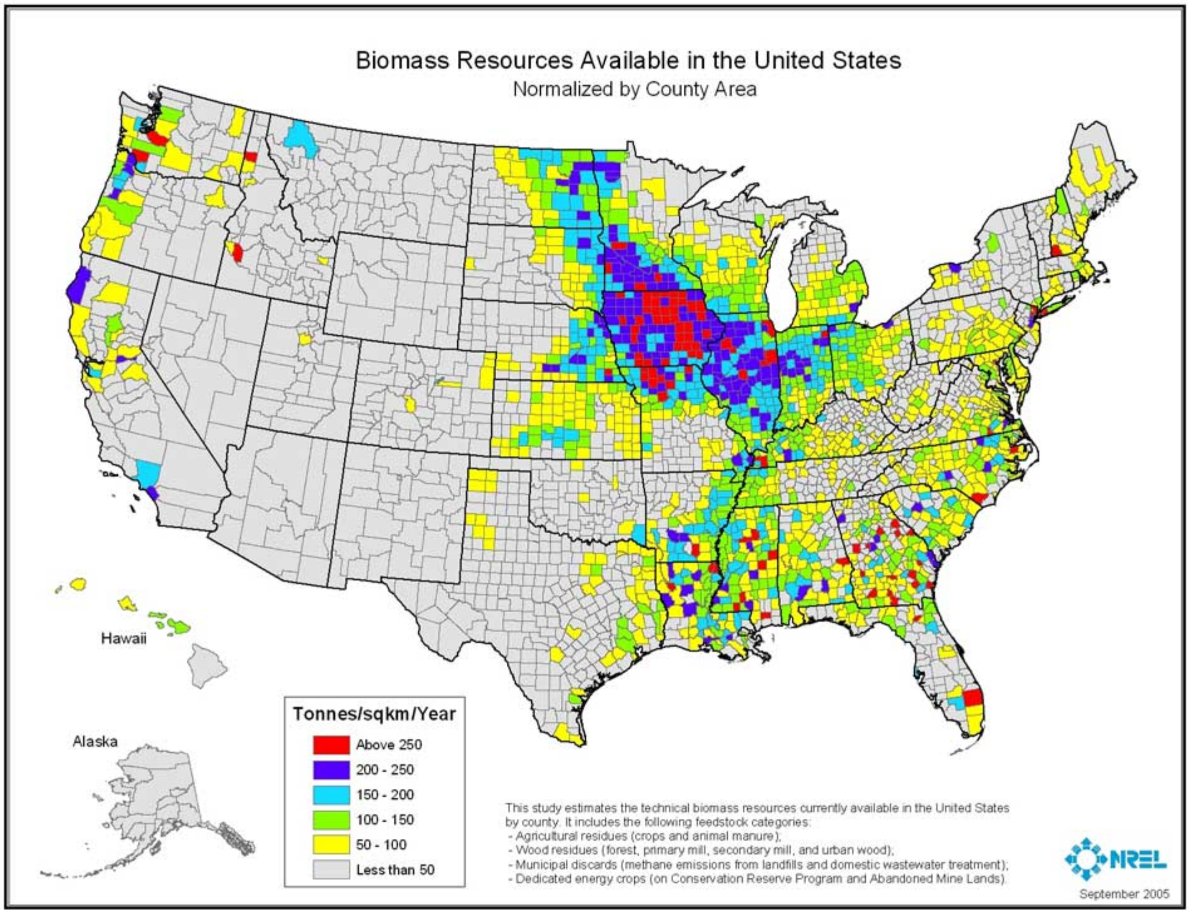

Figure 4-3: <u>Biomass resources available in the U.S.</u> (Source: NREL [10])

According to a 1999 analysis by the ORNL, at the price of $50/ton, there would be over 500 million dry tons of biomass available in the U.S., which would provide over 8 quads of energy [11]. About 7.5 percent of this biomass could come from urban wood wastes, while the wood, paper, and forestry industries could provide about 18 percent. Forest residues could contribute another 9 percent, while agricultural residues would add 29 percent. According to the *Billion Ton* report [3], the amount of biomass in the U.S. could be increased to 1 billion tons a year through new technologies, different industrial and farming methods, and government incentives.

NREL is conducting research into biomass from many different angles. Research into biochemical conversion technologies focuses on improving the conversion of sugars into readily usable fuels. This includes improving the efficiency of producing ethanol, and researching ethanol production from sources other than corn. New biocatalysts are also being developed to improve the conversion of lignin and hemicellulose in plant fibers into fuel [12].

Research into thermochemical conversion technologies focuses on biomass gasification and the production of syngas from biomass. Using syngas instead of direct biomass results in environmental benefits, and reducing the cost and improving the efficiency of syngas production is important. Research in gasification is geared towards addressing the technological shortcomings laid out in Section 4.2. An important area of research concerning gasification is in manufacturing small modular gasifiers. These gasifiers, which are being researched by the Carbona Corp. and the Community Power Corp. in association with the NREL, can be deployed in impoverished communities worldwide. Many communities today lack access to electricity, but have supplies of biomass available; thus, they could produce their own electricity using small modular gasifiers [13].

There are many commercially operated stations throughout the U.S. that co-fire biomass with traditional fossil fuels to generate electricity. In 2005, according to IEA Bioenergy, there were 41 co-firing stations in the U.S. [14]. Most of the co-firing operations use an input mix of less than 10 percent biomass, though some use up to 40 percent biomass. The Bay Front station in Ashland, WI, can generate electricity using coal, wood, rubber and natural gas [15]. Co-firing caused excessive ash and slag formation, and therefore it was better to operate exclusively on coal during heavy loads and on biomass during light loads. Up to 40 percent of the output of the Bay Front station is from biomass. The Tacoma Steam Plant in Tacoma, WA, can co-fire wood, refuse-derived fuel, and coal [15].

There is interest in improving biomass gasification technology in the future, especially by combining gasification systems with fuel cell systems. These systems will have reduced air emissions and will become more competitive economically as technology improvements cause costs to drop [16].

4.4 Organic waste biomass in Indiana

In 2006 biomass contributed 0.2 percent of the 130,490 GWh of total electrical energy generated in Indiana while all renewable resources combined contributed a total of 0.5 percent [2]. Wood is the most commonly used biomass fuel for heat and power, while landfill gas is the most common biomass fuel for electricity generation. The estimated supplies of urban and mill residues available for energy use in Indiana are respectively 470,000 and 28,000 dry tons per year [17].

Indiana has a large agricultural residue biomass potential, as shown in Figures 4-4 and 4-5. Over 16 million dry tons of agricultural residues, mainly from corn stover, are available each year in Indiana [17, 18].

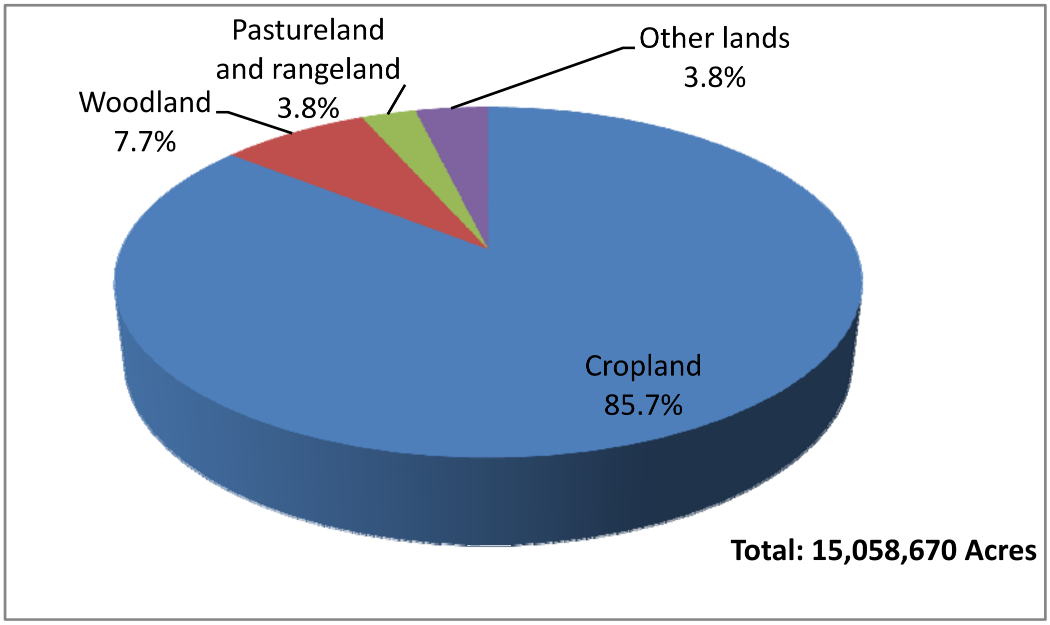

Figure 4-4: Indiana land use in 2002 (Data source: USDA [18])

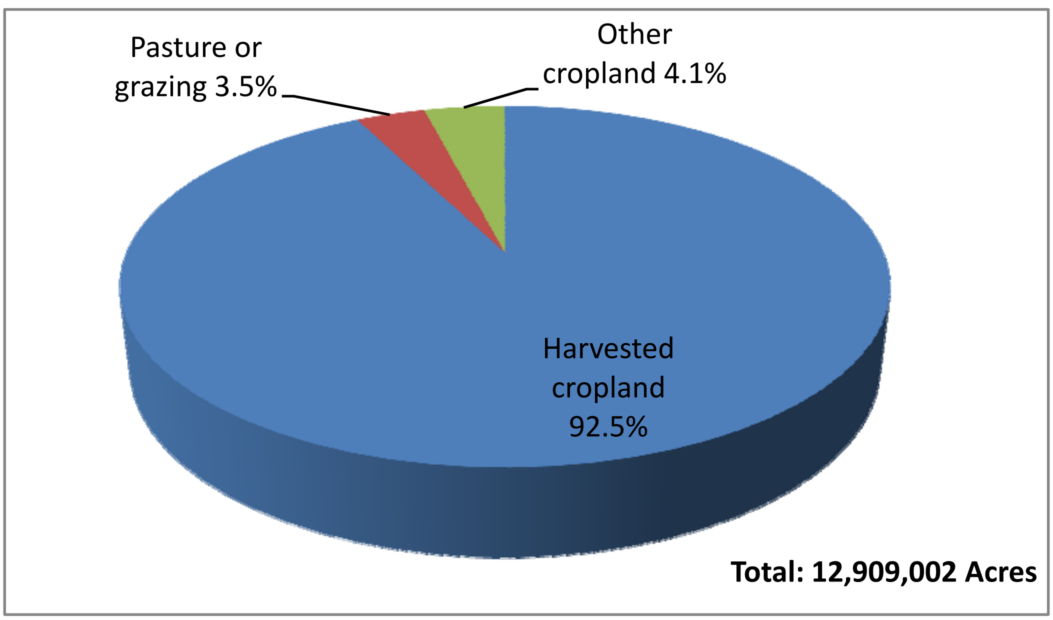

Figure 4-5: Indiana cropland use in 2002 (Data source: USDA [18])

An estimated 27,100 GWh of electricity could be generated using biomass fuels in Indiana. This is enough electricity to fully supply the annual needs of 2.7 million 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 [19].

The annual potential of biomass in Indiana is shown in Figure 4-6. Estimates of crop residues were made based on two types of planting systems; conventional tillage and no till which is a form of conservation tillage designed to preserve soil resources. Biomass production potential is much greater when no till farming is practiced. Central Indiana has the highest potential for producing in Indiana. The northwest, north central and northeast regions also produce significant amounts of crop residues accounting for 18 percent, 14 percent and 13 percent, respectively [17].

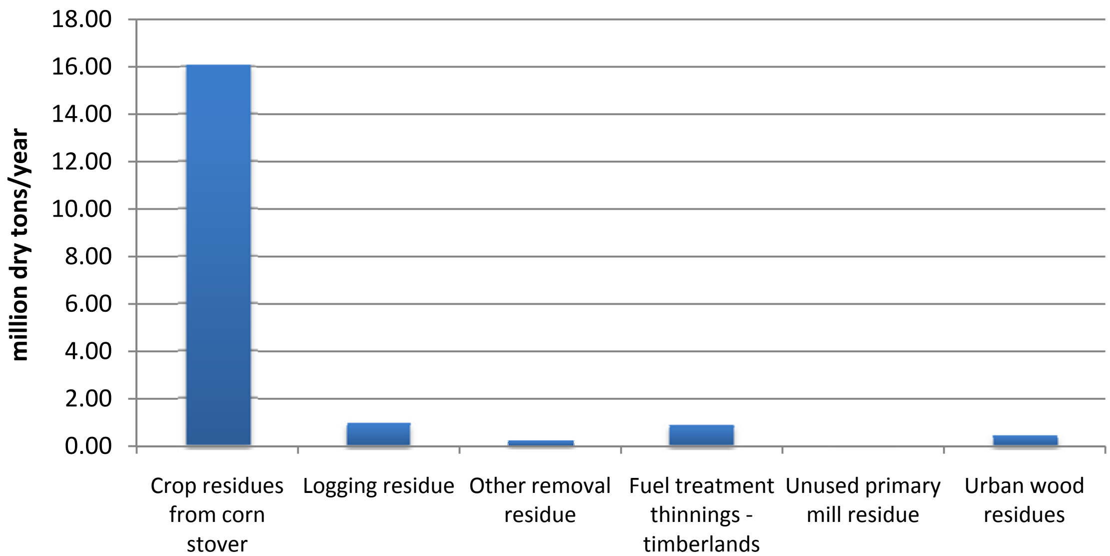

Figure 4-6: Estimated biomass production potential in Indiana (Source: ORNL [17])

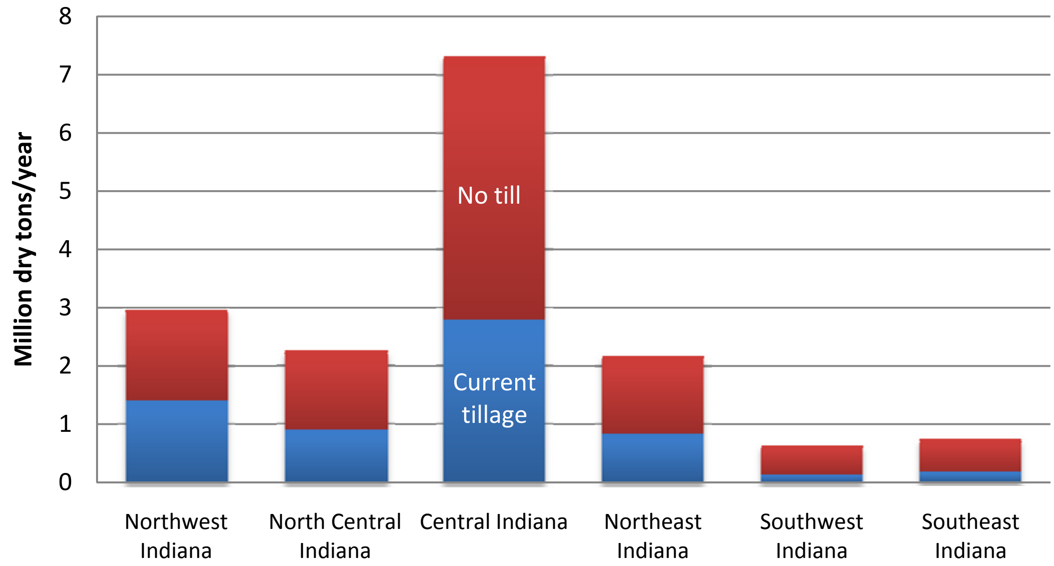

Figure 4-7: Estimated production potential of crop residues from corn stover in Indiana (Source: ORNL [17])

Figure 4-8 shows the estimate of the cost of harvesting and collecting corn stover in Indiana presented in a working paper by Brechbill and Tyner [20].

The cost of the stover is dependent on various farm level characteristics. One of these is the choice to either purchase the harvest equipment or to hire a specialized custom operator. The choices are marked as "owned" or "custom" in Figure 4-8. The other farm level characteristics affecting the cost of harvesting and collecting the stover are grouped into three scenarios as follows.

Scenario 1 – The farmer decides to only bale the stover, i.e., the corn is harvested and residue collected in a windrow behind the combine. This results in removing 38 percent of the stover and requires only one additional pass by the baler after the corn harvesting pass.

Scenario 2 – The farmer decides to rake and bale the stover. This results in removing 52.5 percent of the available stover, and requires two additional passes after the corn harvesting pass.

Scenario 3 – The farmer decides to shred, rake and bale the stover. This results in removing 70 percent of the residue, and requires three additional passes after the corn harvesting pass.

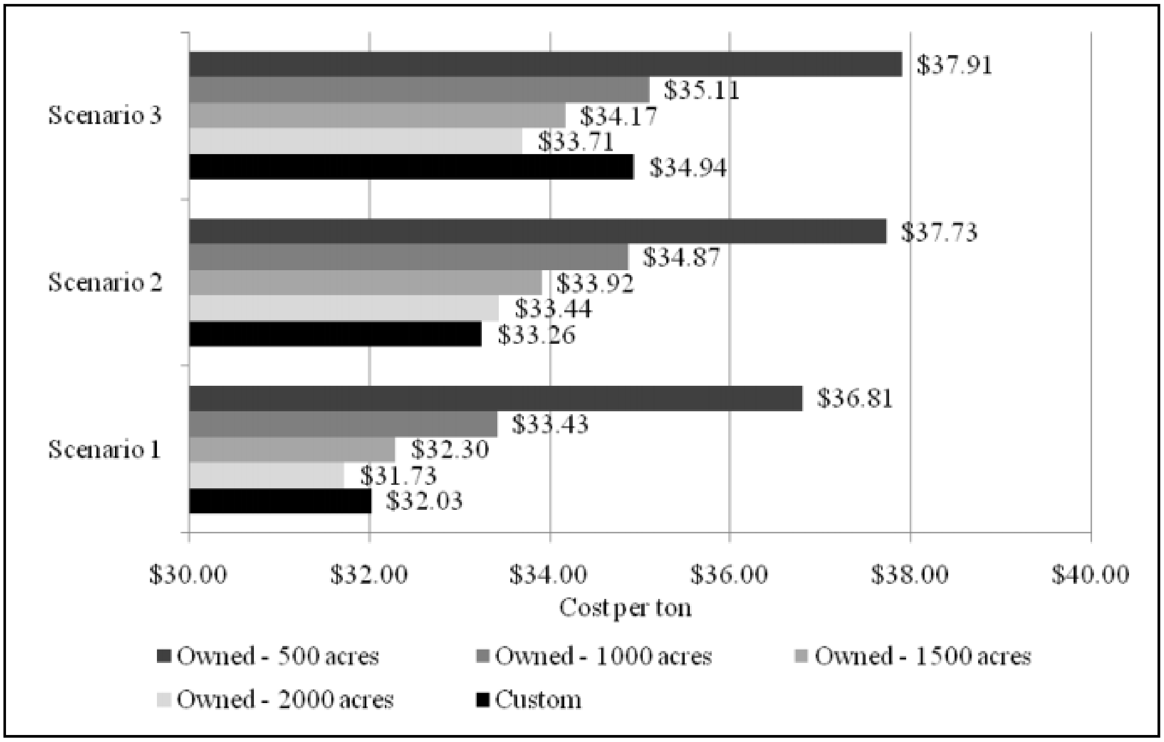

Figure 4-8: Corn stover product only costs (Source: Brechbill and Tyner [20])

According to the Electric Power Research Institute *Biomass Interest Group technical Report for 2002* [21] Northern Indiana Public Service Company (NIPSCO) conducted biomass co-firing tests at two of its coal-fired power plants of Michigan City Station (425 MW) in Michigan City and Bailly Station (160 MW) in Chesterton under a DOE Biomass Program. The tests were conducted with a biomass input fuel mix for the Michigan City station at 6.5 percent and 5 percent for the Bailly Station. Both of these co-firing tests resulted in reductions of nitrogen oxides, sulfur dioxide and carbon dioxide emissions.

As mentioned previously, landfill 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 the Wabash Valley Power Association with a total of 23.2 MW of landfill gas generation capacity [22]. The total generating capacity from Indiana's landfills is 45.2 MW [23]. There are also several dairies in Indiana which use methane gas (biogas) from their herds as a source of electric generation. These dairies include the Boss Dairy No. 4, the Fair Oaks Dairy, and the Herrema Dairy. Each of these dairies has over 700 kW of generating capacity [24].

4.5 Incentives for organic waste biomass

Federal Incentives

- Renewable Electricity Production Tax Credit (PTC) which credits wind energy producers 2.0 cents/kWh during the first ten years of operation. The PTC originally covered wind and biomass and was expanded and extended in the Energy Policy Act of 2005. It has been further extended to December 2008 by Section 207 of the Tax Relief and Health Care Act of 2006. Only solar energy plants operational before December 31, 2005 are eligible for this credit [25].
- Conservation Security Program: For 2008, the Conservation Security Program offers a $200 payment for each renewable energy generation system installed on an eligible farm. The Food, Conservation, and Energy Act of 2008 reincorporates the program as the "Conservation Stewardship Program" in 2009 and increases funding in the program by $1.1 billion [25].
- Rural Energy for America Program (REAP): The Food, Conservation, and Energy Act of 2008 converted the USDA Renewable Energy Systems and Energy Efficiency Improvements Program into the Rural Energy for America Program (REAP). Eligible renewable energy projects include wind, solar, biomass and geothermal; and hydrogen derived from biomass or water using wind, solar or geothermal energy sources. REAP incentives are generally available to state government entities, local governments, tribal governments, land-grant colleges and universities, rural electric cooperatives and public power entities, and other entities, as determined by USDA. [25].
- Value-Added Producer Grant Program: Available to independent producers, agricultural producer groups, farmer or rancher cooperatives, and majority-controlled producer-based business ventures. Grant awards for fiscal year 2006 supported energy generated on-farm through the use of agricultural commodities, wind power, water power, or solar power. The application period for year 2008 closed on March 31, 2008. Funding decisions are scheduled to be made by August 31, 2008. In 2008, a total of $18.4 million in grants is available to support the development of value-added agriculture business ventures [26].

Indiana Incentives

- Alternative Power and Energy Grant Program: This program offers grants of up to $25,000 to Indiana public, non-profit, and business sectors for the purchase of alternative energy systems, including solar hot water and photovoltaic systems [26].
- Energy Project Feasibility Study Program: This grant program offers cost share grants to public, non-profit, or business groups in Indiana to explore the feasibility of renewable energy [26].

- Emissions Credits: Electricity generators that do not emit NO_x and that displace utility generation are eligible to receive NO_x emissions credits under the Indiana Clean Energy Credit Program [27]. These credits can be sold on the national market.
- Renewable Energy Systems Property Tax Exemption provides property tax exemptions for the entire renewable energy device and affiliated equipment [25]

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5. Solar Energy

5.1 Introduction

Solar energy entails using energy from the sun to generate electricity; provide hot water; and to heat, cool, and light buildings. Solar energy can be converted either directly or indirectly into other forms of energy, such as heat or electricity. In this section, the indirect conversion of solar energy using solar thermal technology is discussed. The direct conversion of solar energy into electricity by photovoltaic cells is discussed in the following section (Section 6).

Solar thermal energy is captured using a solar-energy collector. There are two main types of collectors: concentrating and non-concentrating. Concentrating collectors are used to harness a large quantity of solar energy, and they are usually deployed to generate electricity [1]. Non-concentrating collectors are used for small-scale projects that require relatively low temperatures, such as solar water heating for pools and homes [2].

There are several major types of non-concentrating collectors. The most commonly used non-concentrating collectors are flat-plate designs. Of the various flat-plate design types, all consist of (1) a flat-plate absorber, which intercepts and absorbs the solar energy, (2) a transparent cover (glazing) 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. Flat-plate collectors often look like skylights when installed on residential roofs. Figure 5-1 shows the basic components of a flat-plate collector. Other non-concentrating collectors include evacuated-tube collectors and integral collector-storage systems [2].

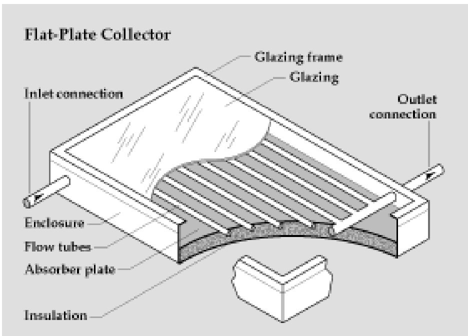


Figure 5-1: General layout of a flat-plate collector (Source: EERE [2])

There are three main types of thermal concentrating solar power (CSP) systems in use or under development. These are the parabolic trough, solar power tower, and solar dish [3], which are illustrated in Figure 5-2.

- The trough system has trough shaped collectors with a receiver tube located at the focal line of the trough. A working fluid is then used to transport the heat from the receiver systems to heat exchangers. Trough systems can be hybridized with conventional generators or coupled with thermal storage to enable them to be dispatched to meet utility demand. Current systems range from small-scale 1 MW to large-scale 350 MW [3]. While the trough system is a well-developed technology, there are major disadvantages. For example, herbicides must be used to prevent grass and weed growth between troughs. Also, the trough design cannot produce as high of temperatures as the power tower design, resulting in lower efficiency of power production. Both the trough system and the power tower design have relatively high cooling water requirements, which may cause problems in the desert Southwest [3].
- The dish/engine system utilizes a parabolic shaped dish that focuses the sun's rays to a receiver at the focal point of the dish. An engine/generator located at the focal point of the dish converts the absorbed heat into electricity. Individual dish/engine units currently range from 10-25 kW [4]. Many of these dish systems would be combined to make a utility-scale power plant. The dish/engine design results in the highest efficiency of the thermal designs; an array of dishes can produce 60 percent more electricity per acre than a trough system [3]. The dish/engine system does not use any cooling water, and these systems can be installed near residential areas.
- The 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. They are typically equipped with hot salt energy storage tanks at the base of the towers that enable them to store energy for several hours [4]. This system provides higher efficiency than the trough system because all sunlight is concentrated on a single point, which can then reach a very high temperate [3].

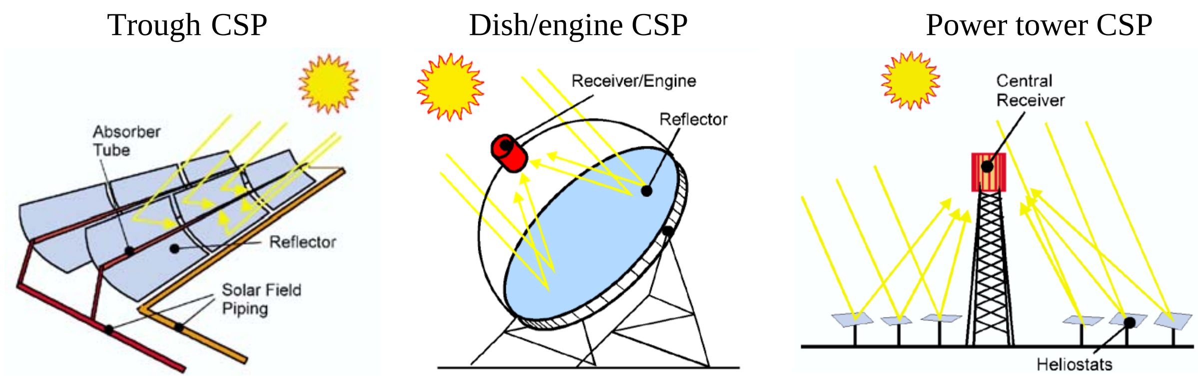


Figure 5-2: Types of concentrating solar collectors (Source: Sandia [3])

Table 5-1 illustrates further differences between the three types of solar thermal technologies [5].

		Parabolic Trough	Power Tower	Dish/Engine
Size#		30 – 320 MW	10 – 200 MW	5 – 25 kW
Operating Temperature (°C/°F)		390 / 734	565 / 1,049	750 / 1,382
Annual Capacity Factor#		23 – 50 percent	20 – 77 percent	25 percent
Net Annual Efficiency#		11 – 16 percent	7 – 20 percent	12 – 25 percent
Commercial Status		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
	$/kW	4,000 – 2,700	4,400 – 2,500	12,600 – 1,300
	$/kW$_p$+	4,000 – 1,300	2,400 - 900	12,600 – 1,100

Values indicate changes over the 1997 – 2030 time frame.

+ $/kW$_p$ removes the effect of thermal storage (or hybridization for dish/engine).

Table 5-1: Characteristics of solar thermal electric power systems (Source: Sandia [5])

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 is a source of clean, quiet, non-polluting energy; and
- It is a modular and scalable technology.

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

- Solar is an intermittent source of energy, and
- It has high equipment costs when compared to traditional technologies.

5.2 Economics of solar thermal technologies

Researchers today are working to reduce the cost of parabolic trough power plants to $2,000/kW. Present estimates for the cost of a large-scale facility (above 50 MW) are around $3,000/kW. New developments made in materials for high temperature performance may lead to an increase in efficiency. Estimated costs of large scale (above 50 MW) dish/engine facility are approximately $2,500/kW. However, current costs based on several demonstration systems could be three to four times lower, as indicated in the Department of Energy's *Solar Energy Utilization Report*. Future research and development could potentially reduce the cost for both trough and dish systems by more than $500/kW [3].

The cost of electricity produced by current large-scale (above 10 MW) concentrating solar power technologies are in the range of 9 – 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 [6]. Table 5-2 shows the forecast costs of energy from the solar thermal technologies in areas with high solar resources [7].

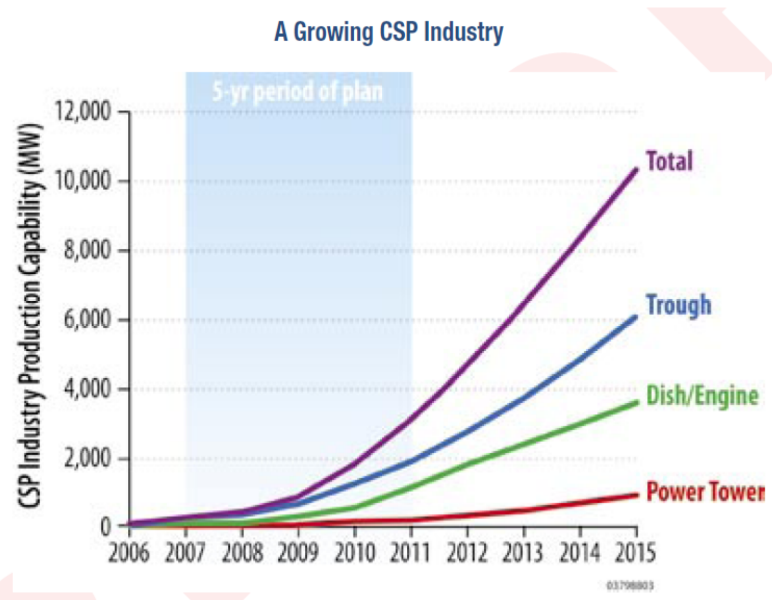
		Levelized COE *(constant 1997 cents/kWh)*				
Technology	**Configuration**	*1997*	*2000*	*2010*	*2020*	*2030*
Dispatchable Technologies						
Solar Thermal	Parabolic Trough	17.3	11.8	7.6	7.2	6.8
	Power Tower	--	13.6	5.2	4.2	4.2
	Dish Engine—Hybrid	--	17.9	6.1	5.5	5.2
Intermittent Technologies						
Solar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

Table 5-2: Comparative costs of different solar thermal technologies (Source: Sandia [6])

5.3 State of solar energy nationally

Energy from solar resources accounted for about 1 percent of the total renewable energy produced in the U.S. in 2006, and 0.07 percent of all energy produced in the country [8]. The CSP industry has shown to be a potentially viable source of renewable energy in the U.S. The industry is constituted by companies who design, sell, own, and/or operate energy systems and power plants based on the concentration of solar energy. Figure 5-3 shows that strong growth in installed capacity is expected over the next 10 years [4].

The total domestic shipments of solar thermal collectors were 19.53 million square feet in 2006 [9]. This represents an increase from 14.68 million square feet in the previous year. The majority of shipments were low-temperature type collectors (75 percent) while medium and high-temperature collectors represented 25 percent of total shipments [10]. Nearly all low-temperature solar thermal collectors were used for the heating of swimming pools. Medium-temperature collectors were used primarily for water heating applications, while high-temperature collectors were installed solely for electricity generation [11]. Florida, California, and Nevada were the top destinations of solar thermal collectors, accounting for more than half of all domestic shipments [12]. Figure 5-4 illustrates the top states for domestic shipments of solar thermal collectors in 2006.



The production capability of the CSP industry is estimated to grow significantly through 2015. This estimate represents a cumulative 10.3 gigawatts (GW) of additional peak capacity.[4]

Figure 5-3: Expected growth in electricity generation capacity by concentrated solar power (Source: EERE [4])

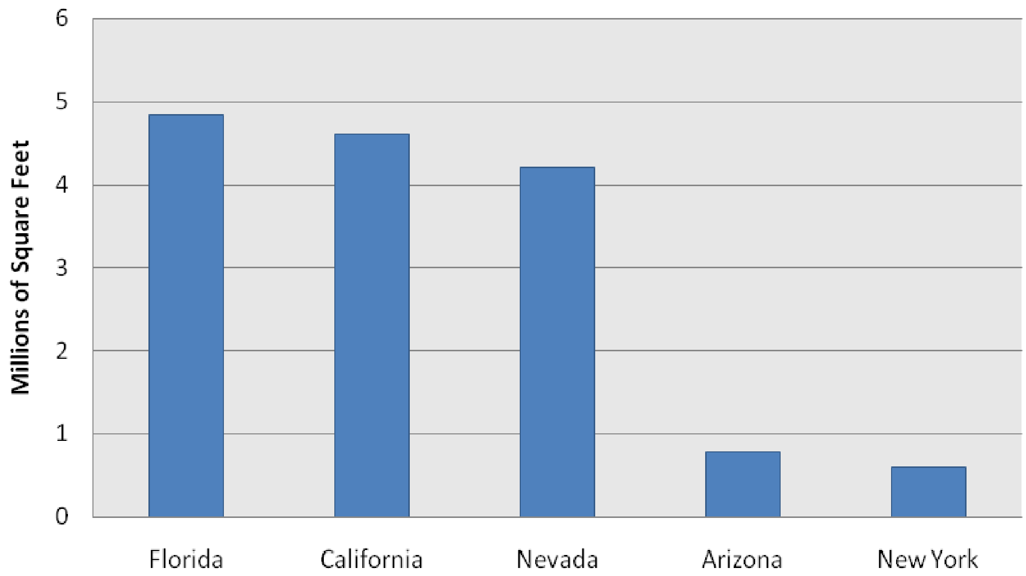


Figure 5-4: Top domestic destinations for solar thermal collectors in 2006 (Source: EIA [12])

Figure 5-5 shows annual average solar radiation with a fixed, flat-plate, collector orientation fixed at its latitude [13]. 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, concentrating collectors work better in regions with more intense sunlight. Figure 5-6 illustrates the solar radiation available to concentrators which move to track the sun, such as a dish/engine [13].

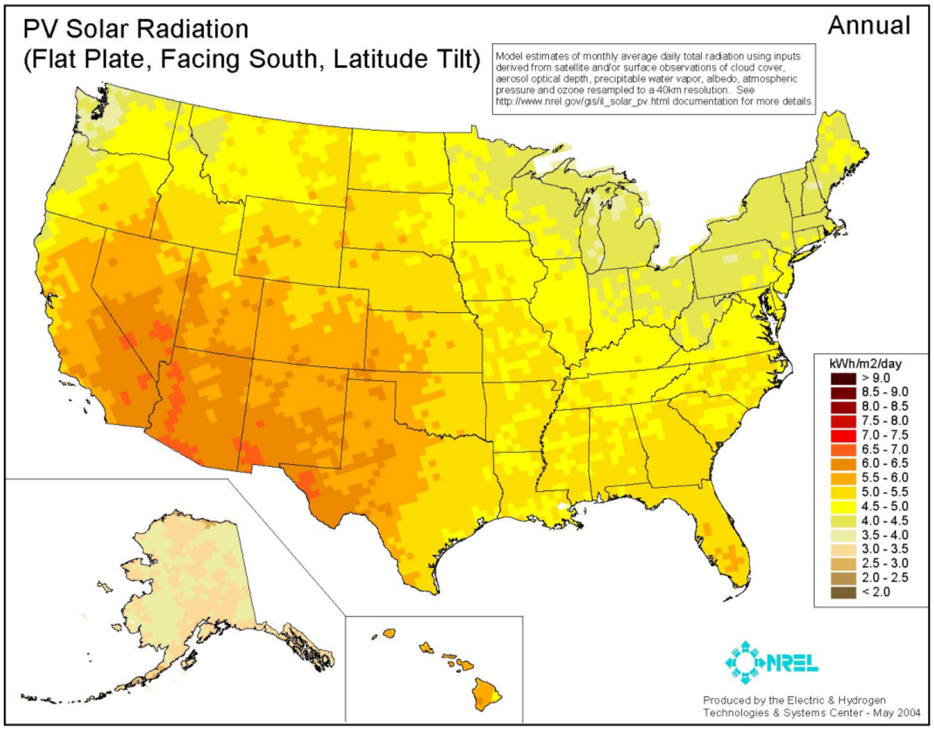


Figure 5-5: Annual average solar radiation for a flat-plate collector (Source: NREL [14])

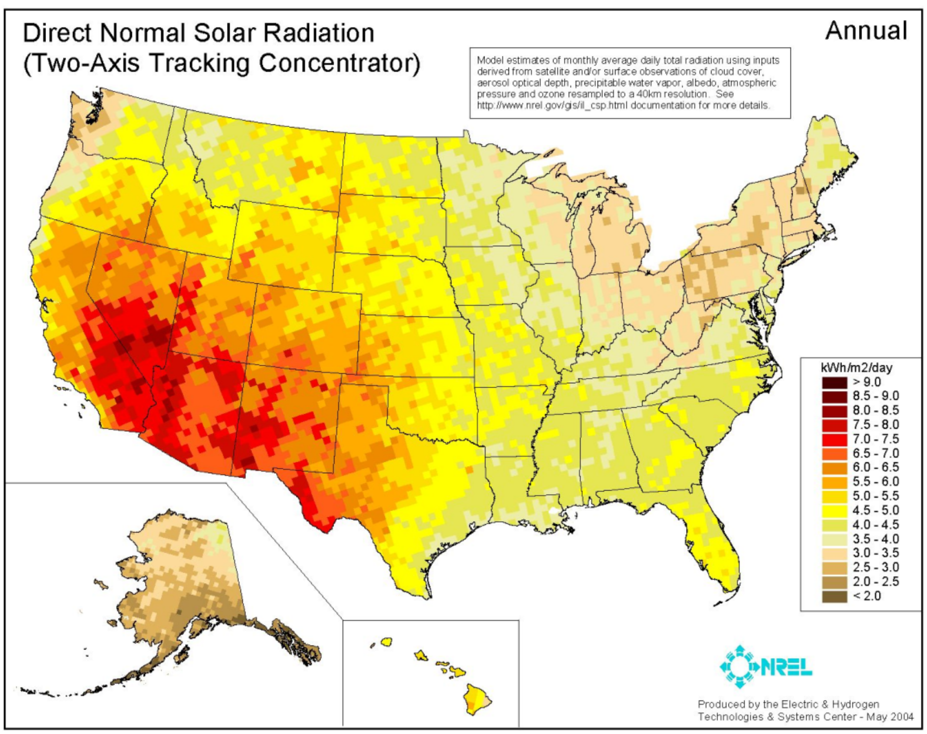


Figure 5-6: Direct normal solar radiation (two-axis solar concentrator) (Source: NREL [14])

These maps clearly illustrate the potential for solar power in the southwestern parts of the U.S. It is in this part of the U.S. that solar thermal power plants have been built. The largest grid connected solar project in the U.S., the 354-MW Solar Electric Generation System (SEGS), is located in the Mojave desert in California [3]. The SEGS consists of nine parabolic trough power plants built in the late 1980s and early 1990s. SEGS accounts for over 95 percent of the total solar power electricity generation capacity in the U.S. The SEGS power plants are hybrid stations, in that they can use natural gas during periods of low levels of solar energy. The plants are used as peaking stations, as the system peak in the area is largely driven by air conditioning loads that coincide with the maximum output of the facility. In addition to the California plants, a 64 MW parabolic trough power plant came online in Boulder City, Nevada, in June, 2007. This plant, called the Nevada Solar One, has a capacity to produce electricity for 40,000 homes at a cost of 9 – 13 cents/kWh [8].

There are currently no active power tower type plants in the U.S. [3]. Two facilities, Solar One and Solar Two, were built in Barstow, California, in the 1980s and 1990s as demonstrations for the feasibility of the power tower technology. The Solar One facility used oil as the transfer fluid, whereas the Solar Two facility used molten salt. The facility consisted of 1,818 heliostats and a total generating capacity of 10 MW. This project was jointly funded by DOE and the utility with the objective of validating the use of molten salt for thermal energy transport and storage in a CSP plant and to also validate the technology's viability as a source for dispatchable power [15]. The Solar Two project was discontinued in 1999.

There are currently many projects in the Southwest investigating the long term use of dish/engine systems for power production [16]. While most of these projects are relatively small-scale, plans were announced in 2005 to construct a 4,500 acre dish/engine plant in southern California. This plant would have a 500 – 850 MW capacity and would be constructed using 20,000 dishes, making it the first large-scale dish/engine power plant in the world. Current projections are that this California dish power plant will sell electricity at 6 cents/kWh [17].

Current government initiatives in the solar industry include [14]:

- The 1,000-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 U.S. 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 7 cents/kWh. 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. 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; and
  - Capital and operation and maintenance (O&M) 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; and
  - Developing O&M data integration and tracking systems.
- Parabolic-Trough Thermal Energy Storage Technology: 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 and has a unit cost of $30-$40/kW. 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; and

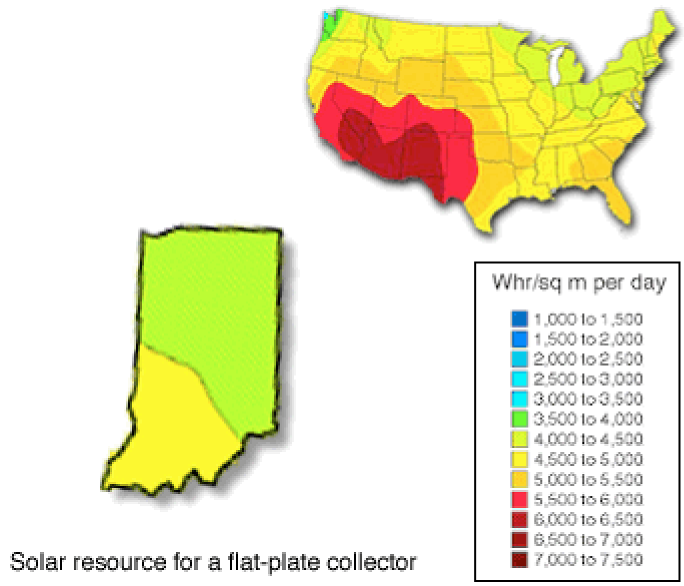
- Help reduce the cost of solar electricity.

The DOE shut down the Million Solar Roofs program in 2006 in order to concentrate on the Solar America Initiative (SAI). Through the Million Solar roofs program, over 200 MW of solar heating capacity was built in the U.S. SAI is aimed towards reducing the cost and improving the technology of photovoltaic systems and concentrating solar systems; the goal is to achieve cost-parity for these technologies by 2015 [18].

5.4 Solar energy in Indiana

Indiana has relatively little potential for grid-connected solar projects like those in California because of the lack of annual solar radiation, as shown in Figures 5-3 and 5-4 [13]. There is, however, some potential (more so in the southern part of the state) for water and building heating using flat-plate collectors. Figure 5-7 shows the solar collection potential for both flat plate and concentrating collectors. As can be seen from the figure, the flat-plate collectors perform better than the concentrating collectors for many northern states.

The actual viability of installing solar energy water heating within Indiana depends on the microclimate of the area of concern. The typical initial cost of a solar water heating system is about $2,000 to $4,500, and the payback period varies due to various state and utility incentives [20].



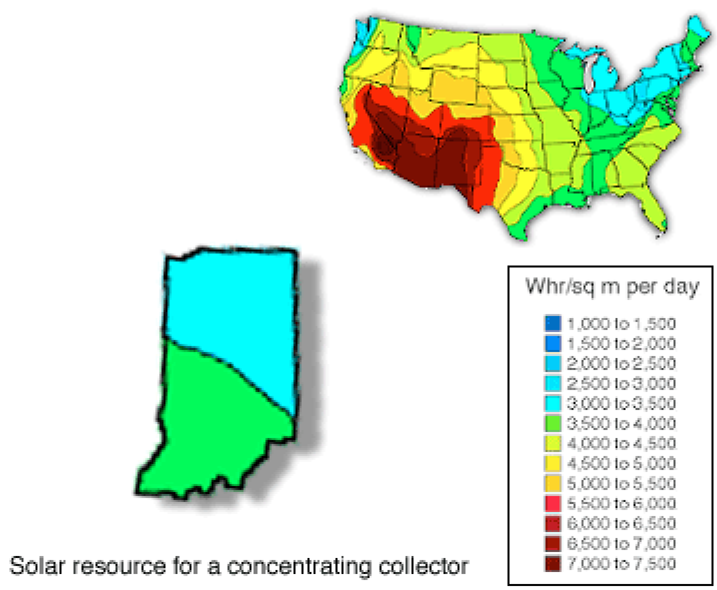


Figure 5-7: Solar thermal energy potential in Indiana (Source: EERE [19])

5.5 Incentives for solar energy

The following available incentives could help increase use of solar energy within Indiana:

Federal Incentives

- Business Energy Tax Credit: The Energy Policy Act 2005 provides a 30 percent tax credit for business investment in solar energy systems (thermal non-power and power uses) installed before December 31, 2008. In 2009, the tax credit will revert to 10 percent [21].

- Clean Renewable Energy Bonds (CREBs): This program, authorized by the Energy Policy Act of 2005, makes available a total of $1.2 billion in 0 percent interest bonds for non-profit organizations, public utilities, and state and local governments to pursue renewable energy projects. The program has currently not been extended past 2008 and is set to close at the end of the year. In February 2008, 312 projects were announced that would receive CREBs funding [21].
- Conservation Security Program: For 2008, the Conservation Security Program offers a $200 payment for each renewable energy generation system installed on an eligible farm [22, 23]. The Food, Conservation, and Energy Act of 2008 reincorporates the program as the "Conservation Stewardship Program" in 2009 and increases funding in the program by $1.1 billion [24].
- Energy Efficiency Mortgage: These mortgages can be used by homeowners to finance a variety of energy efficiency measures, including renewable energy technologies, in a new or existing home. The federal government supports these loans by insuring them through FHA or VA programs. This allows borrowers who might otherwise be denied loans to pursue energy efficient improvements, and it secures lenders against loan default and provides them with confidence in lending to customers whom they would usually deny [21].
- 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 fifty years, over which the property may be depreciated. For solar, wind and geothermal property placed in service after 1986, the current MACRS property class life is five years. The Economic Stimulus Act of 2008 extended an additional 50 percent deduction off the adjusted basis for certain renewable energy systems purchased and installed in 2008 [21].
- Qualified Green Building and Sustainable Design Project Bonds: The American Jobs Creation Act of 2004 authorized $2 billion in tax-exempt bond financing for green buildings, brownfield redevelopment, and sustainable design projects. These bonds are only issued for projects that are at least 75 percent complaint with the U.S. Green Building Council's *Leadership in Energy and Environmental Design* (LEED) building rating system, receive at least $5 million in funding from state or local government, and include one million square feet of construction. 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 program currently expires on December 31, 2009 [25, 26].
- Renewable Energy Production Incentive (REPI) provides financial incentive payments for electricity produced and sold by new qualifying renewable energy generation facilities. Initially, 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 years of production, subject to the availability of annual appropriations in each federal fiscal year of operation. The Energy Policy Act of 2005 expanded the list of eligible technologies and facilities owners, as well as reauthorizing the program through the year 2026. The REPI is available only to non-profit groups, public utilities, or state governments [21].

- 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" [21].
- Rural Energy for America Program (REAP): The Food, Conservation, and Energy Act of 2008 converted the USDA Renewable Energy Systems and Energy Efficiency Improvements Program into the Rural Energy for America Program (REAP). Solar facilities are eligible for grants for up to 25 percent of the cost of the system and loans for another 50 percent of the cost [21].
- Value-Added Producer Grant Program: The application period for year 2008 closed on March 31, 2008. Funding decisions are scheduled to be made by August 31, 2008. In 2008, a total of $18.4 million in grants is available 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 2006 supported energy generated on-farm through the use of agricultural commodities, wind power, water power, or solar power. The maximum award per grant was $300,000. Matching funds of at least 50 percent were required [27].

Indiana Incentives

- Alternative Power and Energy Grant Program: This program offers grants of up to $25,000 to Indiana public, non-profit, and business sectors for the purchase of alternative energy systems, including solar hot water and photovoltaic systems [28].
- Emissions Credits: Electricity generators that do not emit NO_x and that displace utility generation are eligible to receive NO_x emissions credits under the Indiana Clean Energy Credit Program. These credits can be sold on the national market [29].
- Energy Project Feasibility Study Program: This grant program offers cost share grants to public, non-profit, or business groups in Indiana to explore the feasibility of renewable energy [30].
- Net Metering Rule: Solar, wind and hydroelectric facilities with a maximum capacity of 10 kW are qualified for net metering in Indiana. The net excess generation is credited to the customer in the next billing cycle [28].

- Renewable Energy Property Tax Exemption: provides property tax exemptions for active solar equipment used for heating and cooling. Photovoltaic systems are not included in this exemption [28].
- Solar Access Laws: Indiana state law includes both covenant restrictions and solar-easement provisions. The state's covenant restrictions prevent planning and zoning authorities from prohibiting or unreasonably restricting the use of solar energy. Indiana's solar-easement provisions do not create an automatic right to sunlight, though they allow parties to voluntarily enter into solar-easement contracts which are enforceable by law [28].

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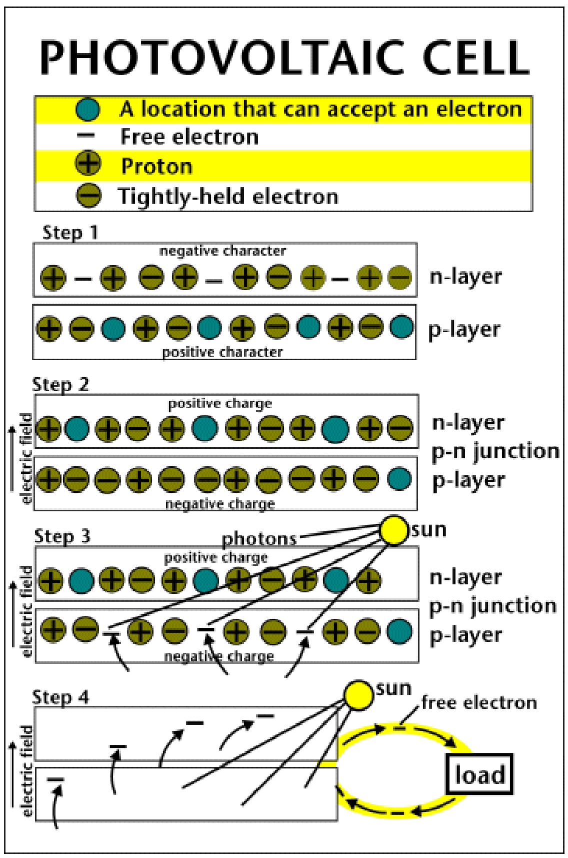
6. Photovoltaic Cells

6.1 Introduction

Unlike solar thermal systems, photovoltaic (PV) cells allow for the direct conversion of sunlight into electricity. The photovoltaic cell is a non-mechanical device constructed from semiconductor materials (see Figure 6-1). When the photons in sunlight strike the surface of a photovoltaic cell, some of them are absorbed. The absorbed photons cause free electrons to migrate in the cell, thus causing "holes." 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].



<u>Figure 6-1:</u> <u>Photovoltaic cell operation</u> (Source: EIA [1])

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 depends upon sunlight, with more sunlight leading to higher power output. Figure 6-2 illustrates how cells can combine to make a module, and how modules are combined to make an array [3].

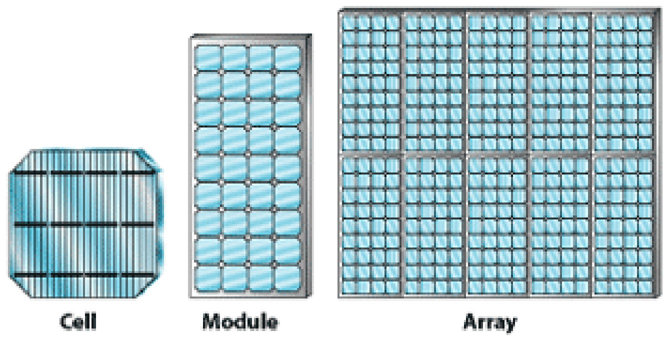


Figure 6-2: Illustration of a cell, module and array of a PV system (Source: EERE [3])

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 and buildings.

There are currently three major types of PV cells: crystalline silicon-based, thin film-based, and concentrator-based. A new experimental type of cell, the spheral cell, aims to reduce the amount of silicon used to construct solar cells; spheral cells remain mostly in the research phase. Silicon PV cells, the most common type, typically cost more than thin film cells but are more efficient [4]. Efficiency ranges of 13 to 17 percent are normal, though Sanyo announced in 2007 that they had built a silicon-based cell that achieves 22 percent efficiency [5]. Thin-film cells have a normal efficiency of 10 percent. Concentrator cells and modules utilize a lens to gather and converge sunlight onto the cell or module surface [4].

PV cells can be arranged into two different types of arrays: flat-plate PV arrays and concentrating PV arrays. 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 throughout the day. Concentrating PV (CPV) arrays use a lens to focus sunlight onto cells. CPV arrays cannot use diffuse sunlight and as such are generally installed on tracking devices. The advantage of CPV arrays is that they use less semiconductor material than flat-plate arrays to produce the same output. A disadvantage, though, is that because they are unable to make use of indirect sunlight, CPV arrays can only be used in the sunniest parts of the country, unlike the broad geographical range of flat-plate PV arrays [2].

NREL is actively researching CPV technology, especially as an alternative to the dish/engine solar thermal system discussed in Section 5. CPV systems have no moving parts (besides the tracking device) and no heat transfer, making them potentially more reliable than dish/engine systems. Also, CPV systems result in efficiencies greater than 40 percent and a reduction in the use of expensive semiconductor materials, lowering the effective total cost compared to flat-plate PV systems. The cost of CPVs is similar to that of solar thermal technologies, and CPVs may eventually be used at the utility-scale. NREL is currently focusing on the development of multi-cell packages (dense arrays) to improve overall performance and reliability [6].

Figure 6-3 represents the historical progress of solar cell efficiencies until 2004. As shown in the graph, experimental multi-junction concentrator-based PV cells reported the highest efficiency levels, approximately 40 percent [7].

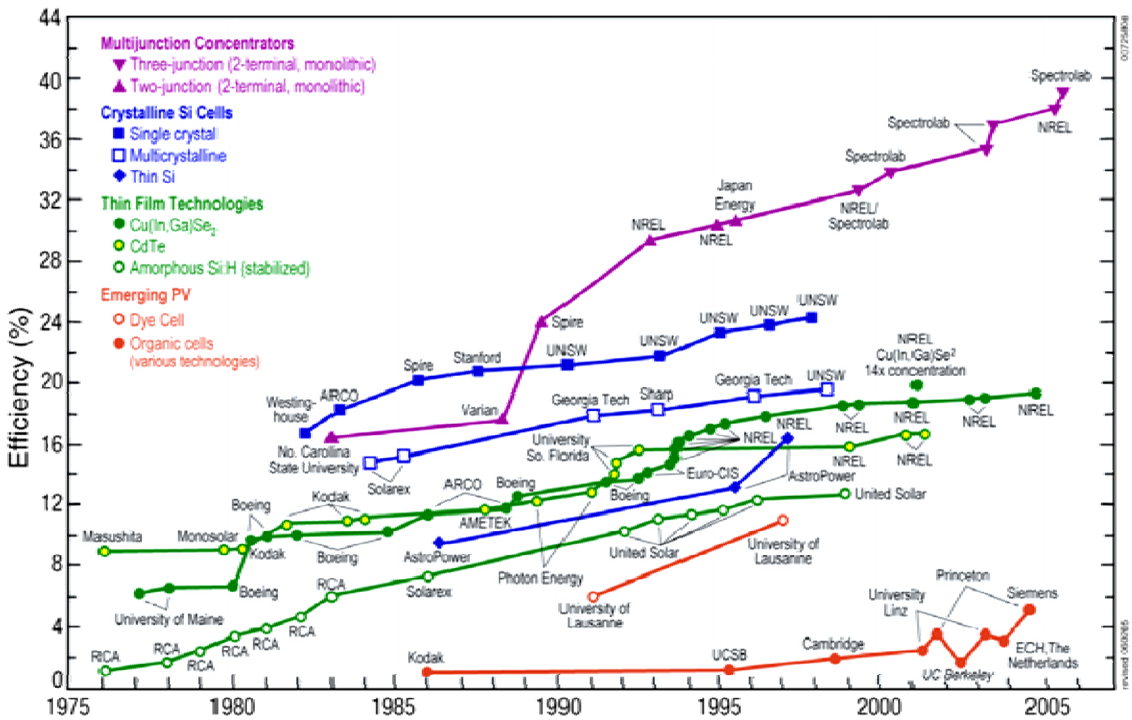


Figure 6-3: Improvements in solar cell efficiency, by system, from 1976 to 2004 (Source: DOE [7])

In addition to multi-junction CPV cells, 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 [7].

Flat-plate PV arrays, CPVs, and other types of solar PV technology are used in many different ways across America. In 1998, a study was carried out by the EIA to determine trends in the U.S. photovoltaic industry. The report divided the national PV market into several niche markets that were labeled and described as follows [8]:

- Building Integrated Photovoltaics (BIPV): These are PV arrays mounted on building roofs or facades. For residential buildings, BIPV capacities may reach 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.

The main advantages to using PV systems are:

- The conversion from sunlight to electricity is direct so no bulky mechanical generator systems are required, leading to high system reliability [1];
- Sunlight is a free and inexhaustible resource;
- There are no emissions (by-products) from PV systems;
- PV systems consume no water, unlike many other power systems;
- PV systems can be located close to the load site, reducing the need to build transmission capacity [9];
- The lack of moving parts[4] results in lower maintenance costs; and
- The modular nature of PV systems (PV arrays) allow for variable output power configurations.

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

The main disadvantages to using PV systems are:

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

Despite the intermittent nature of sunlight, PV has the added potential as a supplier of electricity during periods of peak demand, since it produces more electricity on sunny days when air conditioning loads are the greatest [9].

6.2 Economics of PV systems

The cost of a PV installation depends on the installation size and the degree to which it utilizes standard off-the-shelf components [10]. The capital costs range from $5/watt for bulk orders of standardized systems to around $11/watt for small, one-of-a-kind grid connected PV systems [2, 10].

The recent trend in PV module prices is shown in Figure 6-4 [11]. Overall photovoltaic prices have declined on average 4 percent per year over the past 15 years [12]. However, the increase in PV module prices over the last four years is due to an increase in demand, as consumers look for alternatives to expensive fossil fuels-derived energy sources. DOE believes that increasing silicon production and greater PV manufacturing capacity should lead to markedly lower prices by 2010 [13].

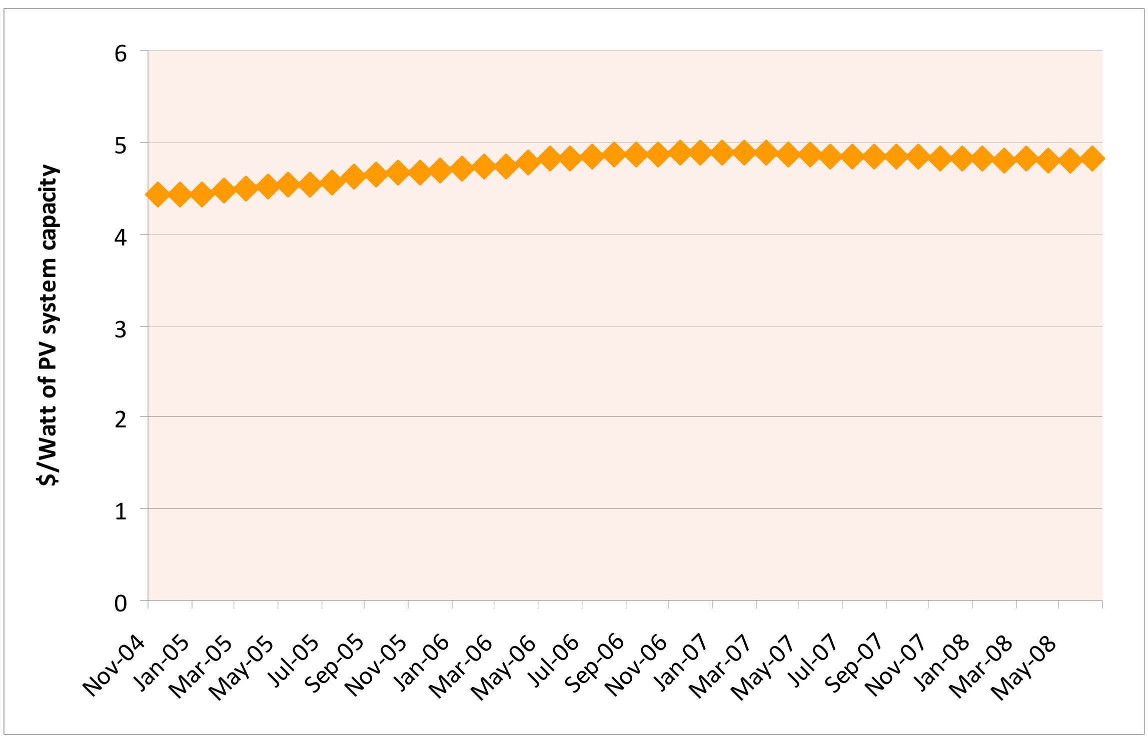
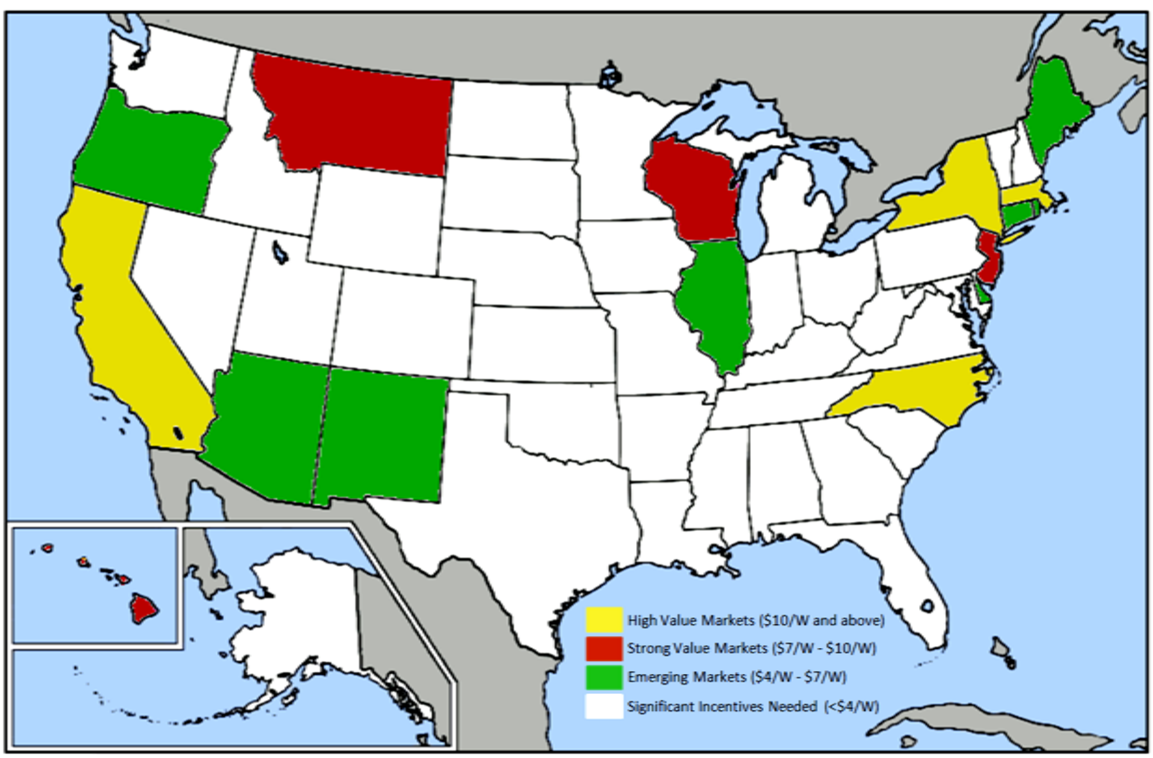


Figure 6-4: Historical PV module prices (Source: Solarbuzz [11])

O&M costs for PV systems are very low. Estimates for these costs range from about 0.5 cents/kWh to 0.63 cents/kWh [10, 14]. These low O&M costs lead to levelized PV energy costs ranging from about 20 to 50 cents/kWh [2, 10], assuming a 20-year lifespan of the PV system. At these prices, PV may be cost effective for residential customers located further than a quarter of a mile from the nearest distribution line because of the relatively high costs of distribution line construction [2].

Distributors have identified markets where photovoltaic power is cost-effective now, without subsidies. 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.

When state and utility subsidies are taken into account, however, there are parts of the country where PV panels are cost-effective. Figure 6-5 shows the breakeven turnkey costs (BTC) for commercial PV installations by state. The BTC represents the highest price of PV that will still breakeven over the lifespan of the system. States with the highest BTC values will have the most PV installations. Four states—California, Massachusetts, New York, and North Carolina—have BTC values above $10/W for PV systems, meaning that PV systems are economically viable in those areas [15].



<u>Figure 6-5:</u> <u>Breakeven turnkey costs by state</u> (Source: DSIRE [15])

Table 6-1 presents a comparison of solar electricity prices compiled by Solarbuzz LLC over an eight year time span. The residential price index is based upon a standard 2 kW peak system, roof retrofit mounted. It is assumed to be connected to the electricity grid with battery back-up. The commercial price index is based on a 50 kW 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 kW flat roof mounted solar system, suitable for large buildings. It is assumed to be connected to the electricity grid and excludes back up power [16].

cents / kWh	avg. cost electricity	cost electricity from PV system	avg. cost electricity	cost electricity from PV system	avg. cost electricity	cost electricity from PV system
	Residential		Commercial		Industrial	
2000	8.24	39.60	7.43	29.45	4.64	21.37
2001	8.59	40.79	7.92	30.17	5.05	21.86
2002	8.44	40.70	7.89	30.06	4.88	21.77
2003	8.72	39.88	8.03	29.36	5.11	21.29
2004	8.95	37.75	8.17	27.42	5.25	20.67
2005	9.45	37.36	8.67	27.01	5.73	20.97
2006	10.40	37.84	9.46	27.66	6.16	21.51
2007	10.63	37.44	9.61	27.48	6.36	21.41

Table 6-1: Solar electricity price vs. U.S. electricity price index (Source: Solarbuzz [16])

Figure 6-6 shows the so-called 80 percent learning curve: for every doubling of the total cumulative production of PV modules worldwide, the price has dropped by approximately 20 percent. DOE's projected learning curve beyond 2003 is between 70 and 90 percent.

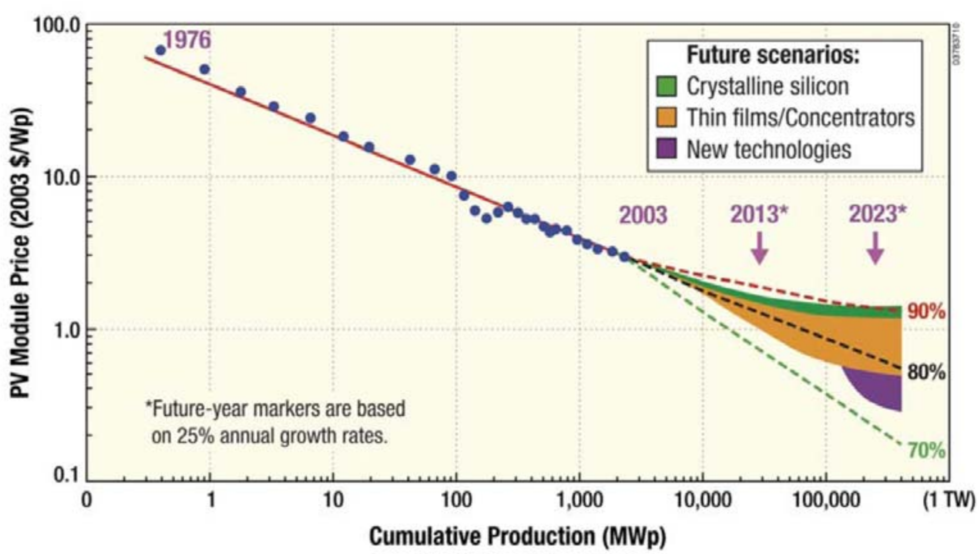


Figure 6-6: Learning curve for PV production (Source: DOE [7])

A key goal of researchers is to make PV technologies cost-competitive by increasing the conversion efficiency of PV systems. Higher efficiency directly impacts the overall electricity costs, since higher efficiency cells will produce more electrical energy per unit of cell area. Another important factor that will contribute to a reduction in capital cost is the utilization of less expensive materials when manufacturing PV systems [7].

By 2015, the goal of DOE's Solar Energy Technologies Program is to reduce the average installed cost of all grid-tied PV systems to the end user to $3.30/watt, from a median value of $6.25/W in 2000. The result will be a reduction in the average cost of electricity generated by PV systems to 9 cents/kWh [17].

6.3 State of PV systems nationally

According to the International Energy Agency (IEA), the U.S. is at the forefront of PV technology and is the world leader in thin-film PV manufacturing. The country accounted for 9 percent of worldwide PV production and 6 percent of PV installations. In 2007, solar PV companies in the U.S. recorded over $15 billion in revenue [18].

Figure 6-7 shows the solar radiation available to a flat plate collector with a fixed orientation while Figure 6-8 shows the radiation available to a concentrating collector that tracks the sun throughout the day [19]. The southwestern region of the U.S. has the highest solar resources in the country for both the flat-plate and the concentrating PV systems, while the eastern Great Lakes states have the worst solar resources.

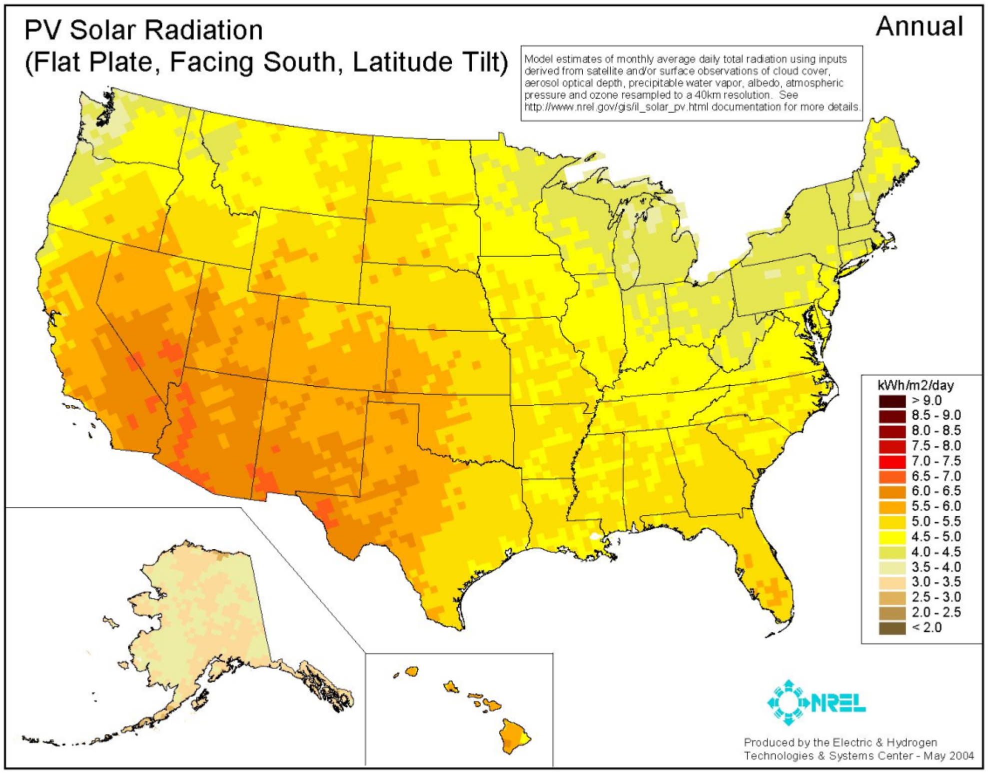


Figure 6-7: Annual average solar radiation for a flat-plate collector (Source: NREL [19])

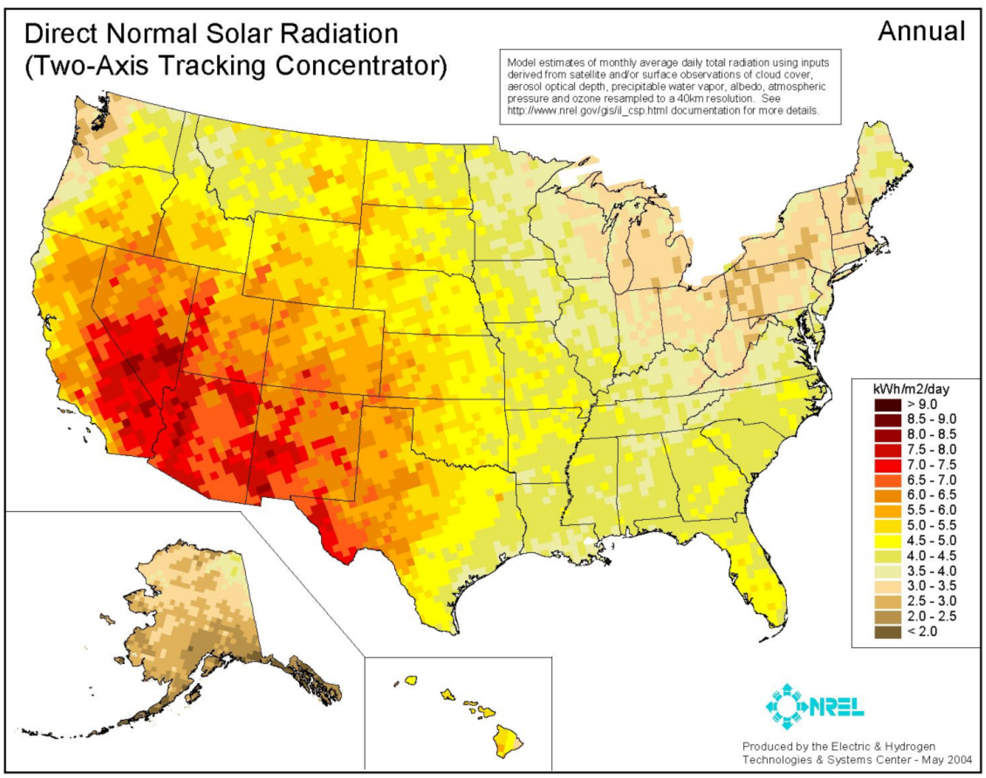


Figure 6-8: Direct normal solar radiation (two-axis solar concentrator) (Source: NREL [19])

The EIA currently tracks the shipments[5] of PV systems within the nation [20]. These domestic shipments provide an indication of the status of the PV market. Table 6-2 shows the total annual shipments, domestic shipments, imports, and exports of PV cells in the U.S.

Year	Total photovoltaic cells and modules shipment (kW)	Domestic photovoltaic cells and modules (kW)	Imported photovoltaic cells and modules (kW)	Exported photovoltaic cells and modules (kW)
1996	35,464	13,016	1,864	22,448
1997	46,354	12,561	1,853	33,793
1998	50,562	15,069	1,931	35,493
1999	76,787	21,225	4,784	55,562
2000	88,221	19,838	8,821	68,382
2001	97,666	36,310	10,204	61,356
2002	112,090	45,313	7,297	66,778
2003	109,357	48,664	9,731	60,693
2004	181,116	78,346	47,703	102,770
2005	226,916	134,465	90,981	95,451
2006	337,268	206,511	173,977	130,757
Total	1,361,801	631,318	359,146	730,483

Table 6-2: Total annual shipments, domestic shipments, imports and exports of PV cells and modules in the U.S. (Source: EIA [20])

As shown in Table 6-2, the total use of PV systems is increasing in the U.S. During 2006, domestic demand for PV systems increased significantly, by 54 percent compared to 2005, which itself had a 71 percent increase from the previous year. Imports also increased significantly from 47,703 kW in 2004 to 90,981 kW in 2005 to 173,977 kW in 2006. This increase indicates an increase in domestic demand. 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. However, an important fraction of U.S. shipments of PV cells and modules are exported – about 40 percent of the total shipments in 2006 [20]. This may be because of strong demand in countries like Germany, which offer heavy rebates for solar power.

Figure 6-9 shows the growth of installed PV installations in the U.S. over the 11 year period from 1995 to 2006 segregated by market sector as defined by the IEA. The U.S. PV installations increased by 40 percent in 2006 compared to the previous year, from 105 MW in 2005 to 145 MW in 2006. The growth came mainly from the grid-connected sector, which increased by 51 percent compared to 2005 (from 70 MW in 2005 to 106 MW in 2006) [21].

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

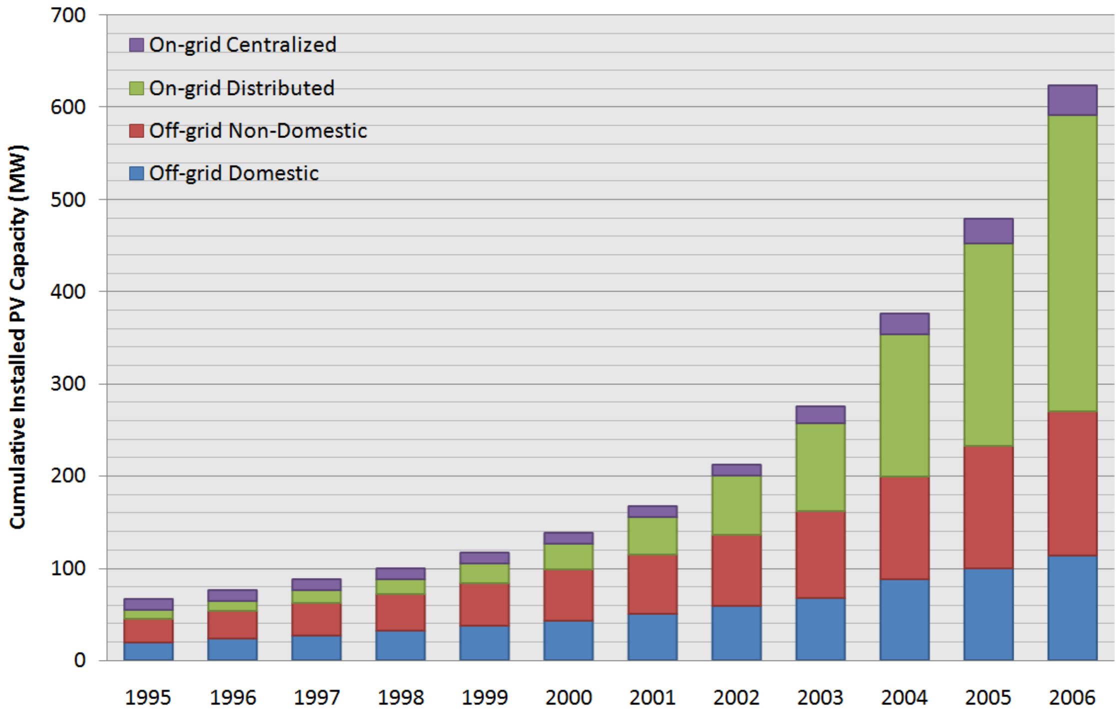


Figure 6-9: Cumulative installed PV capacity in the U.S. by sub-market (Source: IEA [21])

In 2005, grid-connected PV installations for non-residential uses were growing strongly, while residential installations remained steady at the 2004 level of 20 MW of capacity, as shown in Figure 6-10 [22].

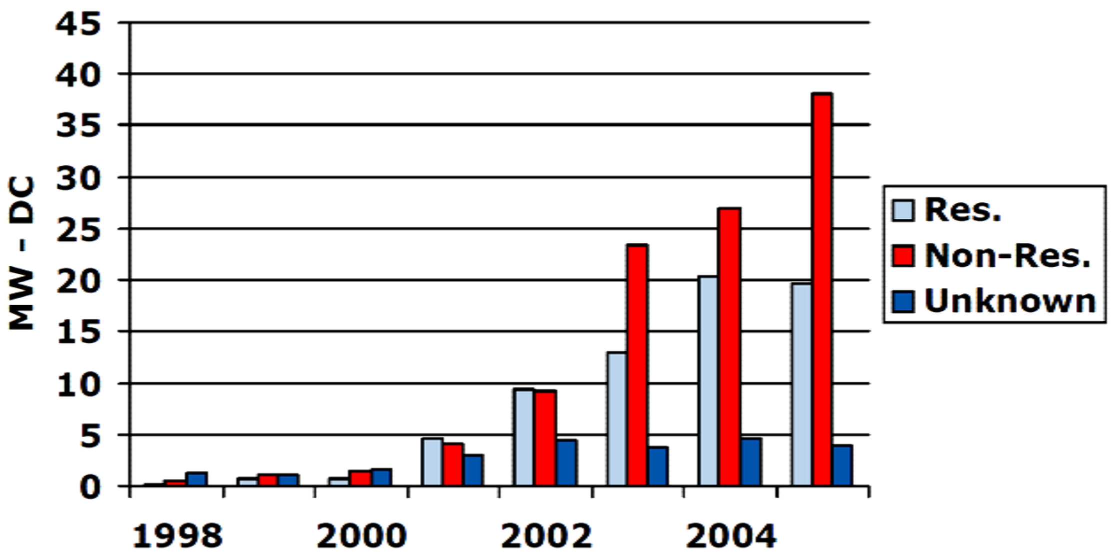


Figure 6-10: Residential and non-residential PV installation (Source: IREC [22])

Figure 6-11 details installed grid-connected PV capacity in the U.S. by state from 1997 to 2005. California leads the nation in the amount of PV capacity installed [22]. In 2007, 70 percent of all PV installations in the country were in California [18].

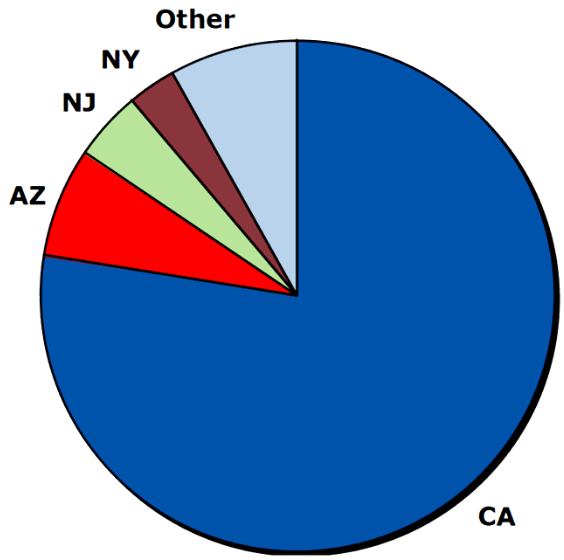


Figure 6-11: PV capacity installed from 1997 to 2005 by state (Source: IREC [22])

The solar industry released a new national PV roadmap in 2004, sketching out the industry's belief that solar power will constitute a significant portion of the country's electrical capacity by 2030. By 2020, the roadmap indicates that 36 GW of solar PV capacity will be installed in the U.S.; that by 2030, 200 GW of capacity will be installed; and that by 2025 half of all new U.S. electricity generation will come from solar power. The roadmap calls for new government investments in solar research and new subsidies for solar power [9].

In 2006, President Bush proposed a new program to reduce the cost of and increase the deployment of solar power across the U.S. This program, the Solar America Initiative (SAI), was part of the Advanced Energy Initiative that President Bush unveiled in his 2006 State of the Union address. The SAI has a budget nearly 80 percent larger than previous solar programs in the Department of Energy. The SAI is responsible for accelerating the development of advanced solar electric technologies, including PV and CPV systems. The SAI's goal is to make solar energy cost competitive with other sources of renewable electricity by 2015 [13].

Along with the launch of the SAI, the DOE decided to shut down the Million Solar Roofs program in 2006, four years ahead of schedule. The goal of the program was to prompt the installation of one million PV and solar heating systems in the country by 2010. By 2006, it had led to 377,000 new solar roof installations and 200 MW in PV capacity [23].

The SAI is currently supporting 25 projects that are researching breakthroughs for next-generation PV technology. The SAI is also supporting many companies in its "PV Incubator" and "Technology Pathway Partnership" programs to help these companies commercialize existing PV technology. Additionally, the SAI provides funding for universities which are helping to improve and commercialize PV technology [24].

In addition to pursuing research into PVs, the SAI has launched Solar America Cities, a program in which the DOE partners with 25 cities across the country to increase the deployment of solar technology. The DOE seeks to help cities develop comprehensive approaches to solar technology that facilitate mainstream adoption of solar power. The selected cities receive funding and technical support to develop a city-wide, solar implementation plan to [25]:

- Integrate solar technology into city energy planning and facilities;
- Streamline city-level regulations and practices that affect solar adoption by residents and local businesses (e.g., permitting, inspections, local codes); and
- Promote solar technology among residents and local businesses (e.g., outreach, curriculum development and implementation, incentive programs, etc.).

6.4 PV systems in Indiana

While Indiana does not have optimal 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, as shown in Table 6-3. These installations provide electricity for schools, commercial buildings, and residences.

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
	Solar	PV installation in Indiana	1.0
	Solar	Residential Installation in Indiana	3.6
Fort Wayne	Solar	Science Central	1.0
Buffalo	Solar	Residential Installation	4.0

Table 6-3: Grid-connected PV systems in Indiana (Source: DOE)

In addition, through 2007, Duke Energy Indiana has installed PV arrays on 10 schools in the state. Together, these arrays should produce 2,000 kWh of electricity annually. These schools have also received computerized performance monitoring stations so students can monitor the amount of electricity as it is generated as well as weather conditions affecting power production.   Duke Energy plans to install PV arrays on five more Indiana schools by 2009. The ten schools currently participating in the program are [26]:

- Batesville Middle School – Batesville
- Carmel High School – Carmel
- Clay City Junior/Senior High School – Clay City
- Doe Middle School – New Palestine
- Greenwood Middle School – Greenwood
- New Albany High School – New Albany
- North Manchester High School – Manchester
- Rushville High School – Rushville
- Wabash High School – Wabash
- West Lafayette High School – West Lafayette

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 [27]. In addition, Duke Energy has installed an 8 kW system at its Bloomington office and a 2 kW system at its Kokomo office [28].

The remote locations of farming residences in the state of Indiana make PV energy more attractive. The high installation costs are offset by little or no operating costs, since there is no fuel required[6] and there are no moving parts. Energy from PV systems currently ranges from 20 cents/kWh to 50 cents/kWh [2]. Although this is high for grid connected consumers, it may be acceptable for remote consumers and applications where grid connection is too expensive or where diesel generators are too expensive and unreliable.

The relatively low solar resource (Figures 6-7 and 6-8) in Indiana combined with the availability of low cost energy from coal results in a very low breakeven cost of PV technology (see Figure 6-5). An NREL study indicates that Indiana is ranked 21st in the nation in terms of breakeven cost, and the breakeven cost in the state is currently too low to be economically viable for most situations [15].

The forecast cost of PV systems is $4.65 – 4.87/W by 2010 [9] but this is still above the breakeven cost of entry of PV systems within Indiana.

[6] Besides the energy from the sun.

6.5 Incentives for photovoltaic cells

Federal Incentives

- Business Energy Tax Credit: The Energy Policy Act 2005 provides a 30 percent tax credit for business investment in solar energy systems installed before December 31, 2008. In 2009, the tax credit will revert to 10 percent [29].
- Clean Renewable Energy Bonds (CREBs): This program, authorized by the Energy Policy Act of 2005, makes available a total of $1.2 billion in 0 percent interest bonds for non-profit organizations, public utilities, and state and local governments to pursue renewable energy projects. The program has currently not been extended past 2008 and is set to close at the end of the year. In February, 312 projects were announced that would receive CREBs funding [29].
- Conservation Security Program: For 2008, the Conservation Security Program offers a $200 payment for each renewable energy generation system installed on an eligible farm [30, 31]. The Food, Conservation, and Energy Act of 2008 reincorporates the program as the "Conservation Stewardship Program" in 2009 and increases funding in the program by $1.1 billion [32].
- Energy Efficiency Mortgage: These mortgages can be used by homeowners to finance a variety of energy efficiency measures, including renewable energy technologies, in a new or existing home. The federal government supports these loans by insuring them through FHA or VA programs. This allows borrowers who might otherwise be denied loans to pursue energy efficient improvements, and it secures lenders against loan default and provides them with confidence in lending to customers whom they would usually deny [29].
- 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 fifty 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 Economic Stimulus Act of 2008 extended an additional 50 percent deduction off the adjusted basis for certain renewable energy systems purchased and installed in 2008 [29].
- Qualified Green Building and Sustainable Design Project Bonds: The American Jobs Creation Act of 2004 authorized $2 billion in tax-exempt bond financing for green buildings, brownfield redevelopment, and sustainable design projects. These bonds are only issued for projects that are at least 75 percent LEED compliant, receive at least $5 million in funding from state or local government, and include one million square feet of construction. 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 program currently expires on December 31, 2009 [33, 34].

- Renewable Energy Production Incentive (REPI): This program provides financial incentive payments for electricity produced and sold by new qualifying renewable energy generation facilities. Initially, 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 years of production, subject to the availability of annual appropriations in each federal fiscal year of operation. The Energy Policy Act of 2005 expanded the list of eligible technologies and facilities owners, as well as reauthorizing the program through the year 2026. The REPI is available only to non-profit groups, public utilities, or state governments [29].
- 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" [29].
- Rural Energy for America Program (REAP): The Food, Conservation, and Energy Act of 2008 converted the USDA Renewable Energy Systems and Energy Efficiency Improvements Program into the Rural Energy for America Program (REAP). Solar facilities are eligible for grants for up to 25 percent of the cost of the system and loans for another 50 percent of the cost [29].
- Value-Added Producer Grant Program: The application period for year 2008 closed on March 31, 2008. Funding decisions are scheduled to be made by August 31, 2008. In 2008, a total of $18.4 million in grants is available 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 2006 supported energy generated on-farm through the use of agricultural commodities, wind power, water power, or solar power. The maximum award per grant was $300,000. Matching funds of at least 50 percent were required [35].

Indiana Incentives

- Alternative Power and Energy Grant Program: This program offers grants of up to $25,000 to Indiana public, non-profit, and business sectors for the purchase of alternative energy systems, including solar hot water and photovoltaic systems [36].
- Emissions Credits: Electricity generators that do not emit NO_x and that displace utility generation are eligible to receive NO_x emissions credits under the Indiana Clean Energy Credit Program. These credits can be sold on the national market [37].

- Energy Project Feasibility Study Program: This grant program offers cost share grants to public, non-profit, or business groups in Indiana to explore the feasibility of renewable energy [38].
- Net Metering Rule: Solar, wind and hydroelectric facilities with a maximum capacity of 10 kW are qualified for net metering in Indiana. The net excess generation is credited to the customer in the next billing cycle [36].
- Solar Access Laws: Indiana state law includes both covenant restrictions and solar-easement provisions. The state's covenant restrictions prevent planning and zoning authorities from prohibiting or unreasonably restricting the use of solar energy. Indiana's solar-easement provisions do not create an automatic right to sunlight, though they allow parties to voluntarily enter into solar-easement contracts which are enforceable by law [36].

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7. Fuel Cells

7.1 Introduction

A fuel cell is an electrochemical device that silently produces direct current electrical power without combustion [1]. One way to think about fuel cells is to imagine a battery that never "runs down" or requires charging, but will produce energy as long as fuel is supplied [2]. The basic fuel cell consists of two electrodes (the anode and the cathode) encompassing an electrolyte, illustrated in the polymer electrolyte membrane (PEM) fuel cell in Figure 7-1.

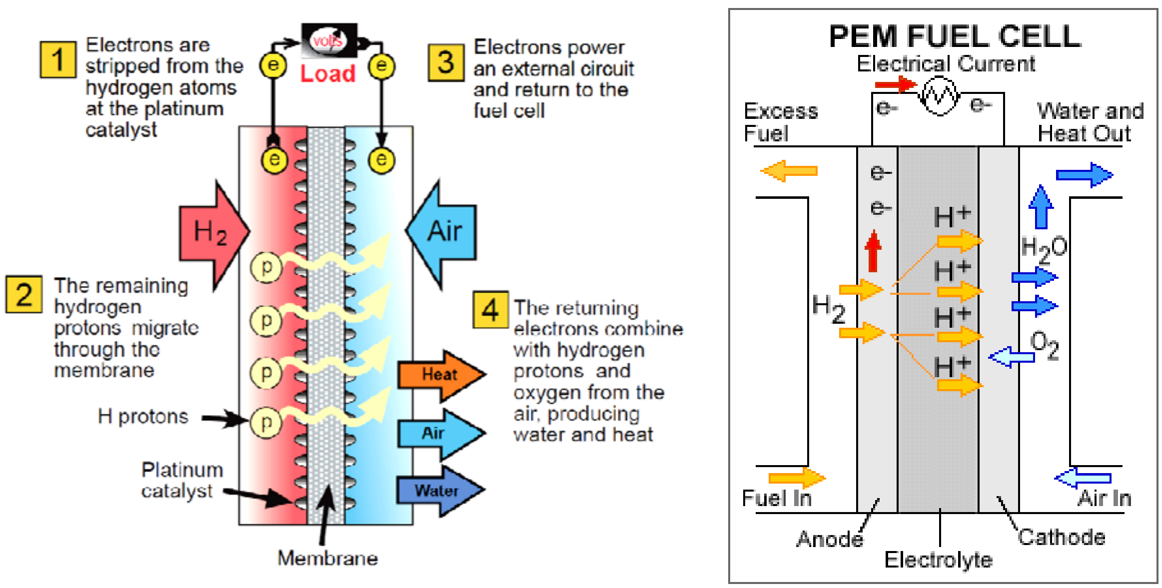

Figure 7-1: Schematic of basic fuel cell operation (Source: EERE [1, 3])

Hydrogen (H_2) is fed into the anode, and oxygen (or air) enters the fuel cell through the cathode. At the anode, the hydrogen molecule splits into separate atoms, and each atom releases an electron (e^-) with the aid of a catalyst. The remaining protons (H^+) pass through the electrolyte towards the cathode, whereas the electron flows through an external electric circuit (thereby producing electric current). The protons, electrons, and oxygen are rejoined at the cathode to produce water as the exhaust [2].

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 type of hydrogen input 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 [4].

- 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. However, the costs associated with the catalyst required by PEMFCs, as well as the space required for hydrogen storage, prevent the use of these fuel cells in vehicles.
- Direct Methanol Fuel Cells (DMFCs): These fuels cells are a subset of PEMFCs typically used for small portable power applications, with a size range of about less than one watt to 100W and operating at 60 - 90° C [6]. These cells are powered by pure methanol (CH_3OH), which is mixed with steam and 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 energy density than hydrogen. Moreover, methanol is liquid at room temperature, obviating the need for the special storage technology required for hydrogen. However, this technology is relatively new and research is still being conducted on its efficacy and economic viability. DMFCs may be used to power consumer electronics, such as cell phones and laptops.
- Alkaline Fuel Cells (AFCs): These fuel cells use a solution of potassium hydroxide in 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 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 the electrolyte, porous carbon as electrodes, and a platinum catalyst. PAFCs are one of the most mature cell types and were 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 heat, but only 37-42 percent efficient at generating electricity alone.
- 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. With cogeneration, overall fuel use efficiencies could surpass 80-85 percent. SOFCs operate at temperatures of approximately 1,000°C, which can result in slow startups and requires 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 that 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 cogeneration 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[7] [5].

There are five main attractive features of fuel cell technology [5]:

- 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), resulting in less noise and less maintenance than conventional generation technologies (turbine-generator sets); and
- More flexibility than batteries—doubling the operating time only requires the doubling of the amount of fuel, not the capacity of the unit.

Cost and durability are the major challenges to fuel cell commercialization. Other barriers to commercialization include size, weight, and thermal and water management. However, hurdles vary according to the application in which the technology is employed. In transportation applications, these technologies face more stringent cost and durability hurdles [7].

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

	Polymer Electrolyte Membrane	**Alkaline**	**Phosphoric Acid**	**Molten Carbonate**	**Solid Oxide**
Acronyms	PEM/PEFC/PEMFC	AFC	PAFC	MCFC	SOFC
Electrolyte	Solid organic polymer polyperfluoro-sulfonic acid	Aqueous solution of potassium hydroxide soaked in a matrix	Liquid phosphoric acid soaked in a matrix	Liquid solution of lithium, sodium, and/or potassium carbonates, soaked in a matrix	Yttria stablized zirconia
Operating Temperature	50 - 100°C	90 - 100°C	150 - 200°C	600 - 700°C	650 - 1000°C
System Output	1 – 250 kW	10 – 100 kW	50 kW – 1 MW	1 kW – 1 MW	5 kW – 3 MW
Efficiency	Transportation: 53 – 58% Stationary: 25 – 35%	60%	32 - 38%	45 – 47%	35 – 43%
Applications	Backup power, portable power, small distributed generation, transportation	Military, space	Distributed generation	Electric utility, large distributed generation	Auxiliary power, electric utility, large distributed generation
Advantages	Solid electrolyte reduces corrosion and management problems, low temperature, and quick startup	Cathode reaction faster in alkaline electrolyte so high performance	High efficiency in cogeneration of electricity and heat, can use impure H_2 as fuel	High efficiency, fuel flexibility, can use a variety of catalysts, suitable for cogeneration	High efficiency, fuel flexibility, can use a variety of catalysts, solid electrolyte reduces corrosion and management problems, suitable for cogeneration, hybrid/GT cycle
Disadvantages	Low temperature requires expensive catalysts, high sensitivity to fuel impurities, not suitable for cogeneration	Expensive removal of CO_2 from fuel and air streams required	Requires expensive platinum catalyst, low current and power, large size/weight	High temperature enhances corrosion and breakdown of cell components, complex electrolyte management, slow startup	High temperature enhances corrosion and breakdown of cell components, slow startup, brittleness of ceramic electrolyte with thermal cycling

Table 7-1: Comparison of fuel cell technologies (Source: EERE [6])

Although fuel cells run on hydrogen, the most plentiful gas in the universe, hydrogen is never found alone in nature[8]. Therefore, efficient methods of extracting hydrogen in large quantities are required. There are several methods being currently pursued by DOE to produce hydrogen at an economically competitive price [9]:

- Natural Gas Reforming: Hydrogen can be produced from methane in natural gas using high-temperature steam. This process, called steam methane reforming, accounts for about 95 percent of the hydrogen used today in the U.S.
- Renewable Electrolysis: Electrolysis uses an electric current to split water into hydrogen and oxygen. The electricity required can be generated using renewable energy technologies, such as wind, solar, geothermal, and hydroelectric power.
- Gasification: Gasification is a process in which coal or biomass is converted into gaseous components by applying heat under pressure and in the presence of steam. A subsequent series of chemical reactions produces a synthesis gas, which is reacted with steam to produce hydrogen that then can be separated and purified. Producing hydrogen directly from coal by gasification and reforming is much more efficient than burning coal to make electricity that is then used to make hydrogen. Moreover, because biomass resources consume CO_2 in the atmosphere as part of their natural growth process, producing hydrogen through biomass gasification releases near-zero net greenhouse gases.
- Renewable Liquid Reforming: Biomass can be processed to make renewable liquid fuels, such as ethanol or bio-oil, that are relatively convenient to transport. These renewable liquid fuels can be reacted with high-temperature steam to produce hydrogen at or near the point of end-use.
- High-Temperature Thermochemical Water Splitting: This method uses high temperatures generated by solar concentrators or nuclear reactors to drive a series of chemical reactions that split water. All of the chemicals used are recycled within the process.
- Photobiological and Photoelectrochemical: When certain microbes, such as green algae and cyanobacteria, consume water in the presence of sunlight, they produce hydrogen as a byproduct of their natural metabolic processes. Similarly, photoelectrochemical systems produce hydrogen from water using special semiconductors and energy from sunlight.

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 are not yet available [5].

[8] H_2 gas is light enough that it will escape Earth's atmosphere and exit into space [8].

Fuel cells can have a variety of applications as shown in Figure 7-2 [10]. One of the primary uses of fuel cells is to power transportation vehicles. The organization Fuel Cells 2000 estimates that commercial production of fuel cell vehicles may commence by 2012. To date, more than 50 fuel cell powered buses have been successfully demonstrated. One of the promising uses of fuel cells is as “auxiliary power units” in heavy-duty trucks. These trucks often include features like air-conditioning, refrigerators, and microwaves that make life on the road more comfortable for the truck driver. By powering these features with fuel cells instead of diesel, the production of harmful pollutants could be reduced [11].

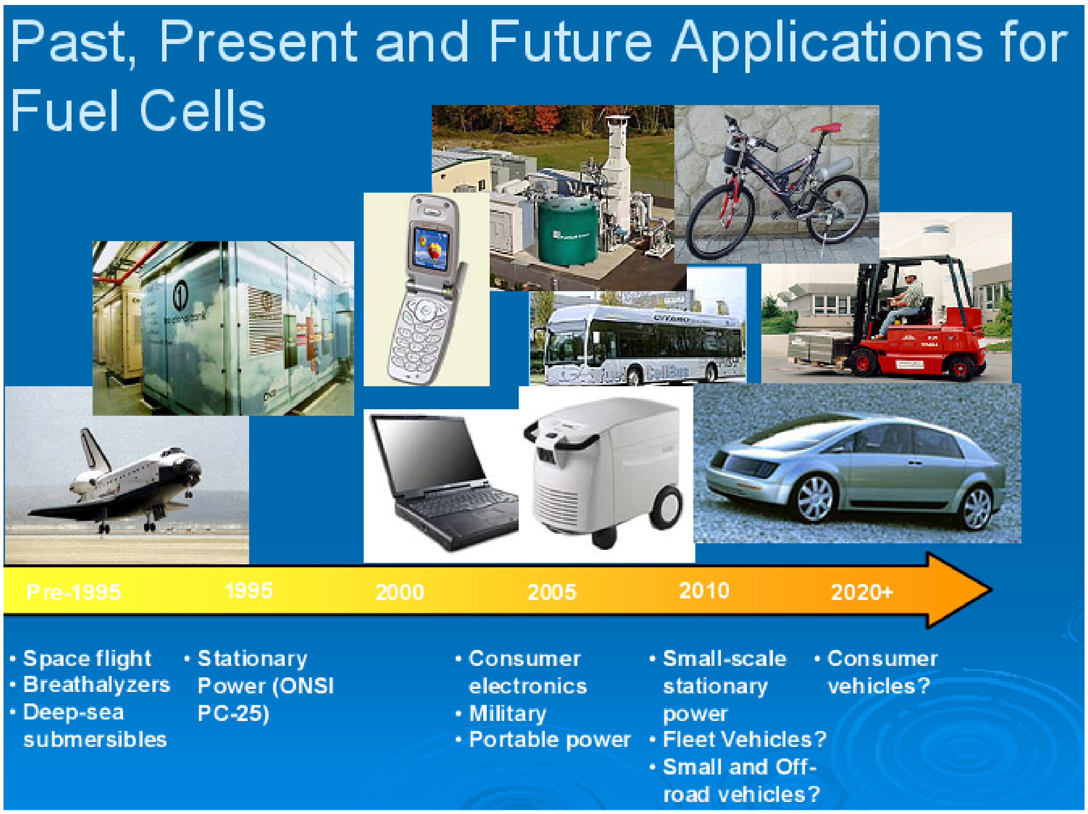

Figure 7-2: Fuel cells applications (Source: www.fuelcells.org [10])

In addition to transportation, fuel cells can also be used to provide power to buildings and remote locations. Fuel cells have many benefits for such stationary applications, such as reliable power supply, consistent voltage output, modularity and the ability to scale-up, and waste heat that can be used for heating or cooling. The first commercially available fuel cell power plants, produced by UTC Fuel Cells, create less than 20 grams of pollutants per MWh, compared to over 11,388 grams per MWh for an average U.S. fossil-fueled plant [12]. More than 409 stationary fuel cell systems have been deployed or planned in the U.S. as of 2008 [13].

For many stationary applications today, a ready supply of hydrogen is not available. Thus, most current stationary fuel cell systems include a hydrogen fuel reformer. These reformers allow the extraction of hydrogen from a hydrogen-rich fuel, e.g., natural gas or propane, while removing excess CO and CO_2 that may poison the fuel cell. Other parts of a stationary fuel cell system include [1]:

- Thermal and Water Management System: This system maintains optimal operating temperature and removes the excess produced water;
- Fuel Cell Stack: This system converts the hydrogen and oxygen from air into electricity, water vapor and heat; and
- Power Conditioner: This system converts direct current from the fuel cell to alternating current for use by residential appliances.

Fuel cells have also been deployed at landfills, wastewater treatment plants, and breweries. The hydrogen for these fuel cells is extracted from the methane gas produced at these facilities. The Northeast Regional Biomass program completed a study on the feasibility of using bio-based fuels with stationary fuel cell technologies, and concluded that this is technically feasible for providing a source of clean, renewable electricity over the long-term [14].

7.2 Economics of fuel cells

Currently available stationary PAFC units cost around $2,500/kW, as calculated for United Technology's PureCell Model 400 fuel cell. These units are only produced in 400 kW sizes that are suitable for larger power applications. The long-term cost of electricity produced from natural gas by the Model 400 fuel cell will be roughly 12 cents/kWh, which is competitive with the cost of electricity in many parts of the country. Because fuel cells use natural gas more efficiently than conventional combustion generators, UTC Power's fuel cells produce only half the carbon dioxide of traditional natural gas generation [15]. According to the DOE, the price of stationary fuel cells needs to fall to the $400/kW to $750/kW range in order to be commercially viable [16].

Unlike stationary fuel cells, which are economically viable in certain situations, the cost of fuel cells for transportation purposes remains prohibitively high. Honda released its first commercial fuel cell vehicle, the FCX Clarity, this past June. Though the car is being leased for $600/month, each vehicle costs $950,000 to manufacture. Honda estimates that the cost of fuel cell powered cars will drop to below $100,000 in less than 10 years [17]. The Honda fuel cell system currently costs more than $6,000/kW to manufacture, while the DOE estimates that the cost of manufacturing fuel cells for vehicles needs to drop to $30/kW to become economically viable with internal combustion engines [18].

Hydrogen has potential benefits for U.S. energy security, environmental quality, energy efficiency, and economic competitiveness. While hydrogen can now be produced from natural gas at a price similar to that of gasoline [10], barriers still remain to producing hydrogen cheaply from renewable resources. The DOE is spearheading research to lower the cost of hydrogen production, as discussed in Section 7.1 [19]. Figure 7-3 illustrates the potential of producing hydrogen from renewable resources in the U.S. Another barrier to using hydrogen as a fuel source is the lack of hydrogen infrastructure, such as hydrogen pipelines and hydrogen fueling stations [20].

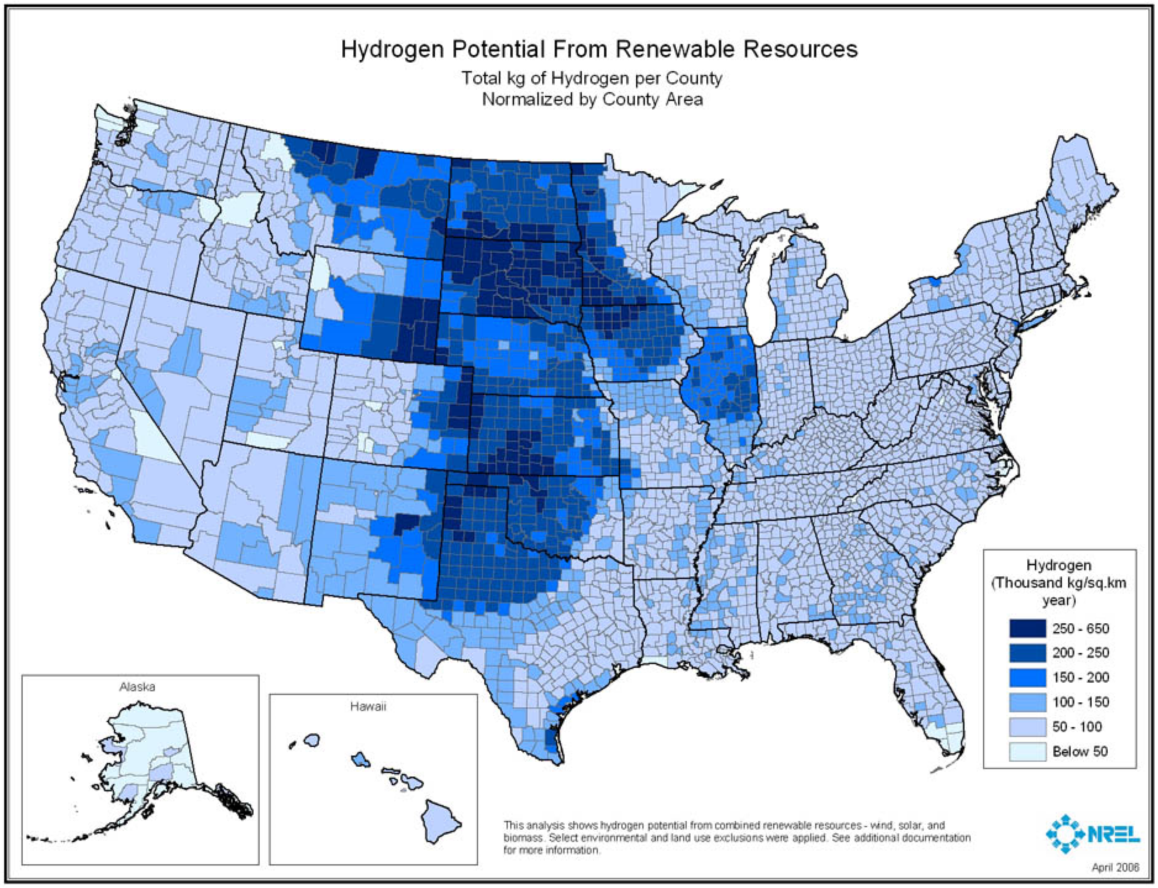

Figure 7-3: Potential for hydrogen production in the U.S. (Source: NREL [21])

7.3 State of fuel cells nationally

Fuel cells are currently in service at over 150 landfills and wastewater treatment plants in the U.S. A few of these projects include [22]:

- Groton Landfill (Connecticut): Installed a fuel cell in 1996. This plant produces about 600,000 kWh of electricity per year.
- Yonkers Wastewater Treatment Plant (New York): Installed a fuel cell in 1997 and produces over 1.6 million kWh/year.

- City of Portland (Oregon): Installed a 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.

Several of the hundreds of stationary fuel cell systems deployed in the country include [13]:

- U.S. Postal Service (Anchorage, Alaska): Installed a 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. The system was the largest commercial fuel cell system in the nation when constructed in 2000 and was the first time a fuel cell system was part of an electric utility's grid.
- South Windsor High School (Connecticut): Installed a natural gas powered 200 kW fuel cell system in 2002. A comprehensive fuel-cell curriculum has been developed for high school students, providing learning opportunities for students in programs that include earth sciences, chemistry/physics, and general studies.
- Freedom Tower (New York City): The design of the new Freedom Tower, to be built in New York City over the next few years, calls for the use of fuel cells. Twelve 400-kW fuel cell systems have been ordered, which will produce 4.8MW of electricity from natural gas and will also cogenerate hot water. The cost of the 12 fuel cell systems is estimated at $10.6 million.

Other projects at various levels of development include [23]:

- Adaptive Materials Provides SOFC System to AeroVironment Unmanned Aerial Vehicle: Adaptive Materials's solid oxide fuel cell (SOFC) systems recently powered AeroVironment's PUMA unmanned aerial vehicle on a test flight. Adaptive Materials's fuel cell system provided enough power for a test flight lasting more than seven hours as well as for two surveillance cameras on the unmanned aerial vehicle.
- Delphi and Peterbilt Successfully Demonstrate SOFC Auxiliary Power Unit: Delphi Corporation and Peterbilt Motors Company successfully demonstrated a Delphi solid oxide fuel cell (SOFC) auxiliary power unit powering a Peterbilt Model 386 truck's "hotel" loads. The Delphi SOFC provided power for the Model 386's electrical system and air conditioning and maintained the truck's batteries—all while the Model 386's diesel engine was turned off.
- SFR Installs IdaTech Fuel Cell in Corsica: SFR, a leading French mobile phone service provider, has installed an IdaTech 48VDC ElectraGen 5 XTR fuel cell system using liquid methanol as a backup power source at one of its remote base stations in Pigna Corbino, Corsica.
- PolyFuel Develops Notebook Prototype: PolyFuel has developed the first functional version of its prototype power supply for notebook computers that can provide continuous performance with the simple replacement of small cartridges of methanol

fuel. The consumer-friendly design has been fully integrated with a representative notebook, the Lenovo T40 ThinkPad.

As stated in Section 7.2, the commercial use of stationary fuel cells is currently limited to larger power applications. Smaller residential-type fuel cells are being researched, and commercial production of these units is expected soon [5]. In 2004, the NREL conducted a demonstration study to understand the economics of residential fuel supply systems. The report found that fuel cells are feasible as primary or backup power supply, especially for homes that are located more than a mile from utility lines. Cogenerating hot water with the fuel cell can satisfy 40-60 percent of hot water needs [24].

To promote the commercialization of fuel cells for power generation, *Fuel Cells and Hydrogen: The Path Forward* recommended that Congress should enact a tax incentive program that 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 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 [25].

In 2008, the National Research Council released a report, *Transition to Alternative Transportation Technologies: A Focus on Hydrogen*, which catalogued research conducted by the National Academies regarding the future of hydrogen and fuel cells for transportation. The report indicated that the best case scenario would be that 2 million vehicles (out of 280 million vehicles) would be powered by fuel cells by 2020. Not until 2023 would fuel cell cars be made and sold profitably by automakers, and only if the government were to invest a total of $55 billion in research and other incentives for automakers over 15 years. By 2030, 25 million vehicles would be powered by fuel cells, and nearly all cars would have fuel cells by 2050 [26].

Currently the 15 states shown in Figure 7-4 and Washington D.C allow for the use of hydrogen/fuel cells in meeting their renewable portfolio standards. The states of Washington, Oregon, California, Idaho, New Mexico, Iowa, Michigan, New York, Maryland, Massachusetts, Delaware, and Montana provide tax incentives or rebates for power generation from stationary fuel cells [27].

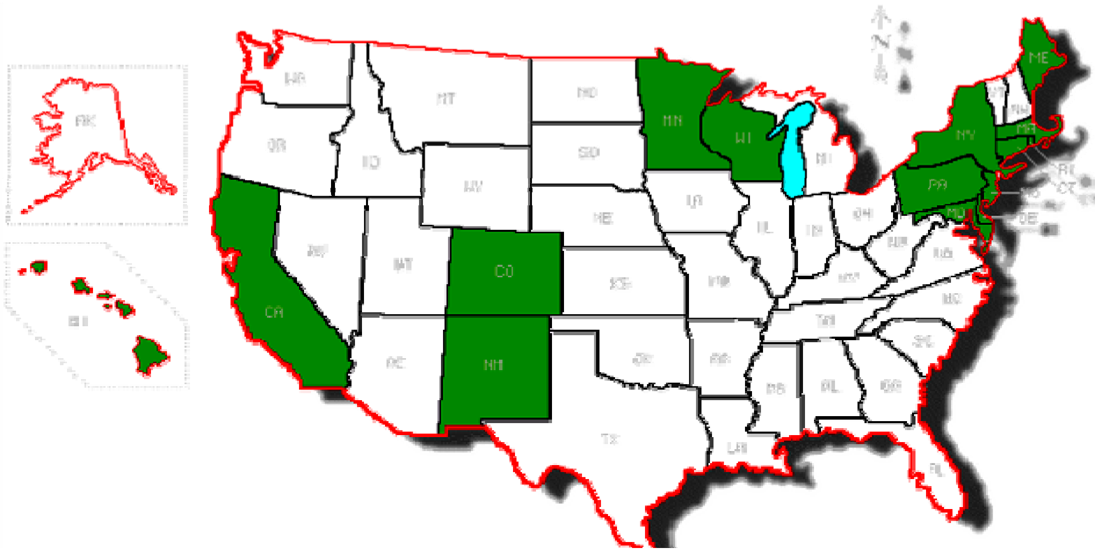

Figure 7-4: Renewable portfolio standards that include H_2/fuel cells (Source: www.fuelcells.org)

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 U.S. Navy installed a PEM-powered refueler at Crane [13].

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 [13].

A fuel cell installation is also listed in the *Fuel Cells 2000* database [13] for a residence in Chesterton, Indiana. According to this source, the installation was put in place in the year 2000 with a total capacity between 1kW and 5kW. The project was developed in a partnership involving NiSource, Gas Technology Institute and Ishikawajima-Harima Heavy Industries.

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 [5]. Once this occurs, there is expected to be an increase in the number of fuel cell installations in Midwestern states (although the expected numbers are small) [5]. 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 2006, Indiana had the 10th cheapest average retail electricity prices in the nation [28]. The low cost of electricity in Indiana might provide a barrier to entry for emerging fuel cell technologies and other renewable sources.

Commercial production of fuel cells should lead to reductions in unit costs, thus making stationary fuel cell systems more competitive for both on- and off-grid applications. 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 account for the true promise of small-scale distributed fuel cell systems [5].

Current stationary fuel cells would use existing natural gas supplies for fuel [5]. Figure 7-5 shows the average annual residential price of natural gas in the nation and within Indiana [29]. The cost of natural gas within Indiana is slightly below the national average but not enough so as to give Indiana a significant advantage in terms of costs.

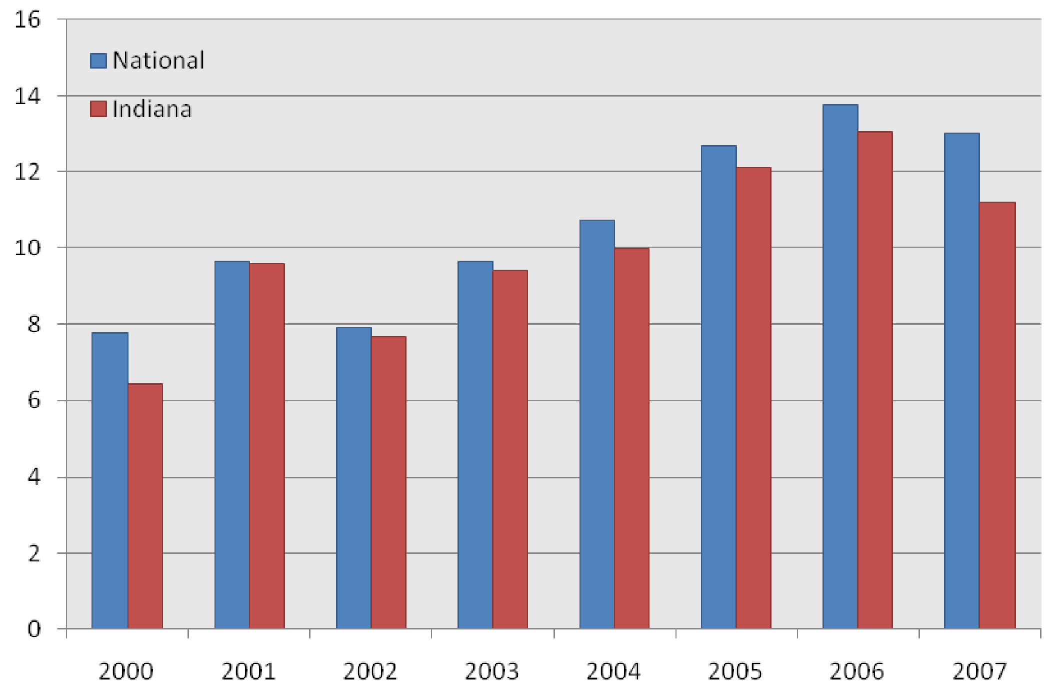

Figure 7-5: Residential natural gas prices in dollars per thousand cubic feet (Data source: EIA [29])

Certain farms within Indiana where biogas supplies are available (e.g., dairies) might benefit from the reduced costs of fuel cells in the future. Biogas could be used to supply hydrogen to fuel cells, 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 also could utilize the methane produced to supply hydrogen to the fuel cell.

Government incentives and programs are seen as critical in terms of commercializing the use of fuel cells in stationary power applications, particularly when commercial availability is still in its infancy [25].

The Hydrogen Fuel Initiative was launched by President George W. Bush in 2003 to pursue the promise of hydrogen. The initiative requires DOE to invest $1.7 billion over five years in research and development of advanced hybrid vehicle components, fuel cells, and hydrogen infrastructure technologies [30]. DOE has also pursued the FreedomCAR and Fuel Initiative, a fuel cell program designed to reduce the cost of the hydrogen fuel cell car. The DOE is working with partners to help improve fuel cell technology for transportation [31].

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 and efficiency of the units, and the government (federal and state) incentives in commercializing this technology, and the price of electricity and natural gas.

7.5 Incentives for fuel cells

Federal Incentives

- Business Energy Tax Credit: The Energy Policy Act 2005 provides a 30 percent tax credit for business investment in alternative energy systems installed before December 31, 2008. In 2009, the tax credit will revert to 10 percent [32].
- Conservation Security Program: For 2008, the Conservation Security Program offers a $200 payment for each alternative energy generation system installed on an eligible farm [33, 34]. The Food, Conservation, and Energy Act of 2008 reincorporates the program as the "Conservation Stewardship Program" in 2009 and increases funding in the program by $1.1 billion [35].
- Modified Accelerated Cost-Recovery System (MACRS): Under this program, businesses can recover investments in alternative energy systems through depreciation deductions. The MACRS establishes a set of class lives for various types of property, ranging from three to fifty years, over which the property may be depreciated. The Economic Stimulus Act of 2008 extended an additional 50 percent

deduction off the adjusted basis for certain alternative energy systems purchased and installed in 2008 [32].

- Qualified Green Building and Sustainable Design Project Bonds: The American Jobs Creation Act of 2004 authorized $2 billion in tax-exempt bond financing for green buildings, brownfield redevelopment, and sustainable design projects. These bonds are only issued for projects that are at least 75 percent LEED compliant, receive at least $5 million in funding from state or local government, and include one million square feet of construction. 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 program currently expires on December 31, 2009 [36, 37].
- Renewable Energy Production Incentive (REPI): This program provides financial incentive payments for electricity produced and sold by new qualifying alternative energy systems. Initially, 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 years of production, subject to the availability of annual appropriations in each federal fiscal year of operation. The Energy Policy Act of 2005 expanded the list of eligible technologies and facilities owners and reauthorized the program through 2026. The REPI is available only to non-profit groups, public utilities, or state governments [32].
- Rural Energy for America Program (REAP): The Food, Conservation, and Energy Act of 2008 converted the USDA Renewable Energy Systems and Energy Efficiency Improvements Program into the Rural Energy for America Program (REAP). Fuel cell systems that run on renewably-produced hydrogen are eligible for grants for up to 25 percent of the cost of the system and loans for another 50 percent of the cost [32].

Indiana Incentives

- Emissions Credits: Electricity generators that do not emit NO_x and that displace utility generation are eligible to receive NO_x emissions credits under the Indiana Clean Energy Credit Program. These credits can be sold on the national market [38].
- Energy Project Feasibility Study Program: This grant program offers cost share grants to public, non-profit, or business groups in Indiana to explore the feasibility of alternative energy [39].

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8. Hydropower from Existing Dams

8.1 Introduction

Hydroelectric energy is produced by converting the kinetic energy of falling water into 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, including [2]:

- Impoundment hydropower: This facility uses a dam to store 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 shows a schematic of this type of facility.
- Pumped storage: When electricity demand is low, excess electricity is used to pump water from a lower reservoir to an upper reservoir. 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 of the river and requires little to no impoundment. Run-of-river plants can be designed for large flow rates with low head[9] or small flow rates with high head.
- Microhydro projects: These facilities are small in size (about 100 kW 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.

In addition, there are a variety of turbine technologies that are utilized for hydropower production. The type of turbine is chosen based on its 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 a number of fixed vanes (usually nine). 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.

[9] Head is the elevation difference between the water level above the turbine and the turbine itself.

- 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 MW.

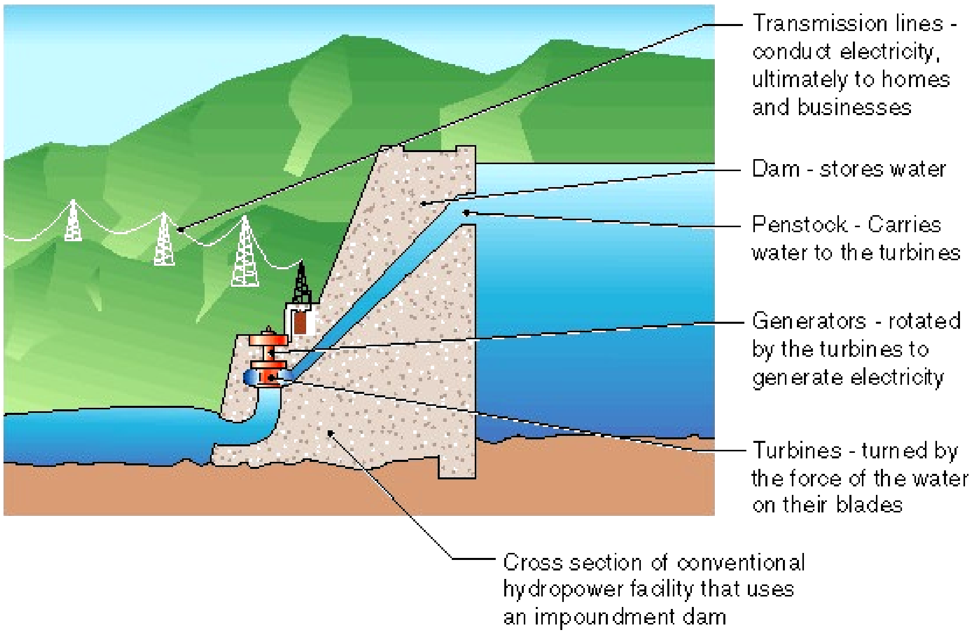

Figure 8-1: Schematic of impoundment hydropower facility (Source: INEL [2])

Hydropower is a renewable resource that has many benefits, including [5]:

- Hydropower is a domestic energy resource and does not require the transportation of fuels;
- Current hydropower turbines are capable of converting 90 percent of available energy to electricity. This is more efficient than any other form of generation;
- Hydroelectric facilities have quick startup and shutdown times, making them an operationally flexible asset. This characteristic is desirable in competitive and fluctuating electricity markets; and
- Hydropower produces negligible air emissions.

Hydropower facilities also provide recreational opportunities for the community such as fishing, swimming, and boating in its reservoirs. Other benefits may include water supply and flood control [6]. Electricity production is the primary function of only two percent of all U.S. dams, as shown in Figure 8-2 [7].

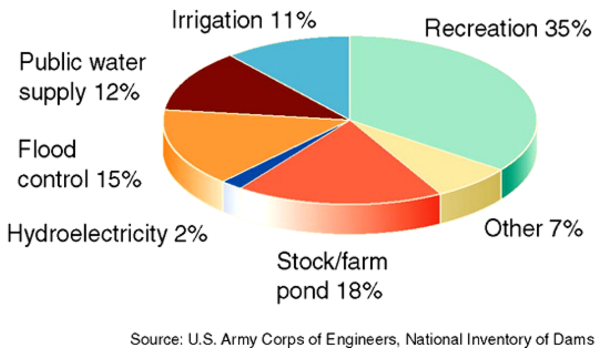

Figure 8-2: Primary function of U.S. dams (Source: NREL [7])

The supply of electricity from hydroelectric facilities can be quite sensitive to the amount of precipitation in the local watershed. Prolonged periods of below-normal rainfall can significantly cut hydropower production potential [6]. Potential environmental impacts of hydroelectric facilities include [6, 8]:

- Blockage of upstream fish passage;
- Fish injury and mortality from passage through the turbine; and
- Changes in the quality and quantity of water released below dams and diversions, including low dissolved oxygen levels.

Other factors may also act as deterrents to potential hydropower projects, including the increasingly costly and uncertain process of licensing or relicensing of hydropower projects. About 300 hydroelectric facilities will have to be relicensed through 2017 [9]. Though the Energy Policy Act of 2005 helped reform the licensing procedure, many consider the process still to be burdensome and complicated [10]. Obtaining a license for a new facility, or renewing the license of an older facility, can take 8 - 10 years or longer [9].

8.2 Economics of hydropower

Hydropower projects face large up-front capital costs. Even with these large capital costs, however, 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. Typically the useful life of a hydroelectric facility exceeds 50 years [11]. Figures 8-2 and 8-3 illustrate the competitiveness of hydropower with respect to other generator plant types. Microhydro projects are more expensive than large-scale hydropower projects, but can be cost-effective for locations far from the grid and that have good hydropower potential.

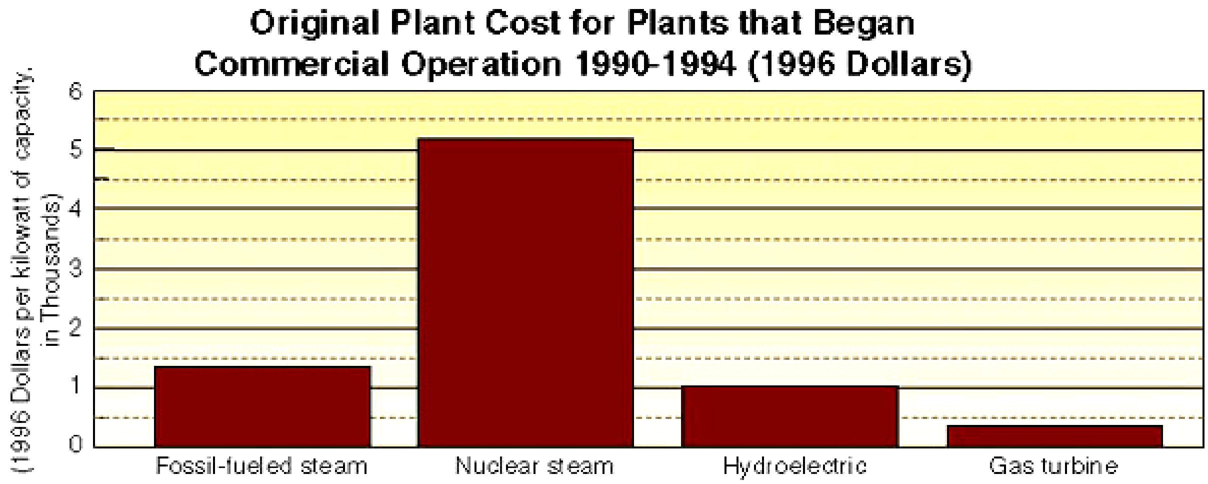

Figure 8-3: Plant costs per unit installed capacity (Source: INEL [11])

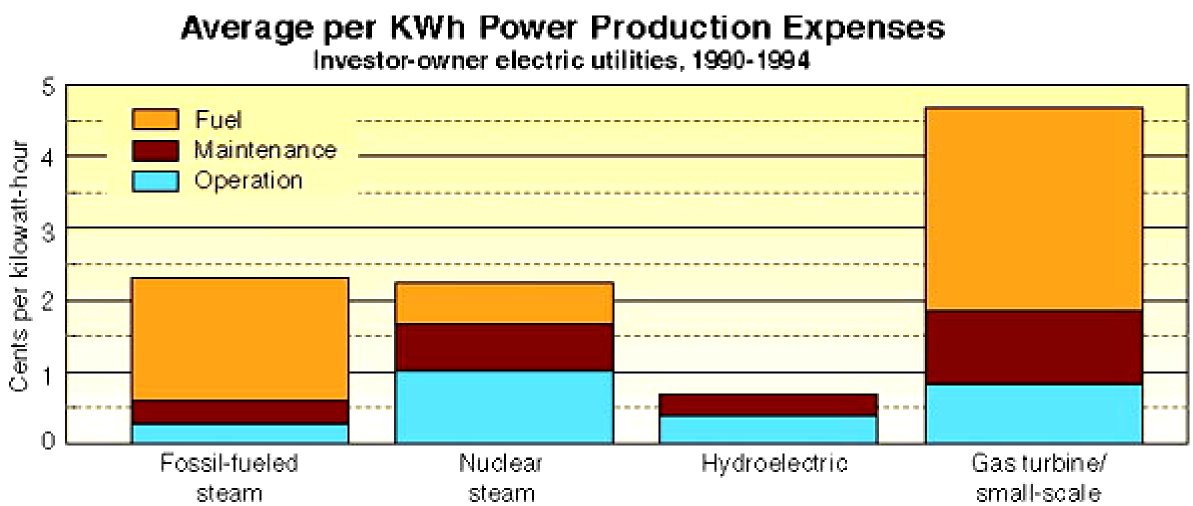

Figure 8-4: Average production costs of various types of generating plants (Source: INEL [11])

8.3 State of hydropower nationally

In 2006, the U.S. consumed 6.922 quads of renewable energy. Of this, 2.869 quads (41.4 percent) were from conventional hydroelectric energy [12]. In 2006, 7.0 percent of electricity in the U.S. was produced from hydropower [13]. There are 4,102 hydropower facilities catalogued by the Energy Information Administration in the U.S. as of 2005 [14], with a total net summer generation capacity (including pumped storage) of 99 GW [15]. The states of Washington, California and Oregon account for 44 percent of total hydropower capacity in the country; see Table 8-1 for the top 10 states in hydropower capacity in 2005 [14].

1. Washington	21,460		6. Georgia	3,989
2. California	13,340		7. South Carolina	3,963
3. Oregon	8,336		8. Alabama	3,240
4. New York	5,503		9. Virginia	3,088
5. Tennessee	4,205		10. Arizona	2,936

Table 8-1: Top ten U.S. states in hydropower capacity in 2005 (MW) (Data source: EIA [14])

The Idaho National Laboratory launched an effort to catalogue untapped hydropower potential in the U.S. in 1989. The U.S. Hydropower Resource Assessment Final Report was issued in 1998 with subsequent revisions in 2004 and 2006. At the heart of this assessment effort is a computer model known as the Hydropower Evaluation Software, which identified 5,677 sites with a total undeveloped capacity of 30 GW. Of this capacity, 57 percent (17.0 GW) is at sites with some type of existing dam or impoundment but with no power generation. Another 14 percent (4.3 GW) exists at projects that already have hydropower generation but are not developed to their full potential; only 28 percent (8.5 GW) of the potential would require the construction of new facilities. Therefore the potential for hydropower from existing dams is about 21.4 GW [16]. The breakdown of the state-by-state contribution to the total 30 GW identified is shown in Figure 8-5 [17].

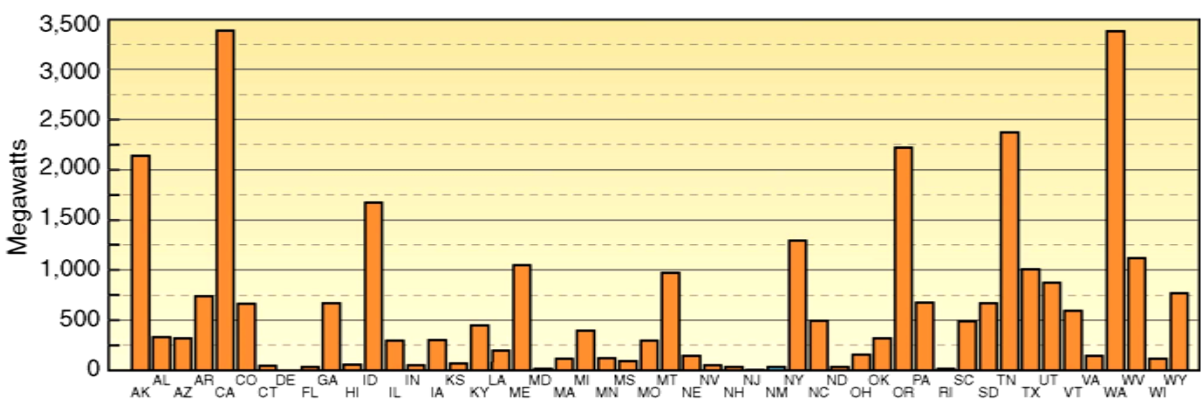

Figure 8-5: State breakdown of potential hydropower capacity (Source: INEL [16])

The National Hydropower Association estimates that more than 4,300 MW of additional or "incremental" hydropower capacity could be brought on line by upgrading or augmenting existing facilities [7].

Although there are substantial undeveloped resources for hydropower, hydropower's share of the nation's total electricity production is predicted to decline through 2020, with minimal capacity increases, due to a combination of environmental issues, regulatory complexities and pressures, and changes in economics [8]. The most viable hydropower capacity addition in the coming years will be the 4.3 GW of "incremental" capacity available at existing facilities. Improvements in turbine design to minimize environmental impacts, and federal and state government incentives, could help further develop potential hydropower projects at existing dams.

Currently, DOE is researching technologies that will enable existing hydropower projects to generate more electricity with less environmental impact. Their main objectives are to develop new turbine systems with 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. Together, these advances in hydropower technology will reduce the cost of implementation and help smooth the hydropower integration process [18].

8.4 Hydropower from existing dams in Indiana

Hydroelectric energy contributed only 0.4 percent (489 GWh) of the total electricity generated in Indiana in 2006, as shown in Figure 8-6. Indiana has 60 MW of hydroelectric generation capacity, which makes up about 0.2 percent of the state's total generation capacity.

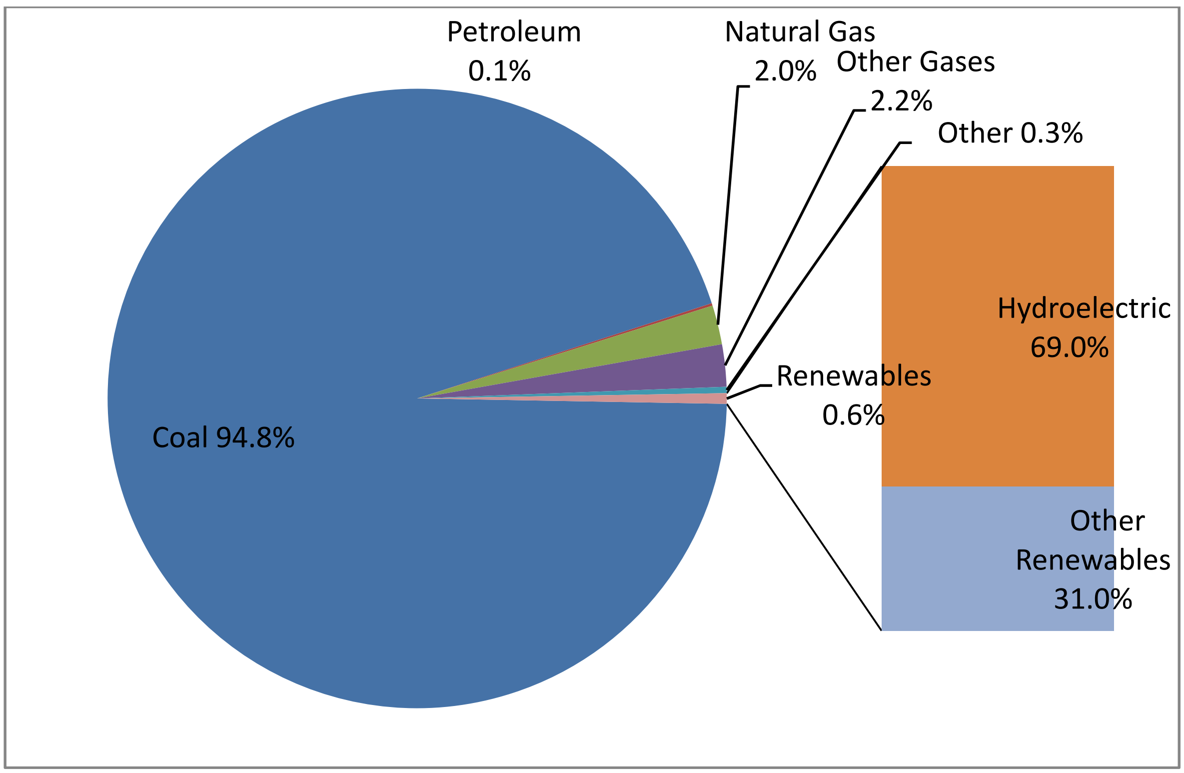

Figure 8-6: Indiana electricity generation by energy source in 2006 (Source: EIA [19])

In 1995, a report was published for DOE that assessed the potential hydropower resources[10] available in Indiana [19]; the study indicated a total of 30 sites[11] as potential undeveloped hydropower sources. Table 8-2 shows a breakdown of these identified sites.

The following key[12] was used to indicate the status of the potential hydropower site [20]:

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

	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 8-2: Undeveloped hydropower potential in Indiana (Source: INEL [20])

The HES computer models indicated that only about half of the identified hydropower potential could be captured effectively. This was particularly apparent for undeveloped projects, which are less viable than other projects due to environmental and legislative constraints. The majority of potential projects within Indiana have capacities below 1 MW, and would use predominantly smaller hydropower and micro-hydro designs [20].

All of the identified projects were located within Indiana's five major river basins. The Wabash River Basin had the most undeveloped hydropower potential (about 23 MW) of the Indiana river basins [20]. The viability of these projects could be increased with federal and state government incentives.

[10] Undeveloped pumped-storage hydropower potential was not included.
[11] A complete list of these projects is given in [19].
[12] 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.

8.5 Incentives for hydropower

Federal Incentives

- Renewable Electricity Production Tax Credit (PTC): The PTC credits hydroelectric producers 1.0 cents/kWh during the first ten years of operation. The PTC originally covered wind and biomass and was expanded to include hydropower in the Energy Policy Act of 2005. The PTC has been renewed for hydropower through 2011 [21].
- Clean Renewable Energy Bonds (CREBs): This program, authorized by the Energy Policy Act of 2005, makes available a total of $1.2 billion in 0 percent interest bonds for non-profit organizations, public utilities, and state and local governments to pursue renewable energy projects. The program has currently not been extended past 2008 and is set to close at the end of the year. In February, 312 projects were announced that would receive CREBs funding [21].
- Conservation Security Program: For 2008, the Conservation Security Program offers a $200 payment for each renewable energy generation system installed on an eligible farm [22, 23]. The Food, Conservation, and Energy Act of 2008 reincorporates the program as the "Conservation Stewardship Program" in 2009 and increases funding in the program by $1.1 billion [24].
- Rural Energy for America Program (REAP): The Food, Conservation, and Energy Act of 2008 converted the USDA Renewable Energy Systems and Energy Efficiency Improvements Program into the Rural Energy for America Program (REAP). Hydroelectric facilities are eligible for grants for up to 25 percent of the cost of the system, and loans for another 50 percent of the cost [21].

Indiana Incentives

- Emissions Credits: Electricity generators that do not emit NO_x and that displace utility generation are eligible to receive NO_x emissions credits under the Indiana Clean Energy Credit Program. These credits can be sold on the national market [25].
- Energy Project Feasibility Study Program: This grant program offers cost share grants to public, non-profit, or business groups in Indiana to explore the feasibility of renewable energy [26].
- Net Metering Rule: Solar, wind, and hydroelectric facilities with a maximum capacity of 10 kW are qualified for net metering in Indiana. The net excess generation is credited to the customer in the next billing cycle [27].

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Appendix: Issues Associated with Intermittent Resources

A.1 Introduction

Intermittency is a characteristic associated with certain renewable resources, such as wind and solar power. The electrical output of a generator powered by such renewable resources is determined by the quantity of resource available at any given moment. While conventional generators based on nuclear or fossil fuels may have unexpected disruptions based on technical or mechanical problems, the intermittency of conventional generators is of a far lesser order than that of generators powered by certain forms of renewable energy. Unlike for a conventional generator, the system operator has no control over how much power is available at any one moment with an intermittent renewable energy source. This issue is becoming more important for system operators and policy makers to manage as the proportion of solar and wind-powered electricity generation increases across the country.

A variety of problems arise from intermittency in electricity generation. For instance, generation output may be low at a time of high demand, which is often true for wind power. Moreover, at a time of high or increasing demand, there may be a sudden drop in generation due to resource variability. If sufficient resources are not available in reserve to compensate for this lost generation, a loss of service may result. This problem is best illustrated by a situation in Texas on February 26, 2008, when a 1,700 MW drop in the output from wind farms coincided with rising electricity demand and caused the grid operator ERCOT to activate an emergency plan to cut service to interruptible customers after scheduled backup generators failed to produce [1].

Likewise, the inverse situation, too much generation during periods of low demand, is also problematic. A resource may overproduce during periods of low demands; system operators are thus challenged to dispose of this excess energy. In July in the Pacific Northwest, in a brief period of about five hours, wind farms were producing at exceptionally high levels due to an unexpected breeze; concurrently the regional reservoirs were unseasonably high. Grid operators were forced to spill water over dams at a rate that was potentially harmful to fish downstream [2].

Intermittency also can have an effect on the price of electricity in wholesale markets. When a relatively large amount of energy is being produced from intermittent sources, prices tend to fall. Similarly, prices will be higher if the resource is unavailable. This effect can be intensified if local transmission constraints limit the network's ability to send power outside the region when the renewable resource is producing or to import power when it is not.

Operators of the electricity network must ensure that there is enough generation capacity in operation to meet demand that varies according to daily, weekly, and seasonal cycles. During the unit-commitment process, the decision is made about which generators will be committed to being available for the expected load in the days ahead. The presence of uncertain resources can result in the need for committing a greater amount of generation to ensure an adequate amount of supply. Operators must also have sufficient generating capacity to match the varying load as it occurs throughout the day (load-following and regulation). Since most traditional generators are limited as to how quickly they can increase or decrease their output, it may be necessary to have additional generation in operation in order to have the capability to make up for sudden changes in the output of intermittent resources. To the extent that wind adds to the variability in system load, it adds to the cost of providing these ancillary services [3].

From a longer-term perspective, another challenge occurs in determining the amount of an intermittent resource's capacity that can be counted towards the reliability of the network for planning purposes. One cannot tell in advance how much of the intermittent capacity will be available when the system peak occurs. Various statistical tools are used in the U.S. to estimate how much wind capacity can be counted towards system capacity for reliability purposes. One such relatively simple measure is the capacity factor. The capacity factor is the actual energy produced over a period of time relative to how much energy the unit would have produced if it had operated at its rated design capacity during the period. According to a recent report produced by DOE [3], the annual capacity factor for wind plants connected to the Midwest Independent System Operator (MISO) system is estimated at 30 percent; baseload coal and nuclear units have capacity factors in the MISO system in excess of 70 percent. A similar statistic, the effective load carrying capability (ELCC), is used by several utilities, as indicated in Table A-1. It is defined as the "*amount of additional load that can be served at the target reliability level with the addition of a given amount of generation*" [3].

Estimates of the effective capacity vary considerably depending on a number of factors in addition to the methodology used. Both the variability and relative strength of the resource are a function of the local geography. The characteristics of the electrical system load can also have a significant impact: a utility or region that experiences its annual peak demand in the winter rather than the summer may get greater value from a given resource than its summer-peaking counterpart.

Region/Utility	Method	Note
California Energy Commission	ELCC	Rank bid evaluations for RPS (20 – 25 percent)
PJM	Peak Period	Jun-Aug HE 3-7 p.m., capacity factor using 3-year rolling average (20 percent, fold in the actual data when available)
ERCOT	10%	May change to capacity factor for the hours between 4-6 p.m. in July (2.8 percent).
Minnesota utility Commission & Xcel Energy	ELCC	Sequential Monte Carlo (26 – 34 percent)
New York State Energy R&D Authority	ELCC	Offshore/land-based (40 percent/10 percent)
Colorado Utility Commission & Xcel	ELCC	PUC decision (10%), Full ELCC study using 10-year data gave average value of 12.5 percent.
Rocky Mountain Area Transmission Study	Rule of Thumb	20 percent for all sites in RMATS.
PacifiCorp	ELCC	Sequential Monte Carlo (20 percent). New Z-method 2006.
Mid-continent Area Power Pool	Peak Period	Monthly 4-hour window, median.
Portland General Electric		33% (method not stated)
Idaho Power	Peak Period	4-8 p.m. capacity factor during July (5 percent).
Pugent Sound Electric and Avista	Peak Period	The lesser of 20 percent or 2/3rds of January capacity factor.
Southwest Power Pool	Peak Period	Top 10 percent loads/month, 85th percentile.

Table A-1: Methods to estimate wind capacity value in the U.S. (Source: DOE [3])

The amount of geographic diversity of the intermittent resources being used can have a substantial impact on the significance of resource intermittence. If all of the intermittent generators are located near each other, they are likely to be affected by the same weather patterns. Thus, all generators tend to produce at similar levels at a given time. Table A-2, which shows the percent of overall wind capacity that was actually operating at the time of MISO's peak demand for three years, illustrates this issue [4]. During these years, most of the wind capacity in the MISO system was located in a relatively small geographic region in Iowa and Minnesota. As the resources become more geographically diverse, it becomes less likely that all of the generators will be producing at the same level. That is, it may be windy in Minnesota but not in Indiana or vice versa. With the development of wind resources in

Indiana and elsewhere, neither the extreme high of 2006 nor the extreme low of 2007 are expected to recur due to spatial diversification of wind generation resources.

	2005	2006	2007
Wind power available at peak (percent)	11.8	66.5	1.6

Table A-2: MISO wind production at annual system peak (Source: MISO [4])

Several wind penetration studies for different sections of the U.S. electric grid have quantified the added cost associated with the increasing penetration of wind. Table A-3 shows the breakdown of the wind integration costs from nine such studies. As discussed previously, regulation and load following costs result from the need to follow the natural variations in load throughout the day, while unit commitment costs are due to the process of ensuring sufficient generating capacity will be operational over the next few days. Gas supply costs can be higher due to the presence of intermittent resources because they introduce uncertainty in the fuel procurement process for natural gas-fired generators.

Date	Study	Wind Capacity Penetration (percent)	Regulation Cost ($/MWh)	Load Following Cost ($/MWh)	Unit Commitment Cost ($/MWh)	Gas Supply Cost ($/MWh)	Total Operating Cost Impact ($/MWh)
May ‘03	Xcel-UWIG	3.5	0	0.41	1.44	na	1.85
Jun ‘03	We Energies	29	1.02	0.15	1.75	na	2.92
Jun ‘04	We Energies	4	1.12	0.09	0.69	na	1.90
Jul ‘04	CA Multi-year Analysis	4	0.45	na	na	na	na
Sept ‘04	Xcel-MCDOC	15	0.23	na	4.37	na	4.60
2005	PacifiCorp	20	0	1.6	3.0	Na	4.6
Apr ‘06	Xcel-PSCo	10	0.20	na	2.26	1.26	3.72
Apr ‘06	Xcel-PSCo	15	0.20	na	3.32	1.45	4.97
Nov ‘06	MN/MISO	35 (25% energy)	0.15	na	4.26	na	4.41

Table A-3: Wind integration costs in the U.S. (Source: EERE [3])

The total integration costs in Table A-3 vary from a low of $1.85/MWh to a high of $4.97/MWh. The degree of wind penetration has an obvious effect on wind integration costs: the higher the percentage of wind in the system, the greater the costs. Another factor that affects wind integration costs is the existing mix of generators to which the intermittent resource is being added. A system whose generators have little operational flexibility (i.e., nuclear units) is likely to have higher integration costs than one with more flexible units, such as hydroelectric. Also, as the overall size of the system increases, the integration costs tend to decrease. This occurs because the system regulation and load following requirements (as a percentage of total load) are lower for larger systems [5].

A.2 Current methods of mitigating intermittency

While statistical tools are a useful planning component for grid operators, operators must also have concrete methods to mitigate problems arising from the intermittency of renewable resources. Among the several tools available, the most common is the use of dispatchable generators on the grid, such as existing nuclear and fossil fuel power plants. At low levels of penetration of intermittent generation, it may be adequate to adjust the commitment and dispatch of existing generators in a system without having to add generators specifically designated for mitigation. However, new dispatchable generation may be needed at locations in the grid where wind generation capacity is concentrated. For example, even before the February event in Texas referred to previously, plans were in place to add about 200 MW of natural gas-fired capacity southwest of San Antonio to provide peaking power [1].

Dispatchable generators can also be coupled with intermittent generators before the electricity reaches the grid. A dispatchable generator is integrated as part of the intermittent system to mitigate the variability of the renewable resource. The advantage of such a setup is that system operators can depend on a constant source of power; the disadvantage is that construction of such dispatchable generation adds significant capital costs. Such an arrangement is in place at the FPL Energy-owned Solar Electric Generating System facilities in California. The 310 MW concentrating solar power plants are supplemented with natural gas-fired generation to be used when the sun is not shining.

Grid operators can also use the potential of hydroelectric dams to mitigate the intermittency of renewable power. In systems with both high wind and hydropower potentials, hydroelectric dams can be used to store excess wind energy by pumping water back into the reservoir. The facility can then reuse the water to produce more electricity during periods of high demand. For example, in an Xcel Energy system in Colorado, wind and other off-peak energy is used to pump water up into the reservoir of the Cabin Creek hydroelectric station; the water is later used to meet peak power demands [6]. In the Pacific Northwest, the Bonneville Power Administration (BPA) uses its extensive hydroelectric system to provide storage and other “shaping” services to wind farms, thereby significantly decreasing problems associated with intermittency [7].

The inverse relationship between the output of intermittent resources and the wholesale price of electricity provides a natural mitigation method. If prices rise due to reduced generation of the intermittent resource, consumption is likely to decrease, whether from the action of a consumer or through the utility's use of direct load control and interruptible contracts. The NREL report on the February 26th event in Texas found that system operators in Texas are more advanced in the use of voluntary load response than those in other regions [8]. Although the use of interruptible load as a resource for system reliability is not new, its integration into the system as a voluntary market tool is growing. Such interruptible loads can quickly respond to market signals and enhance a system's ability to respond to a sudden drop in wind or other intermittent resources. ERCOT, the system operator for Texas, was able to quickly deploy this voluntary load response during the event and thus prevented involuntary load shedding.

A.3 Methods under development to mitigate intermittency

An important step in mitigating the consequences of intermittency is integrating wind forecasts into the grid systems operations. For example, NREL concluded [8] that the February 26th incident in Texas could have been mitigated had available wind forecasts been integrated into the operations. Plans are under way as part of Texas market reforms to incorporate wind forecasts into unit-commitment and other system operations procedures [9]. NREL is working, as part of its wind research program, to provide accurate representations of the wind resource over seasonal, daily, and hourly periods. NREL recognizes that "*the seamless integration of wind plant output forecasting…is a critical next step in accommodating large penetrations of wind energy in power systems*" [10].

While energy cannot be stored in the form of electricity, the electricity can be transformed into another form of energy that is storable. For use in conjunction with electric power networks, an energy storage technology should have the capability to store a large amount of energy. Thus, it can deliver a number of MWs over a period of hours. Pumped hydroelectric storage is the most common energy storage mechanism used today; other methods are in various stages of development and deployment. They include:

- Compressed air energy storage: This technology uses wind or another off peak energy source to compress and store air. This compressed air is then released through a gas-fired expander turbine to generate electricity to meet peak demand. The Iowa Stored Energy Plant plans to store excess wind energy during periods of low demand using compressed air; it is in the planning stages and is expected to be completed in 2011 [11].
- Utility-Scale Battery Technology: The types of batteries being considered for utility-scale energy storage include the sodium sulfur battery (NaS), the lithium ion battery, the nickel cadmium battery, the lead-acid battery, and the metal air battery. The first

utility scale NaS battery in the U.S. was installed by a unit of American Electric Power Corporation (AEP) in 2006. This 1 MW battery was installed to provide peak shaving capability and to delay capital expenditure at a substation. Typically it is charged at night and discharged at peak demand during the day [12]. AEP is currently installing 2 MW NaS batteries in Churubusco, Indiana; Milton, West Virginia; and Bluffton, Ohio. In addition to providing peak shaving, the facilities will improve reliability by providing an alternative source of power so that the local system can remain energized when the larger network is unavailable (islanding). AEP also intends to use the Churubusco facility as a test bed for mitigating intermittency from wind power plants [13].

- Flow batteries: In these rechargeable batteries, electrolytes flow through a reactor that converts the chemical potential from the electrolyte into electrical energy. Unlike standard batteries, the electrolytes are stored externally and pumped through the reactor as needed. One advantage over standard batteries is that flow batteries can be rapidly recharged by replacing the electrolyte liquid while simultaneously recovering the spent material for re-energization. However, disadvantages over standard batteries are that flow batteries tend to have lower energy densities and are much more complicated systems with pumps, sensors, control units, and secondary containment vessels [14].
- Distributed Battery Storage: A concept currently under research is the use of distributed batteries to store electricity during periods of low demand, and then providing excess electricity during peak demand. A primary use of such technology would be a new generation of plug-in hybrid-electric vehicles. The concept assumes that most such vehicles would be charged at night during periods of generally low electric demand; later, during the day they would be connected to the electrical grid. If the peak demand for electricity crosses a certain threshold, the cars would discharge excess electricity from their onboard batteries onto the network. Later, as demand falls, the vehicles would recharge their batteries. City officials in Austin, Texas are evaluating this concept and contemplating installation of the necessary infrastructure [15].
- Flywheels: Most modern flywheel systems consist of a rotating cylinder supported by magnetically levitated bearings. One of the great advantages of flywheels is that they require little maintenance and have a lifespan of up to 20 years. They are ideally suited to bridge the gap between short term ride-through and long term storage with excellent cycling and load-following characteristics [16].
- Superconducting Magnetic Energy Storage (SMES) Systems: SMES systems store energy in magnetic fields that have been cooled to very low temperatures. At cryogenic temperatures, certain superconducting materials have no electrical resistance and therefore no power loss in operation. In SMES devices, power is available almost instantaneously; they also provide very high power outputs over

brief periods of time. Among their disadvantages are that their energy content is rather small and that maintaining the required very low temperatures can be a challenge. A string of SMES units is in use in Wisconsin where it helps stabilize a transmission line that is subject to sudden load changes due to the operation of a paper mill [18].

- Electrochemical Capacitors (Super Capacitors): These super capacitors store energy in the form of an electrical field at a density thousands of times higher than standard electrolytic capacitors. Although their energy densities are less than standard lead-acid batteries, these super conductors have a much faster charge-discharge capability. While small electrochemical capacitors are well-developed, larger ones with capacities necessary for utility-scale energy storage are still under development [16].
- Hydrogen: The process of electrolysis uses electricity to separate water into hydrogen and oxygen. The hydrogen can then be stored to produce electricity using a fuel cell or combustion turbine when the intermittent resource is not available. Research on a number of methods for efficient hydrogen production, storage, and utilization is underway. Researchers at Purdue have developed a method for producing hydrogen on demand by adding water to an aluminum-gallium mixture, thus eliminating the need to store hydrogen. For energy storage purposes in conjunction with an intermittent resource, electricity would be generated from hydrogen when needed. The byproduct of this reaction, aluminum oxide, would be reprocessed to aluminum using electricity from the intermittent source as it is available [17].

Figure A-1 compares the capital cost of various energy storage technologies, and Table A-4 compares other characteristics of these technologies. The acronyms used in Figure A-1 and Table A-4 that have not already been defined earlier have the following meanings:

- CAES – Compressed air energy storage;
- Ni-Cd – Nickel-cadmium battery;
- DSMES – distributed superconducting magnetic energy systems; and
- E.C. Capacitor – electrochemical capacitor.

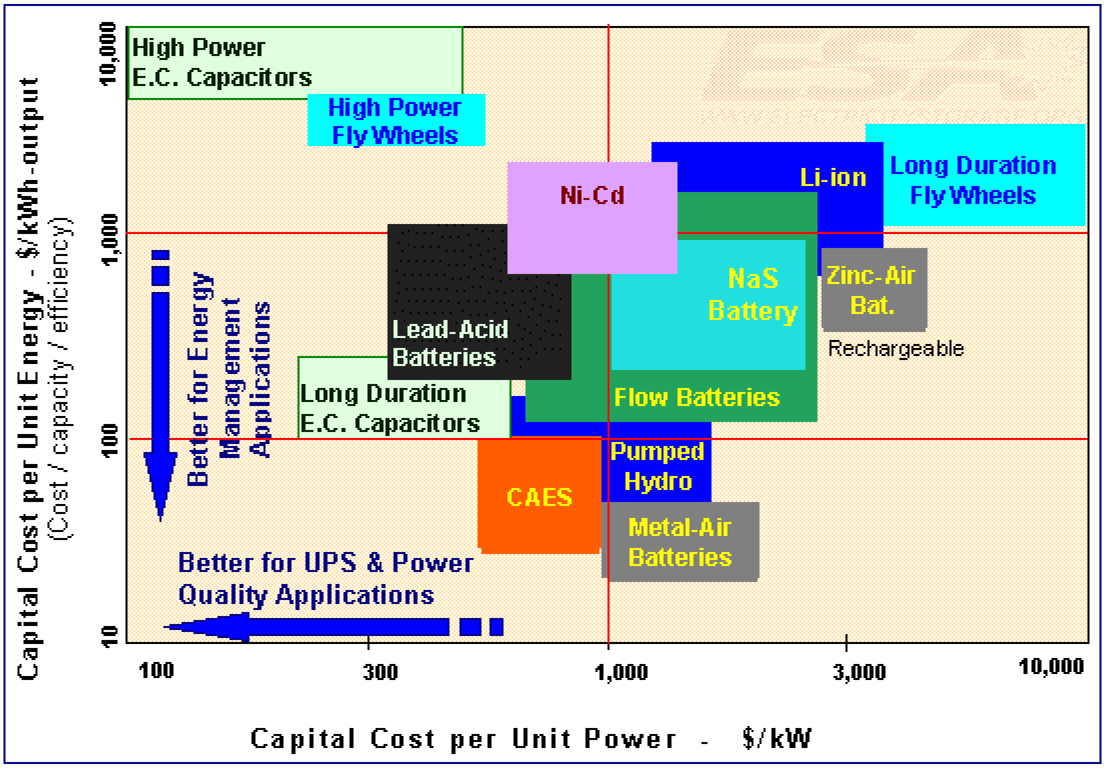

Figure A-1: Relative capital costs of energy storage technologies (Source: Energy Storage Association [16])

Storage Technologies	Main Advantages (relative)	Disadvantages (relative)	Power Application	Energy Application
Pumped Storage	High capacity, low cost	Special site requirement		● (dark blue)
CAES	High capacity, low cost	Special site requirement, need gas fuel		● (dark blue)
Flow Batteries: PSB, VRB, ZnBr	High capacity, independent power and energy ratings	Low energy density	● (light blue)	● (dark blue)
Metal-Air	Very high energy capacity	Electric charging is difficult		● (dark blue)
NaS	High power & energy densities, high efficiency	Production cost, safety concerns (addressed in design)	● (dark blue)	● (dark blue)
Li-ion	High power & energy densities, high efficiency	High production cost, requires special charging circuit	● (dark blue)	○
Ni-Cd	High power & energy densities, high efficiency		● (dark blue)	● (light blue)
Other Advanced Batteries	High power & energy densities, high efficiency	High production cost	● (dark blue)	○
Lead-Acid	Low capital cost	Limited life cycle when deeply discharged	● (dark blue)	○
Flywheels	High power	Low energy density	● (dark blue)	○
SMES, DSMES	High power	Low energy density, high production cost	● (dark blue)	
E.C. Capacitors	Long life cycle, high efficiency	Low energy density	● (dark blue)	● (light blue)

The symbols in the table have the following meanings:
The dark blue circle indicates that the technology is fully capable and reasonable for that application; the light blue circle means that the technology is reasonable for that application; and the unfilled circle means the technology is feasible but not practical for that application. No circle indicates that the technology is neither feasible nor reasonable for that application.

Table A-4: Characteristics of energy storage technologies (Source: Energy Storage Association [16])

A.4 Intermittency in Indiana

The problem of intermittency is largely confined to the use of certain renewable resources, especially solar and wind power. While wind power represents a large and fast-growing resource in Indiana, the state's solar resources are relatively scarce. Indiana's hydroelectric generators are mainly run-of-the-river. Thus, they do experience some variation in output as water flows change. This variation is highly predictable in the short term, so intermittency due to hydroelectricity is generally not an issue. The use of other renewable resources, primarily biomass, is not susceptible to problems of intermittency.

The increasing wind-powered electricity generation in the state means that intermittency is likely to be more significant in the future. The month-to-month average wind speeds for five different sites in Indiana, at 100 meters, are shown in Figure A-2. The data used for Figures A-2, A-3, and A-4 were compiled in 2004 and 2005 for the *Indiana Tall Towers Wind Study* [19]. Notice that the wind speeds generally peak in the spring and are slowest in the summer. These patterns do not vary much from year-to-year; thus, utilities can plan accordingly.

Intermittency, however, becomes much more apparent at the day-to-day level. Figure A-3 examines the first three days in May 2004 at two different sites in Indiana, 200 miles apart. First, note the wide fluctuation in wind speeds from one time to the next at each site. In Gibson County (Haubstadt), wind speeds started near 25 mph before dropping to roughly 1 mph in a few hours' span. Then, wind speeds jumped in Newton County (Goodland) from about 10 mph to near 30 mph in a short period of time. However, although Goodland and Haubstadt are relatively close to one another, wind speeds at each site sometimes move in different directions. This phenomenon—that two nearby wind towers may have divergent wind speeds—actually helps alleviate the problem of intermittency, because one tower can pick up the slack from another. Having many wind towers across a wide geographic range on a well-connected and regulated grid will thus help mitigate potential intermittency problems.

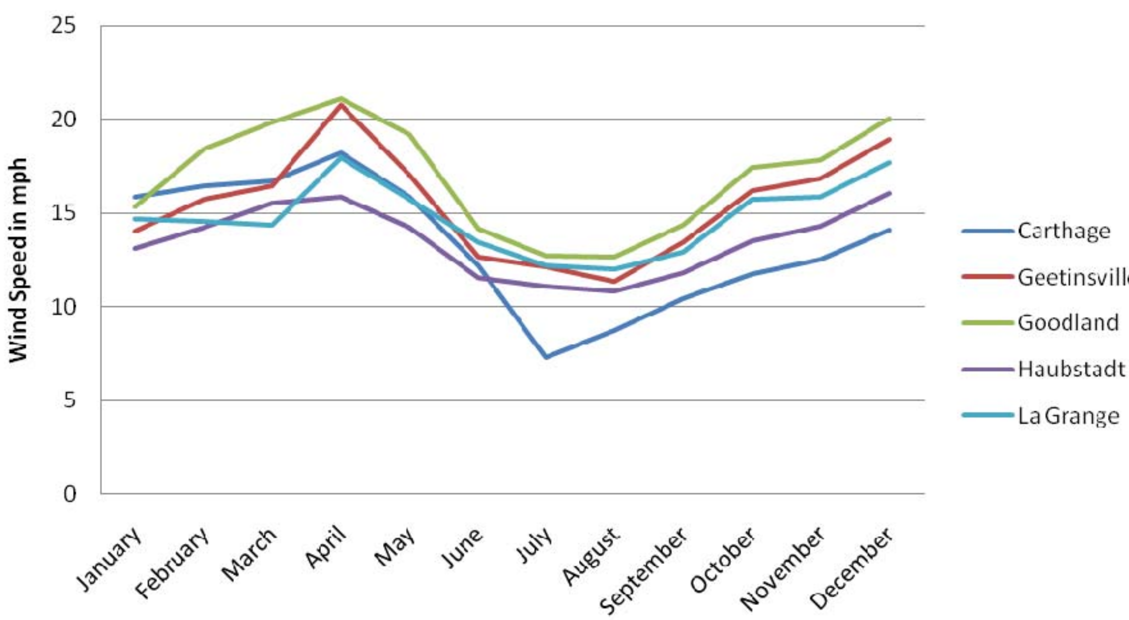

Figure A-2: Average wind speeds at different sites in Indiana at 100m (Data source: Indiana Office of Energy and Defense Development [19])

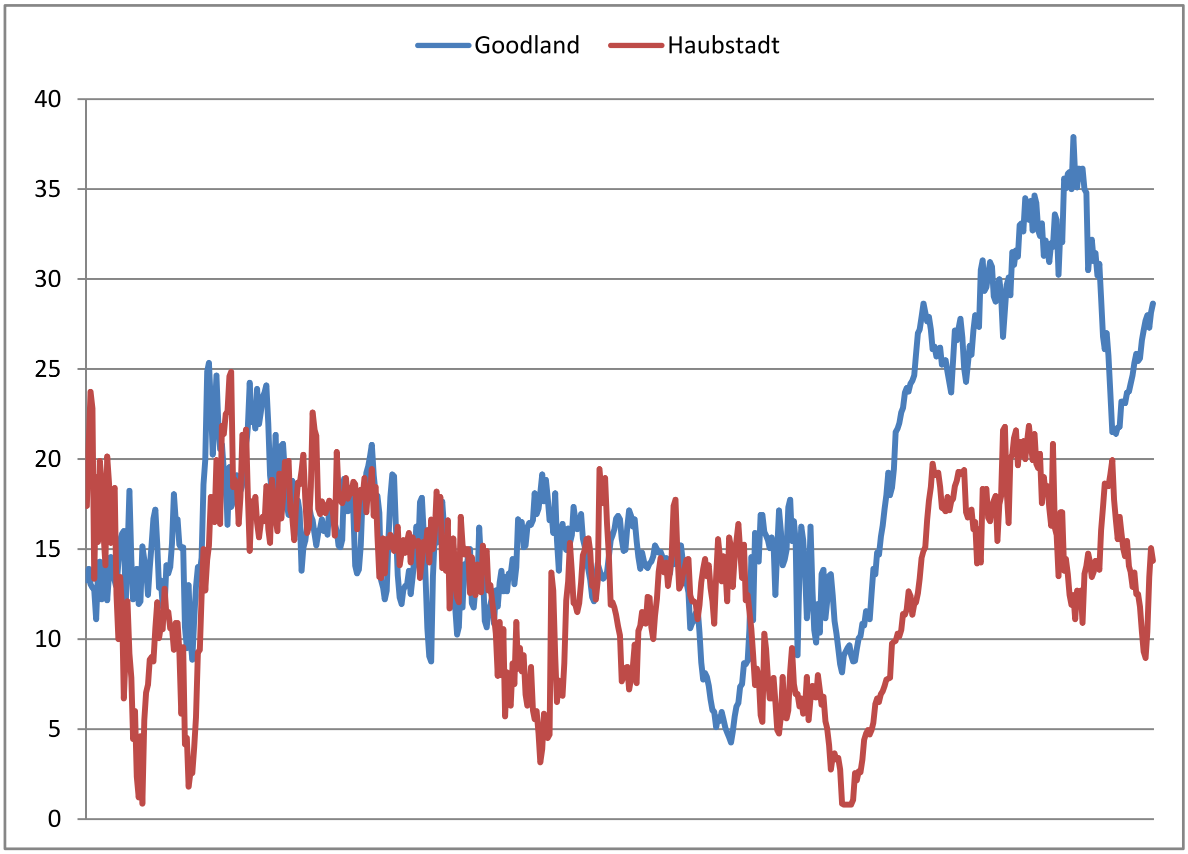

Figure A-3: Wind speeds at different sites in Indiana in May 2004 at 100m (Data source: Indiana Office of Energy and Defense Development [19])

Power production by wind turbines increases with the cube of the wind speed (see Section 2). Thus, a small rise in wind speed results in a significant increase in electricity production; likewise, a small drop can cut production significantly. Thus, when taking the cubic relation into account, the wind speed variability from Figure A-3 is further magnified. Figure A-4 displays the power production, based on a Vestas 3-MW turbine, that would have occurred at Goodland over the same three-day period in May. The variability of power production in Figure A-4 is significantly more than that of wind speed in Figure A-3. Table A-5 shows the variability, as measured by the standard deviation as a percent of the mean, for both wind speed and power production for the two sites. Note that the variability of the two sites combined is lower than for either site individually. This illustrates the mitigation in intermittency that occurs due to geographic diversity of power sources.

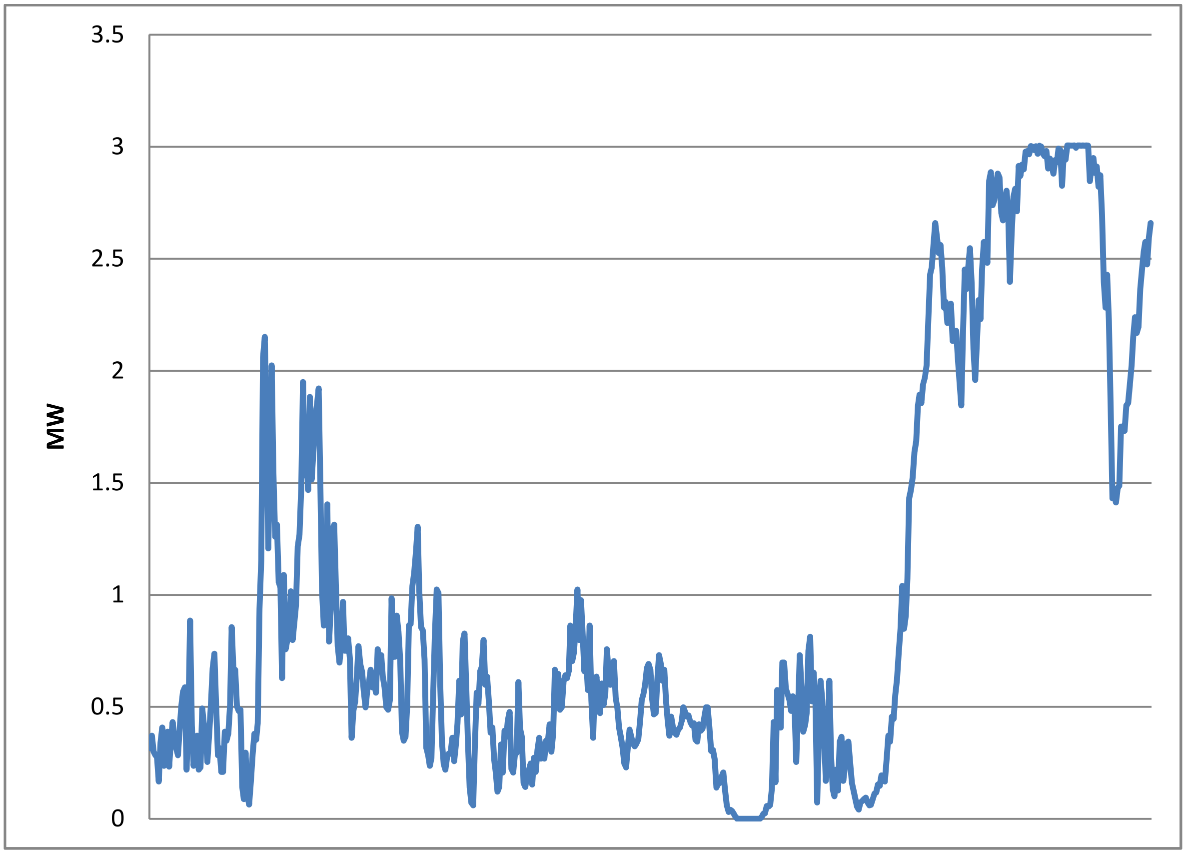

Figure A-4: Equivalent wind power production at Goodland in May 2004 at 100m (Data source: Indiana Office of Energy and Defense Development [19])

	Goodland		Haubstadt		Combined
	Wind speed (mph)	Power (MW)	Wind speed (mph)	Power (MW)	Power (MW)
Mean	18.02	1.002	13.18	0.456	1.458
Standard deviation	7.08	0.939	5.04	0.407	1.160
Standard deviation as percent of mean	39.3%	93.3%	38.2%	89.1%	79.6%

Table A-5: Variability of wind speed and equivalent power output (Source: Indiana Office of Energy and Defense Development [19])

Observations from Duke Energy's Kokomo solar project are used to illustrate the intermittency associated with solar energy. The project is composed of two 960 Watt photovoltaic (PV) panels that supplement electricity supply to Duke's Kokomo office. One panel is stationary at a fixed alignment to the sun, while the other panel tracks the sun as it moves from east to west. Figure A-5 shows the power output from the two panels over the week running from Wednesday, August 20, 2008 to Wednesday, August 27.

Inv. 1 is output from sun-tracking panel. *Inv. 2* is output from the stationary panel

Figure A-5: Power output of Duke Energy Kokomo PV panels, week starting August 20, 2008 (Source: Duke Energy [20])

One advantage of solar systems over wind power plants is that their peak production coincides more closely with the electricity demand, whose highest demand tends to occur in the afternoon. According to Duke Energy, the results from their experiments with PV units in Bloomington (2004 – 2007) are that the PV units' production does not occur late enough in the afternoon to exactly coincide with the system peak demand. Figure A-6 shows the total power output in Watts from the same panels over a month's period running from July 26, 2008 to August 26.

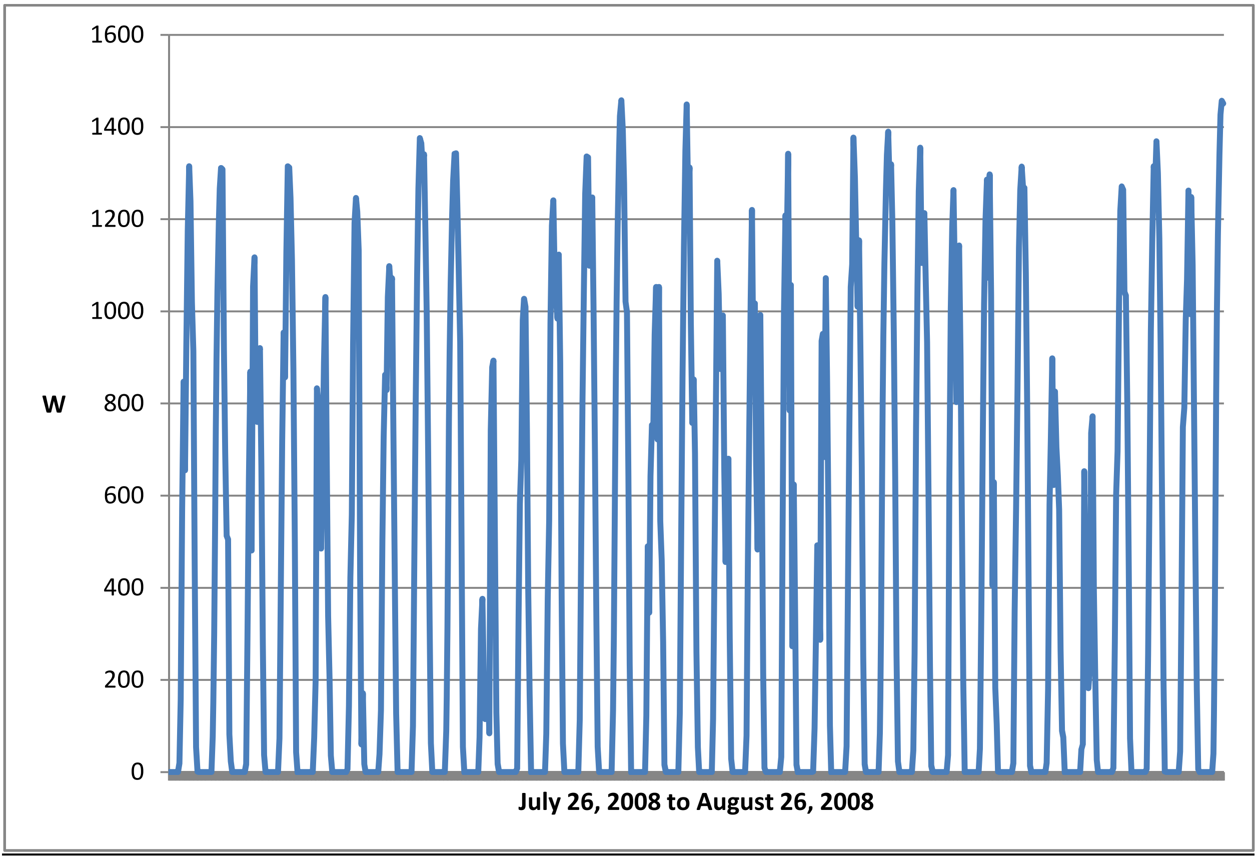

Figure A-6: Power output of Duke Energy Kokomo PV panels (Data source: Duke Energy [20])

Of the established methods of mitigating intermittency problems, while Indiana lacks pumped storage hydroelectric facilities [21], Indiana utilities do have a significant amount of customers under direct load control and interruptible contracts. As the penetration of wind power increases in the state, the need for mitigation of intermittency is likely to increase.

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