PURDUE UNIVERSITY Discovery Park Energy Center

2009 Indiana Renewable Energy Resources Study

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Indianapolis, Indiana

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

2009 INDIANA RENEWABLE ENERGY RESOURCES STUDY

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Acronyms and Abbreviations

AFC	Alkaline Fuel Cell
ASD	Agricultural Statistical District
ASP	U.S. Department of Energy's Aquatic Species Program
APS	Arizona Public Service
AWEA	American Wind Energy Association
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
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
FPL	FPL Energy and Florida Power and Light are subsidiaries of the FPL Group Inc. holding company
GWh	Gigawatthour
H_2	Hydrogen
HES	Hydropower Evaluation Software
IEA	International Energy Agency

IPALCO	IPALCO is the parent company of Indianapolis Power and Light Company
INEL	Idaho National Engineering and Environmental Laboratory, U.S. Department of Energy
IREC	Interstate Renewable Energy Council
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
mph	Miles per hour
MSR	Million Solar Roofs
MSW	Municipal solid waste
MW	Megawatt
MWh	Megawatthour
NBT	Nature Beta Technologies Corporation
NIPSCO	Northern Indiana Public Service Company
NMSU	New Mexico State University
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
POLYSYS	Policy Analysis System
PPA	Power purchase agreement
PTC	Production tax credit
PV	Photovoltaic
REAP	Rural Energy for America Program, U.S. Department of Agriculture
REPI	Renewable Energy Production Incentive
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
SUFG	State Utility Forecasting Group
TAGS	Triacylglycerols (algae oil)
USDA	U.S. Department of Agriculture
VEETC	Volumetric ethanol tax credit
W/m^2	Watts Per Meter Squared
WVPA	Wabash Valley Power Association
WWT	Waste water treatment

Foreword

This report represents the seventh 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 code was amended this year, directing SUFG to "evaluate potential renewable energy generation opportunities from biomass and algae production systems."

The report consists of nine sections. Section one provides an overview of the renewable energy industry in the United States and in Indiana. It includes a discussion on trends in penetration of renewable energy into the energy supply, both nationally and in Indiana. The other eight 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, hydropower from existing dams, and energy from algae. They are arranged to maintain the format in the previous reports as follows:

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

While there are significant amounts of new renewable resources under development or recently completed 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, under construction, 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 2009 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

In the recent past, use of two renewable energy resources, wind and biomass, have shown a rapid increase both nationally and in Indiana. Figure 1-1 shows the levels of consumption of the renewable energy resources nationally. Beginning in the 1950s, through the early 1970s, hydroelectricity generation accounted for most of the increase in renewable energy. Then in the 1970s through the 1980s biomass, mainly wood, accounted for most of the increase. In the 2000s biomass (in the form of corn-based ethanol) and wind energy have been the two fastest growing renewable resources. The rapid increase of ethanol was at first due to its use as a replacement for the oxygenating chemical MTBE and then due to its use as a gasoline blending ingredient mandated by the federal Renewables Fuel Standard first authorized in the Energy Policy Act of 2005 and further expanded by the Energy Independence and Security Act of 2007.

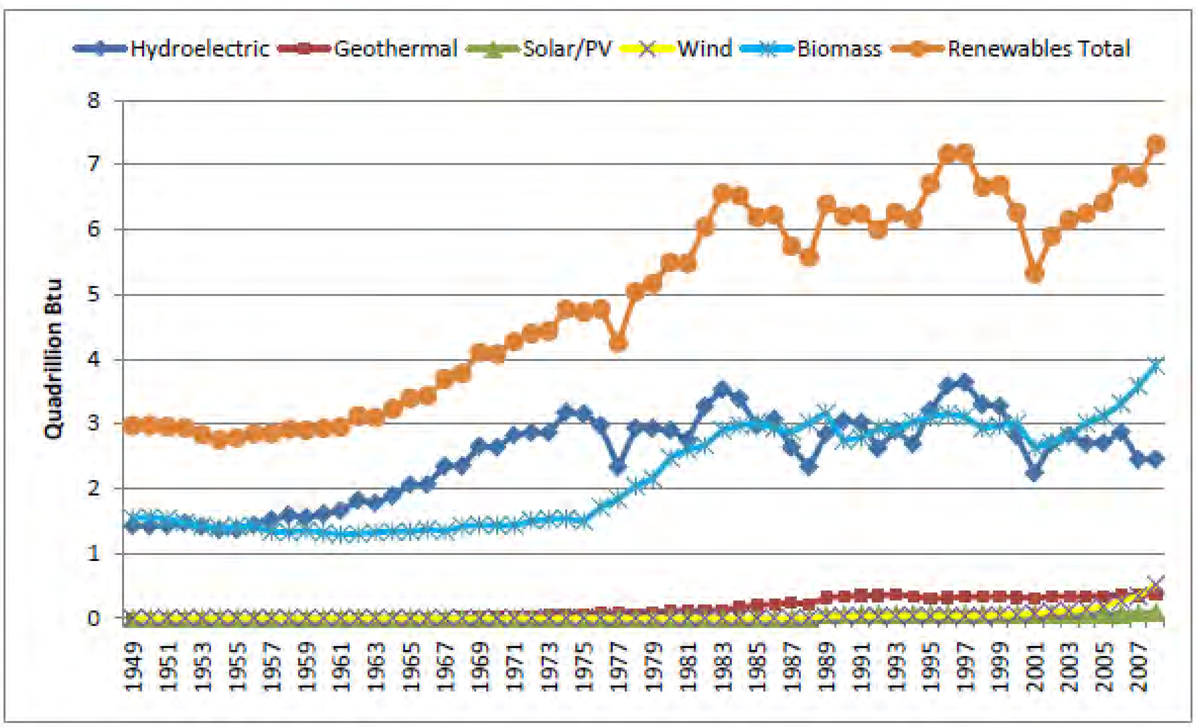


Figure 1-1: Renewable energy consumption in U.S. (1949-2007) (Source: EIA [1])

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.

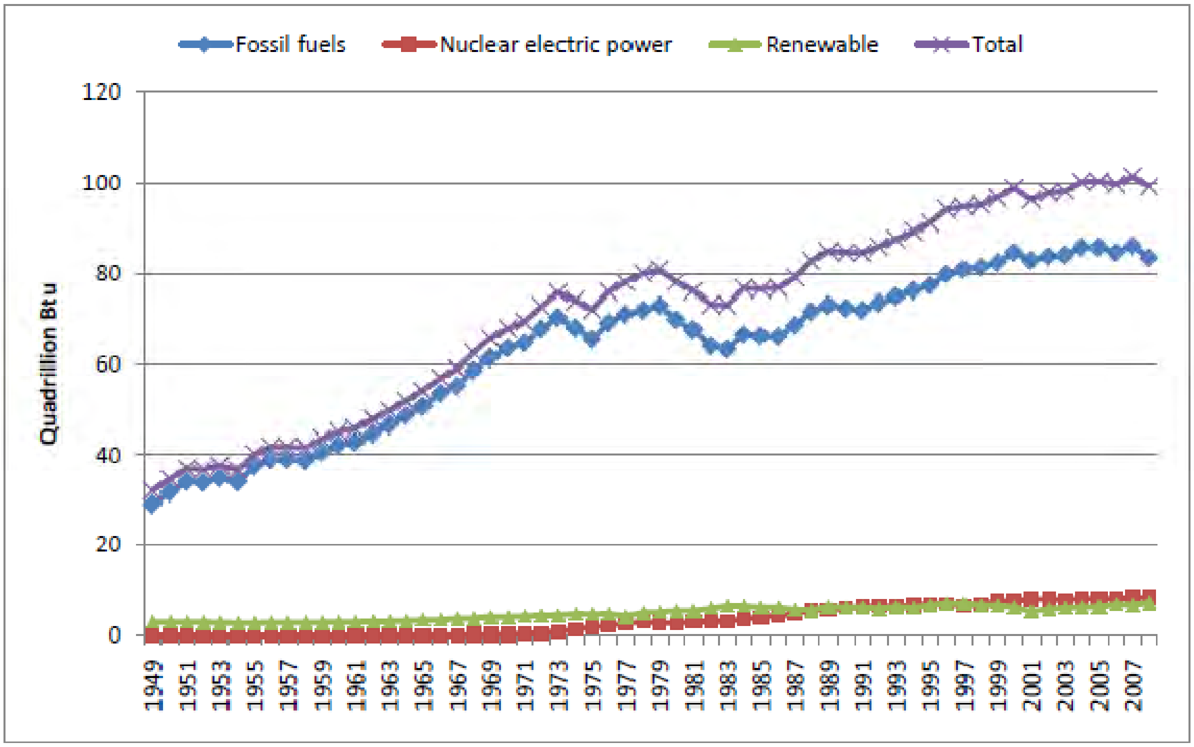


Figure 1-2: U.S. energy consumption by source (1949-2007) (Data source: EIA [1])

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. Wind and geothermal contributed about 5 percent each and solar 1 percent of the energy consumed in the U.S. in 2007.

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 72 percent of the renewable electricity sources, compared to 16 percent by biomass resources. Wind energy is third in share with 10 percent, ahead of geothermal's 4 percent and solar energy's 0.2 percent. As can be seen in Figure 1-4, pumped hydroelectricity's net energy contribution was negative[1].

[1] Pumped hydroelectric facilities use electricity from the grid during periods of low demand so as to be available to generate electricity during high demand periods. Due to evaporation and inefficiencies in the pumping and generating processes, less energy is generated than is used. The lost energy is overcome by converting low cost, off-peak energy to high cost, on-peak energy.

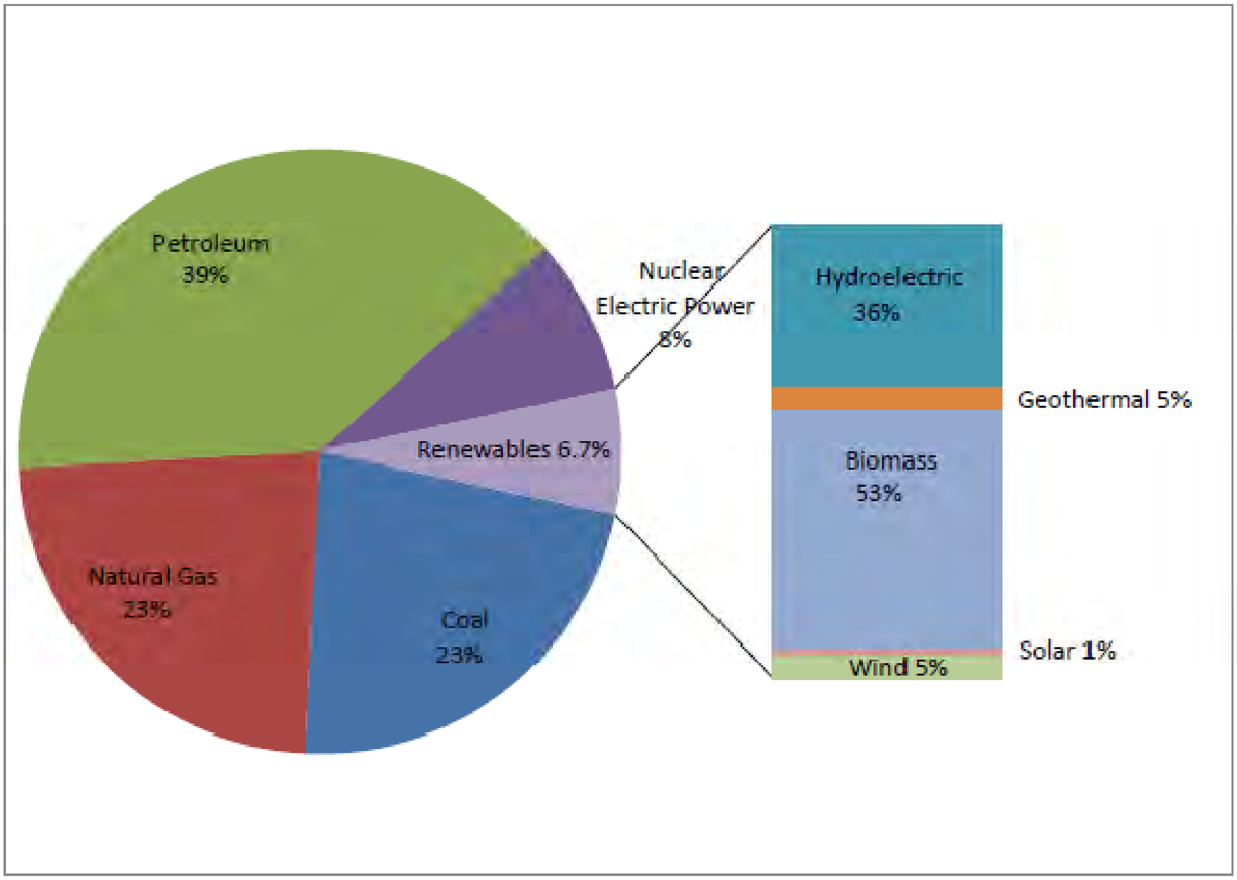


Figure 1-3: U.S. total energy consumption by energy source in 2007 (Source: EIA [2])

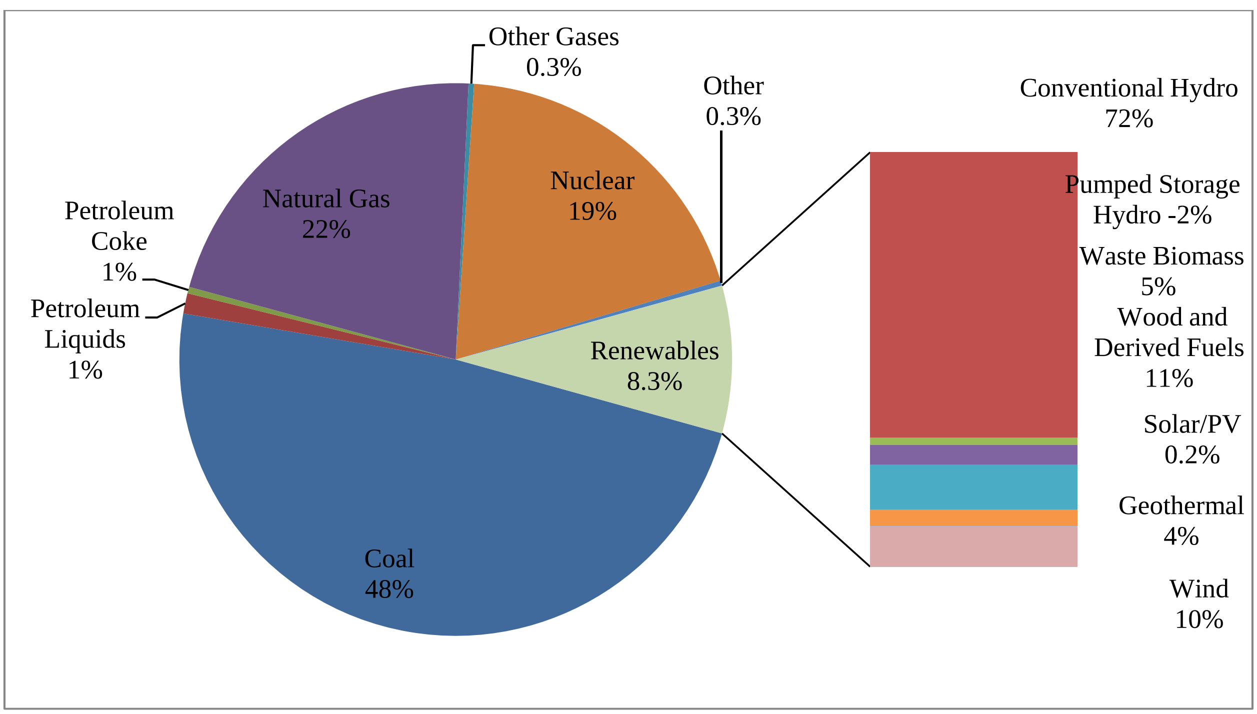


Figure 1-4: Net U.S. electricity generation by energy source in 2007 (Data source: EIA [2, 3])

1.2 Trends in renewable energy consumption in Indiana

Figure 1-5 shows renewable energy consumption in Indiana from 1960 to 2006. 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 the 1990s is accounted for by biomass resources.

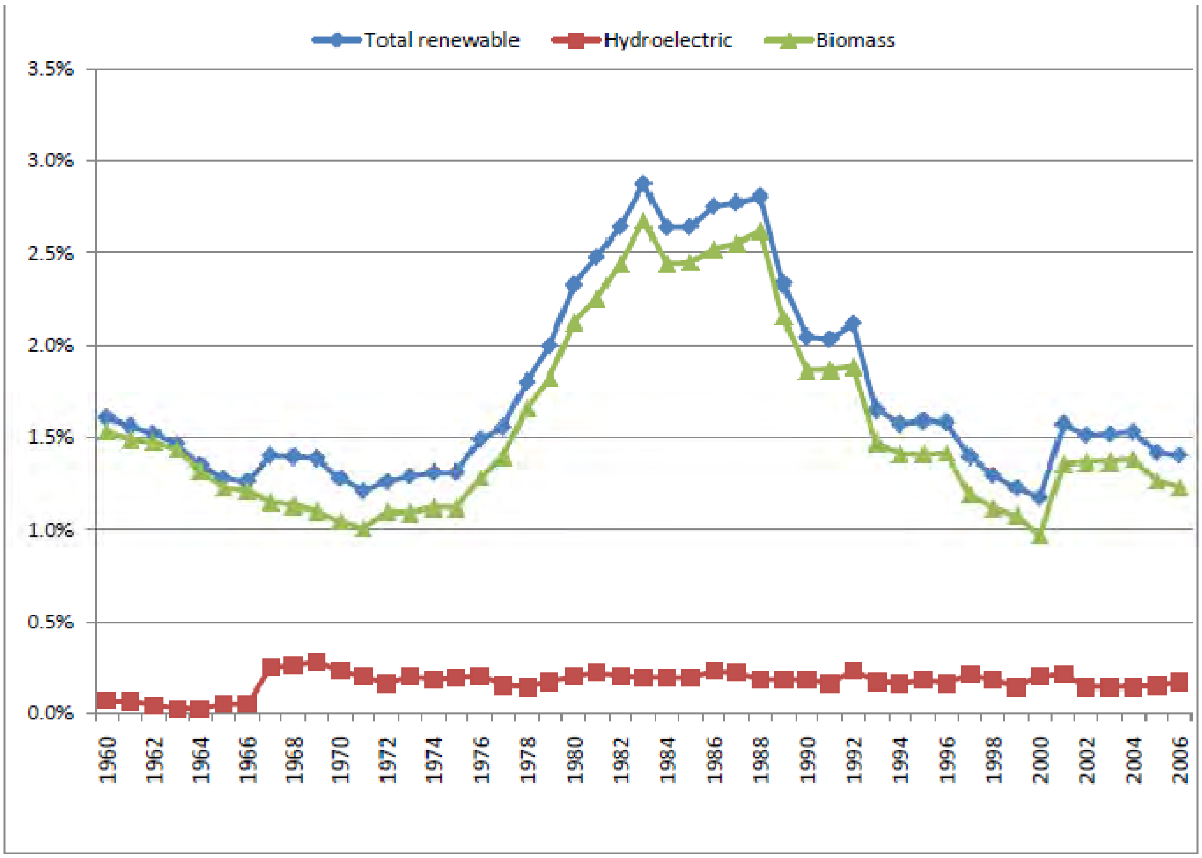


Figure 1-5: Renewables share of Indiana total energy consumption (1960 – 2006) (Data source: EIA [4])

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.

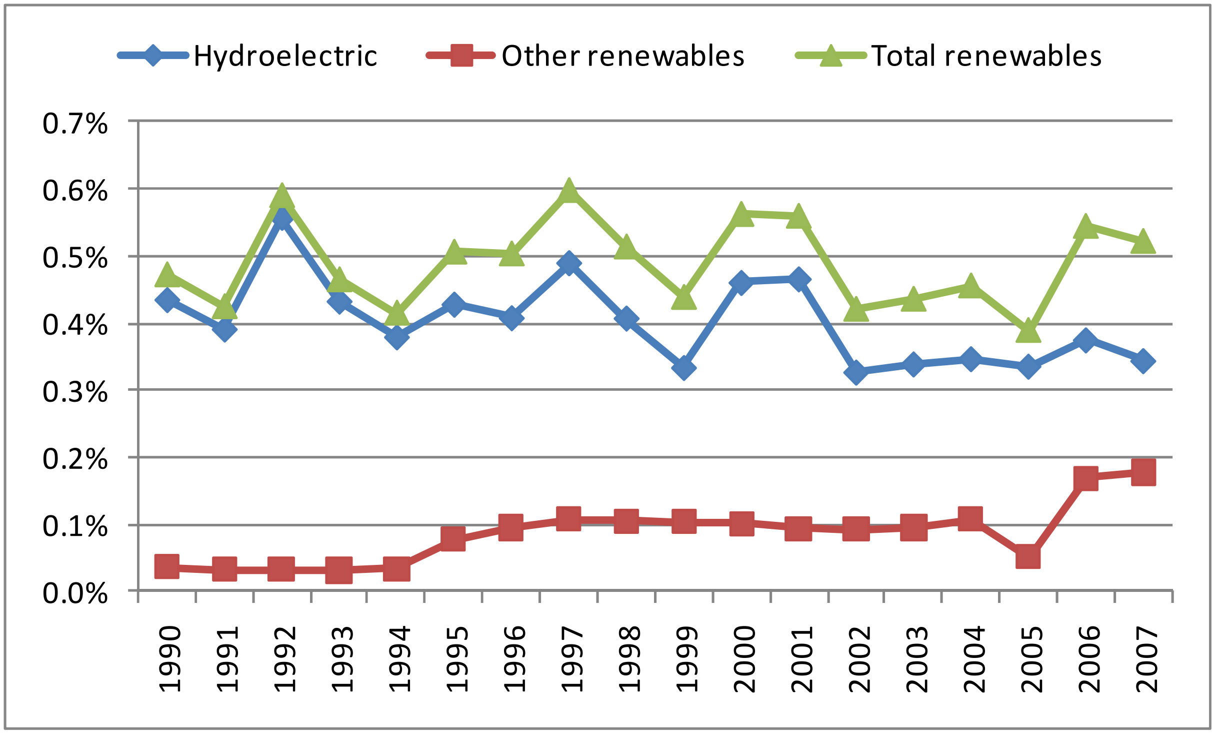


Figure 1-6: Renewables share of Indiana net electricity generation (1990-2007) (Data source: EIA [5])

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 for 2007. It also shows Indiana's ranking among states with respect to electricity cost.

	Indiana (cents/kWh)	*U.S. (cents/kWh)*	*Indiana Rank*
Residential	8.26	10.65	14
Commercial	7.29	9.65	16
Industrial	4.89	6.39	11
All Sectors	6.50	9.13	9

Table 1-1: Indiana's 2007 retail prices comparison and ranking (Data source: EIA [6])

Indiana's wind generating capacity has increased dramatically in the last two years: from a mere 20 kW in 2007 to over 530 MW installed and operational capacity at the time this section was written. The 530 MW capacity commissioned in 2008 and 2009 is distributed between two wind farms in Benton County. They are the Benton County Wind Farm whose 130 MW has been operational since May 2008 and the more recent 400 MW Fowler Ridge Wind Farm that has been operational since March of 2009. Table 1-2 shows the status of the various Indiana wind farm projects.

Project Name	Counties	Developer	Rated Capacity (MW)	Construction Schedule	Status
Benton County Wind Farm	Benton	Orion Energy	130	Completed May 2008	Completed
Fowler Ridge Wind Farm 1	Benton	BP Alternative Energy & Dominion	400	Completed March 2009	Completed
Fowler Ridge Wind Farm II	Benton	BP Alternative Energy	200	Under Construction	Under Construction
Fowler Ridge Wind Farm III	Benton	BP Alternative Energy & Dominion	350		Pending
Hoosier Wind Project	Benton	enXco	106	Under Construction	Under Construction
Tri-County Wind Energy Center	Tippecanoe, Montgomery, Fountain	Invenergy	300-500	Begin construction 2010	Proposed
Meadow Lake Wind Farm Phase I	Benton, White	Horizon Energy	200	Under construction	Under construction
Meadow Lake Wind Farm Phase II	Benton, White	Horizon Energy	800		Proposed
	Randolph	Horizon	100-200		Proposed
	Howard	Horizon	200		Proposed
	Boone	enXco	200-400		Proposed

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

Three wind farms with a combined capacity of 506 MW are currently under construction in Benton and White Counties. They are the Hoosier Wind Farm (106 MW) in Benton County, the first phase of the Meadow Lake Wind Farm (200 MW) in White County and the second phase of the Fowler Ridge Wind Farm (200 MW) in Benton County. The Fowler Ridge project has an additional 350 MW proposed, while the Meadow Lake project has 800 MW proposed. Other proposed projects include a project by Invenergy in Fountain, Montgomery and Tippecanoe Counties and projects in Howard and Randolph Counties by Horizon Energy.

Indiana utilities have signed power purchase agreements (PPAs) to purchase electricity with the developers of wind farms both in and outside Indiana. PPAs with the completed wind farms include Benton County Farms contracts with Duke for 100 MW and 30 MW with Vectren and Fowler Ridge Wind Farm's contract with Indiana Michigan Power (I&M) for 100 MW. PPAs with wind farms under construction in Indiana include Vectren and I&M agreements with Fowler Ridge Phase 2 for 50 MW each and Indianapolis Power and Light's 106 MW contract with the Hoosier Wind Farm. Three of Indiana's utilities have signed agreements to purchase electricity from out of state wind farms. NIPSCO has two PPAs totaling 100 MW: 50 MW from a wind farm in South Dakota and 50 MW from a wind farm in Iowa, Wabash Valley Power Association (WVPA) has an 8 MW PPA with the AgriWind project in Illinois, and Indianapolis Power and Light (IPALCO) has a 201 MW PPA with Lakefield Wind Farm of Minnesota. Table 1-3 lists the purchase agreements for Indiana utilities.

Utility	Project	State	PPA (MW)	Status
Duke Energy	Benton County Wind Farm	Indiana	100	Operational
Vectren	Benton County Wind Farm	Indiana	30	Operational
WVPA	AgriWind	Illinois	8	Operational
Indiana Michigan	Fowler Ridge Wind Farm I	Indiana	100	Operational
Hoosier Energy	Story County Wind Energy Center	Iowa	25	Operational
NIPSCO	Buffalo Ridge	South Dakota	50	Approved
NIPSCO	Barton Windpower	Iowa	50	Approved
IPALCO	Hoosier Wind	Indiana	106	Approved
IPALCO	Lakefield Wind	Minnesota	201	Pending
Vectren	Fowler Ridge Wind Farm II	Indiana	50	Pending
Indiana Michigan	Fowler Ridge Wind Farm II	Indiana	50	Pending

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

1.3 References

1. Energy Information Administration (EIA). 2008 Annual Energy Review, June 2009. http://www.eia.doe.gov/emeu/aer/overview.html
2. EIA. Renewable Energy Trends, 2007 Edition, Release date: April 2009. http://www.eia.doe.gov/cneaf/solar.renewables/page/trends/rentrends.html
3. EIA. Electric Power Monthly, July 2009. http://www.eia.doe.gov/cneaf/electricity/epm/epm_sum.html
4. EIA. State Energy Data System (SEDS), November 2008. http://www.eia.doe.gov/emeu/states/state.html?q_state_a=in&q_state=INDIANA
5. EIA. Indiana Electricity Profile Table 5, Release date: April 2009. http://www.eia.doe.gov/cneaf/electricity/st_profiles/indiana.html
6. EIA. Electric Power Annual 2007 – State Data Tables, Release date: January 2009. http://www.eia.doe.gov/cneaf/electricity/epa/epa_sprdshts.html

2. Energy from Wind

2.1 Introduction

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.

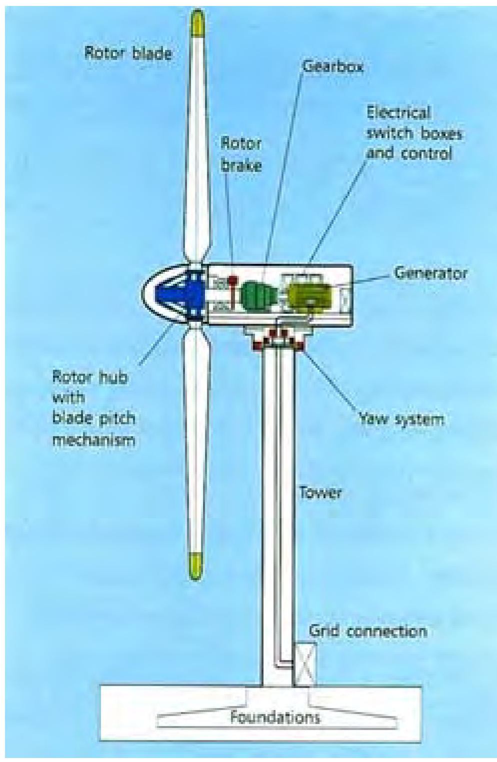


Figure 2-1: Horizontal wind turbine configuration (Source: South Ayrshire Council [1])

Utility scale wind farms in the U.S. began in California in the 1980s, with individual wind turbines 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 [2]. 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 [3], 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 of a wind farm is typically far less than that of a baseload power plant. [2] 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 [4].

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. Wind turbines can be placed on farms or ranches without causing undue interference with farming activities

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.
- 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.

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

- There are concerns regarding the death of birds and bats 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].

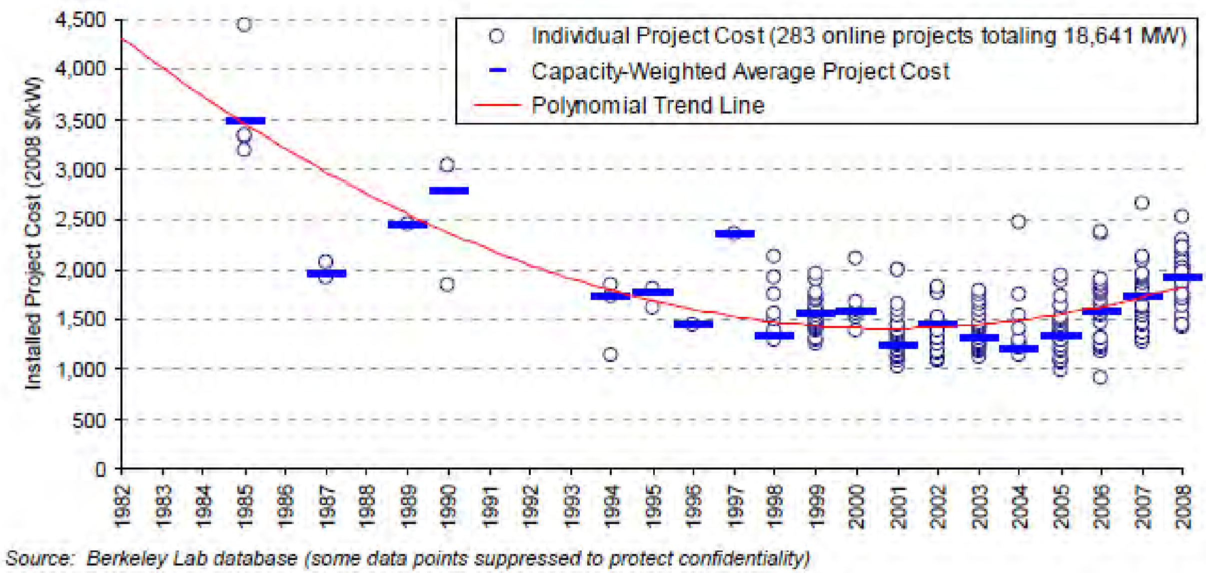


Figure 2-2: Installed wind project costs over time (Source: EERE [8])

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).

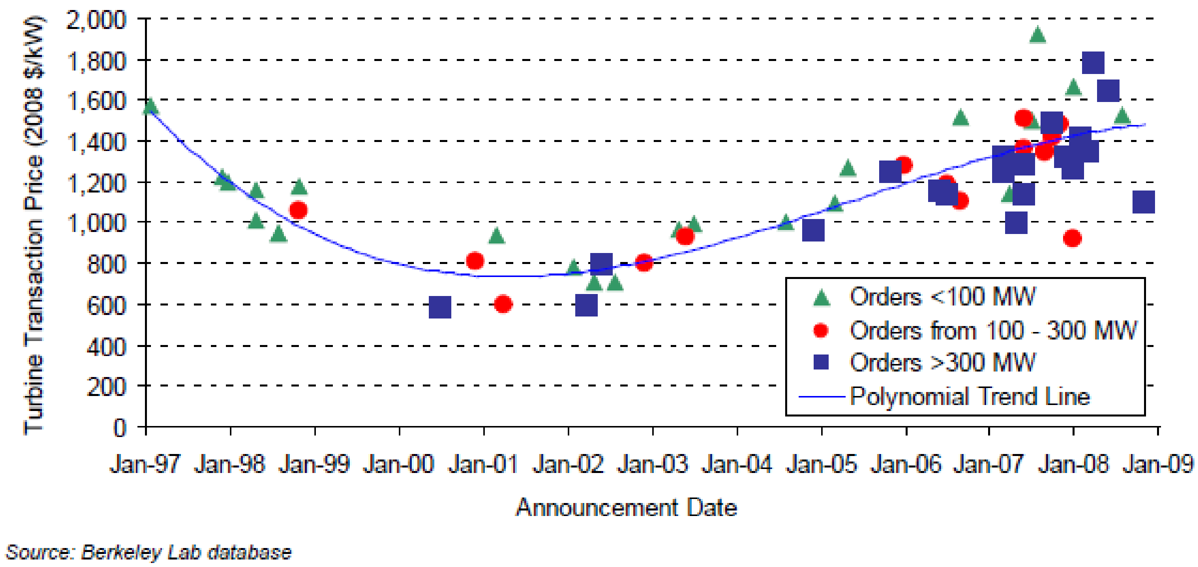


Figure 2-3: Reported U.S. wind turbine prices over time (Source: EERE [8])

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 2008 [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 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.

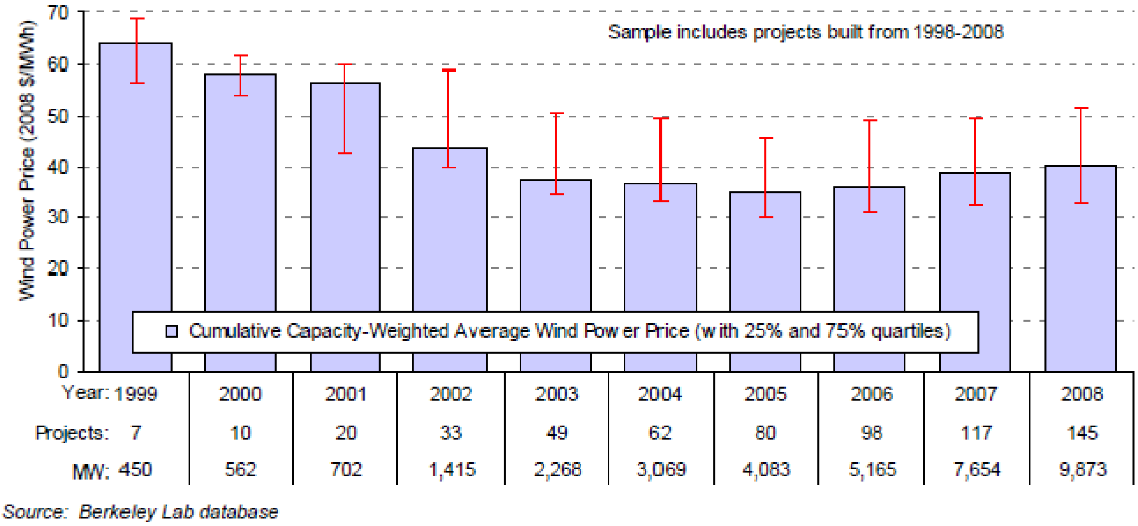


Figure 2-4: Reported U.S. wind power prices over time (Source: EERE [8])

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 wholesale price of electricity in 2008 $/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.

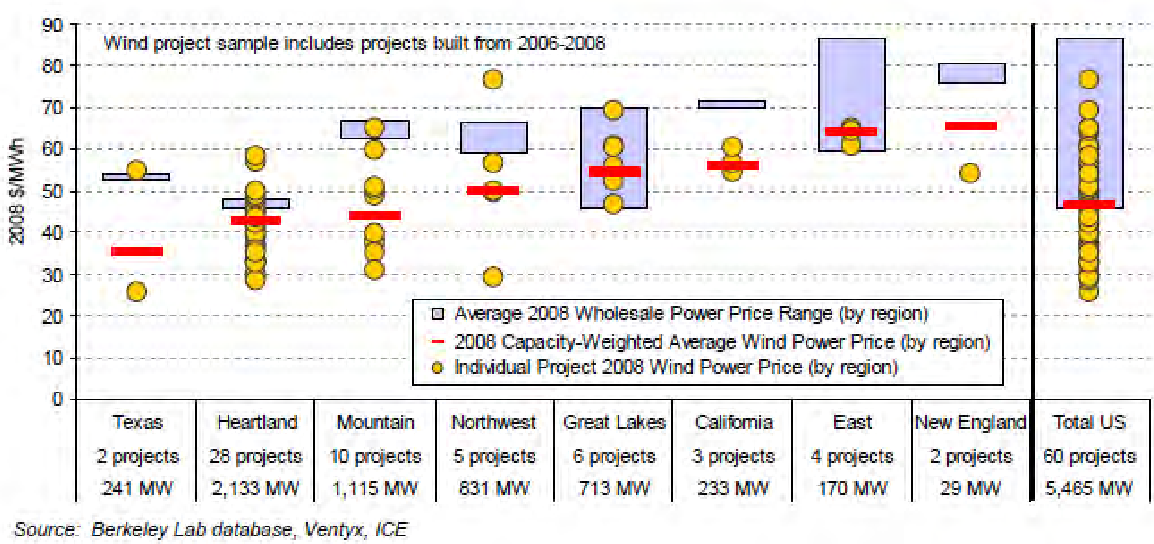


Figure 2-5: Average cumulative wind and wholesale power prices by region (Source: EERE [8])

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 relative to land.

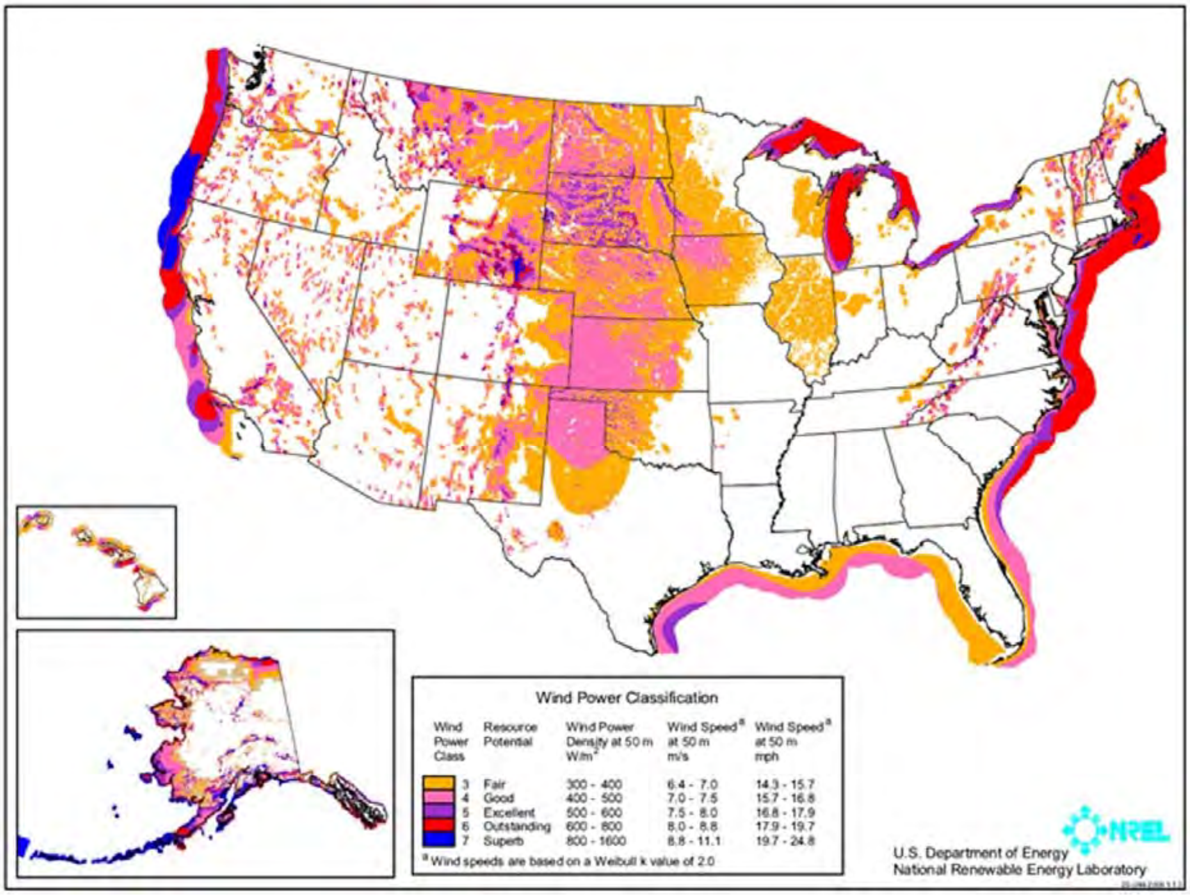


Figure 2-6: National wind energy resource map (Source: EERE [10]

Wind capacity has been expanding rapidly in the U.S. over the past 25 years, as seen in Figure 2-7. A new record for annual wind energy capacity additions was set with the addition of 8,558 MW in 2008. This was 60 percent higher than the previous record set in 2007 of 5,249 MW. To date, all of these installations have been onshore but there are a total of 11 "advanced-stage" proposed offshore wind projects that would add 2,000 MW [8]. The primary drivers behind the rapid expansion of wind energy installations are the federally financed Renewable Electricity Production Tax Credit (PTC), the Renewable Energy Portfolio Standards (RPS) enacted in 29 states at this point, 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 2.1 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 American Recovery and Reinvestment Act of 2009 extended the PTC for wind through 2012. The Act included a provision for renewable facilities that qualify for the PTC to opt for a 30 percent Investment Tax Credit (ITC) or cash grant in lieu of the PTC.

At the state level, three new states established mandatory RPS programs in 2008 (Michigan, Missouri, and Ohio), and Kansas did so in May 2009, bringing the total to 29 states and Washington D.C. [8]. As of April 2009, nine states have surpassed 1,000 MW wind generating capacity. These states are Texas, Iowa, California, Minnesota, Washington, Oregon, New York, Colorado, and Kansas [11]. The RPSs 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 as of May 2009 [12].

In May of 2009, U.S. Energy Secretary Steven Chu, announced that the *American Recovery and Reinvestment Act of 2009* would award $25 million dollars to the state of Massachusetts to further plans for a wind technology testing Center scheduled for opening at the end of 2010 to support the rapid development of the wind industry [13].

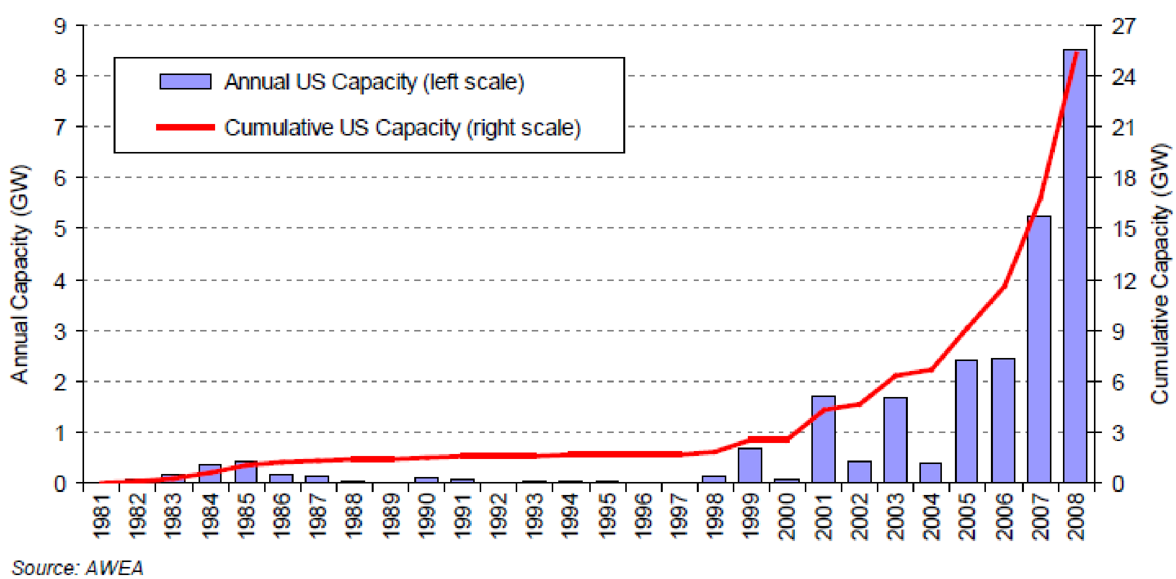


Figure 2-7: Annual and cumulative growth in U.S. wind power capacity (Source: EERE [8])

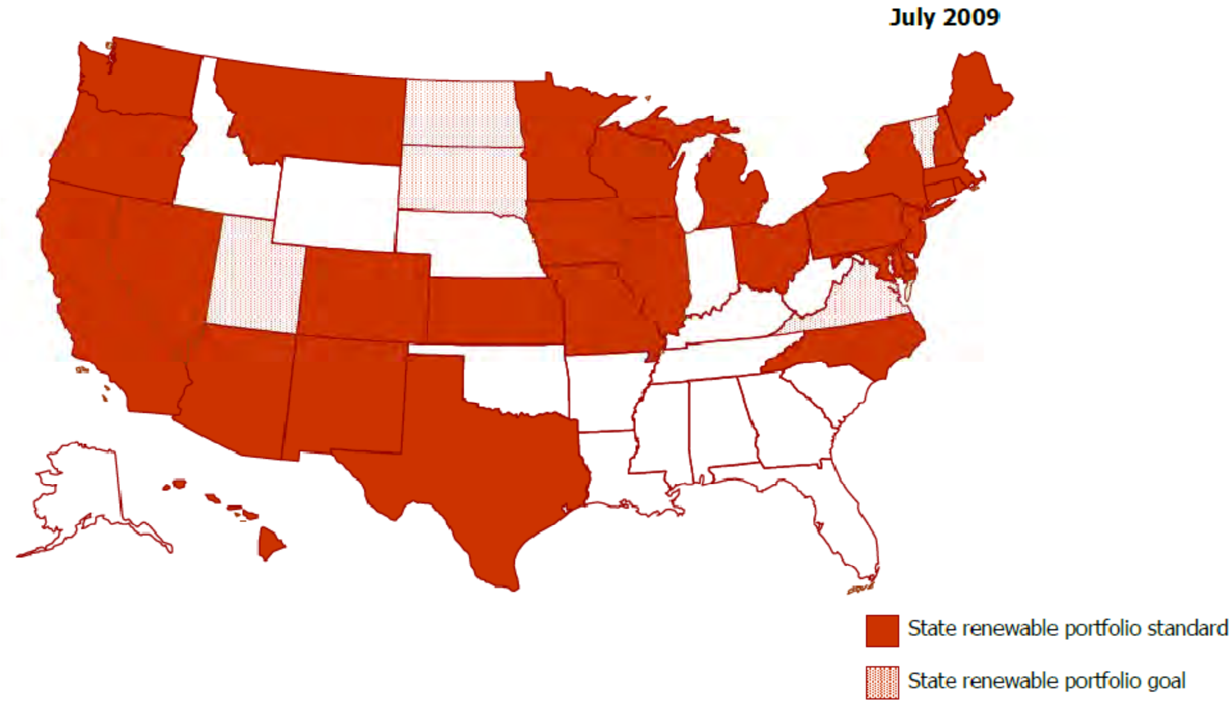
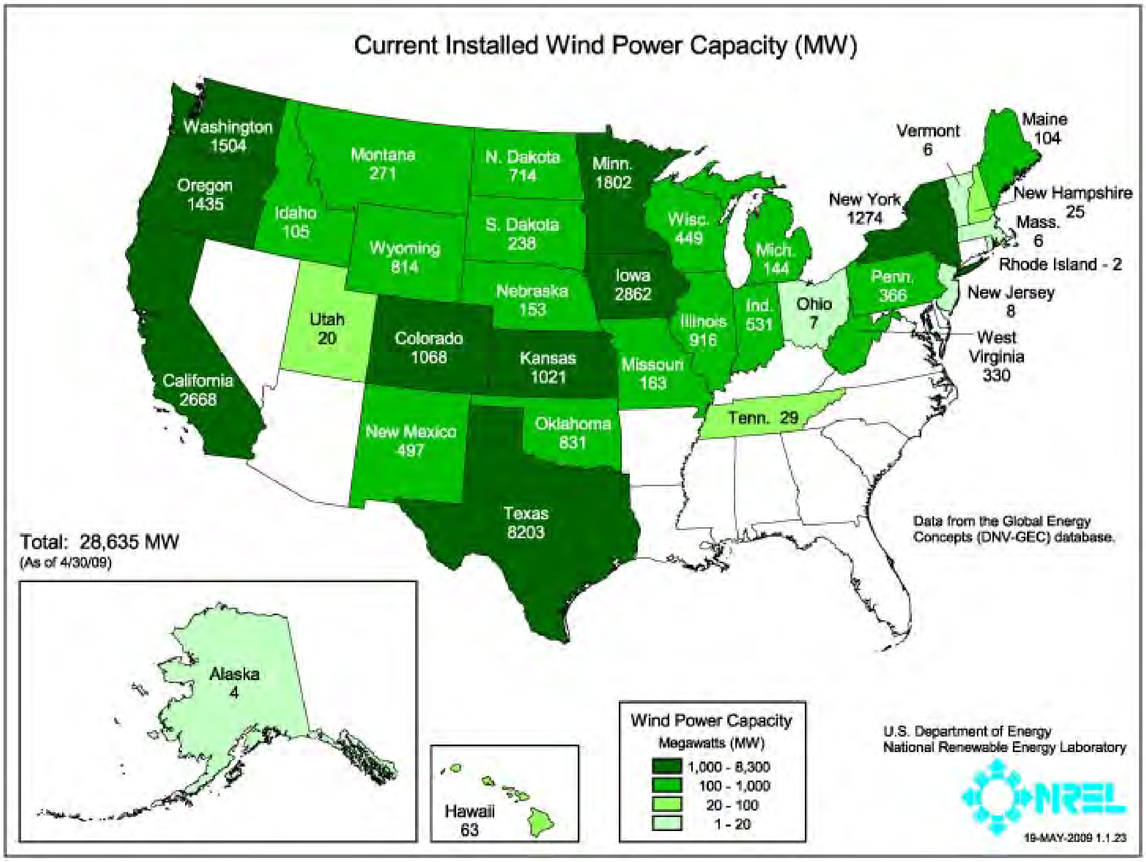


Figure 2-8: Renewable portfolio standards across the U.S. (Source: DSIRE [12])

Figure 2-9 shows the capacity of wind energy installed in states as of May 2009. Texas continued its lead in total capacity at 8,203 MW total wind capacity installed followed by Iowa with 2,862 MW. The other states in the top five were California – 2.668; Minnesota – 1,802; Washington – 1,504.



<u>Figure 2-9:</u> <u>Wind power capacity by state as of May 2009</u> (Source: EERE [8])

When one considers the wind energy as a percent of the total energy generated in 2008, Texas drops to eighth place behind Oregon whose total installed capacity at the end of 2008 was only 1,067 compared to Texas' 7,118. The leading five states in wind energy as percentage of total electricity generated in 2008 are Iowa –13.3 percent, Minnesota – 10.4 percent, South Dakota – 8.8 percent, North Dakota – 7.1 percent and Kansas – 6.7 percent. Table 2-2 shows the top twenty states in capacity added in 2008, total cumulative capacity and wind energy as a percentage of total electricity generated in 2008.

Capacity additions in 2008 (MW)		Total capacity at end of 2008 (MW)		Estimated percentage of in-state generation in 2008	
Texas	2,671	Texas	7,118	Iowa	13.3%
Iowa	1,600	Iowa	2,791	Minnesota	10.4%
Minnesota	456	California	2,517	South Dakota	8.8%
Kansas	450	Minnesota	1,753	North Dakota	7.1%
New York	407	Washington	1,447	Kansas	6.7%
Wyoming	388	Colorado	1,068	Colorado	6.6%
North Dakota	370	Oregon	1,067	Oregon	5.4%
Wisconsin	342	Illinois	915	Texas	5.3%
Washington	284	New York	832	New Mexico	4.5%
West Virginia	264	Oklahoma	831	Wyoming	4.1%
Illinois	216	Kansas	815	Washington	3.9%
Oregon	185	North Dakota	714	Oklahoma	3.7%
Oklahoma	142	Wyoming	676	Montana	3.4%
Indiana	131	New Mexico	497	California	3.1%
Michigan	127	Wisconsin	395	Hawaii	2.2%
Montana	125	Pennsylvania	361	Idaho	1.6%
Missouri	106	West Virginia	330	New York	1.4%
South Dakota	89	Montana	272	Illinois	1.4%
California	89	South Dakota	187	Wisconsin	1.3%
Pennsylvania	67	Missouri	163	West Virginia	0.9%
Rest of U.S.	52	*Rest of U.S.*	622	*Rest of U.S.*	0.2%
TOTAL	**8,558**	**TOTAL**	**25,369**	**TOTAL**	**1.8%**

Table 2-2: U.S. wind power rankings: Top 20 states (Data 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 in 2008 to 20 percent by 2030 [14].

2.4 Wind energy in Indiana

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 [15]. 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.

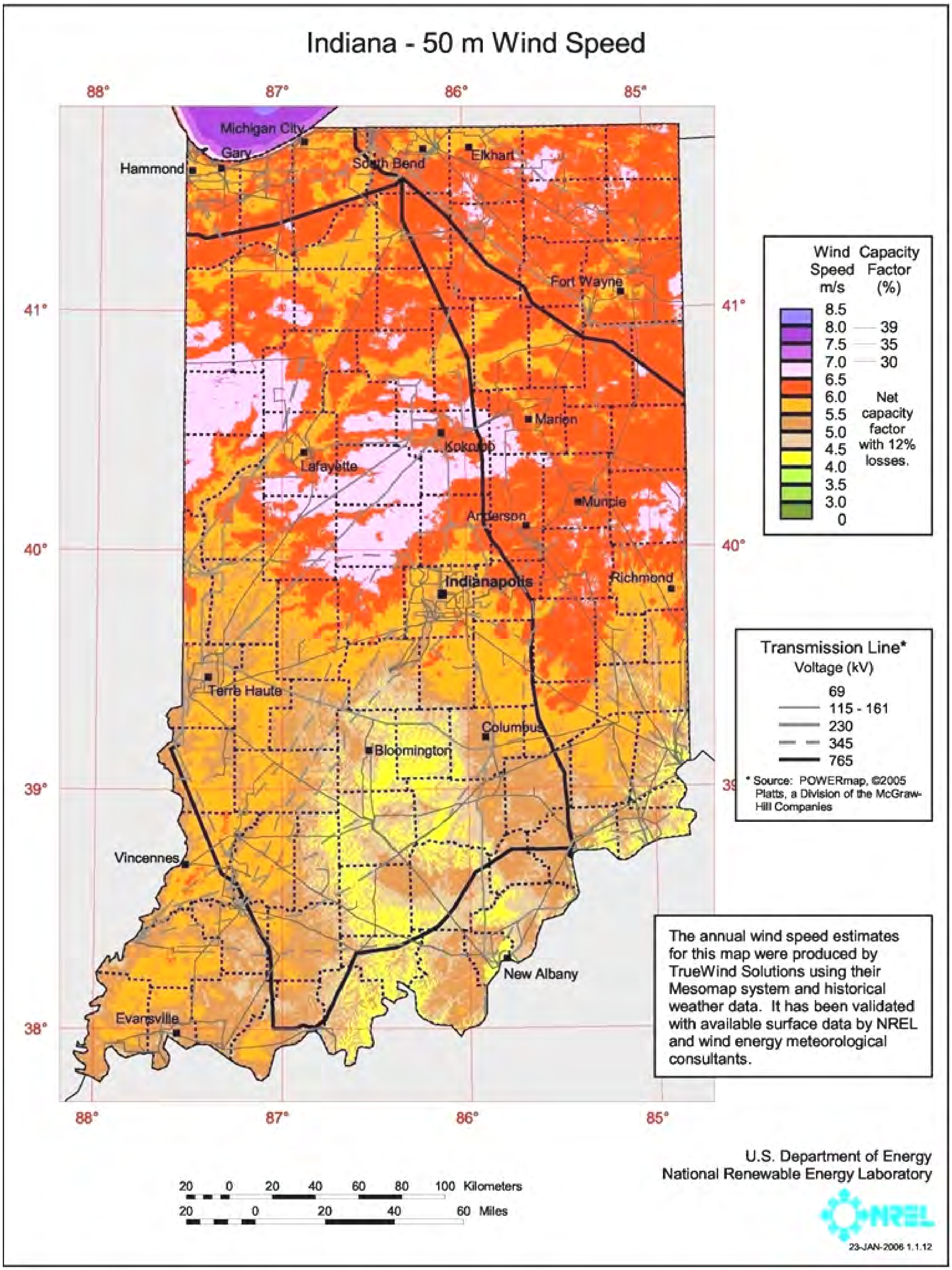


Figure 2-10: Indiana wind speed at 50 meters height (Source: OEDD [15])

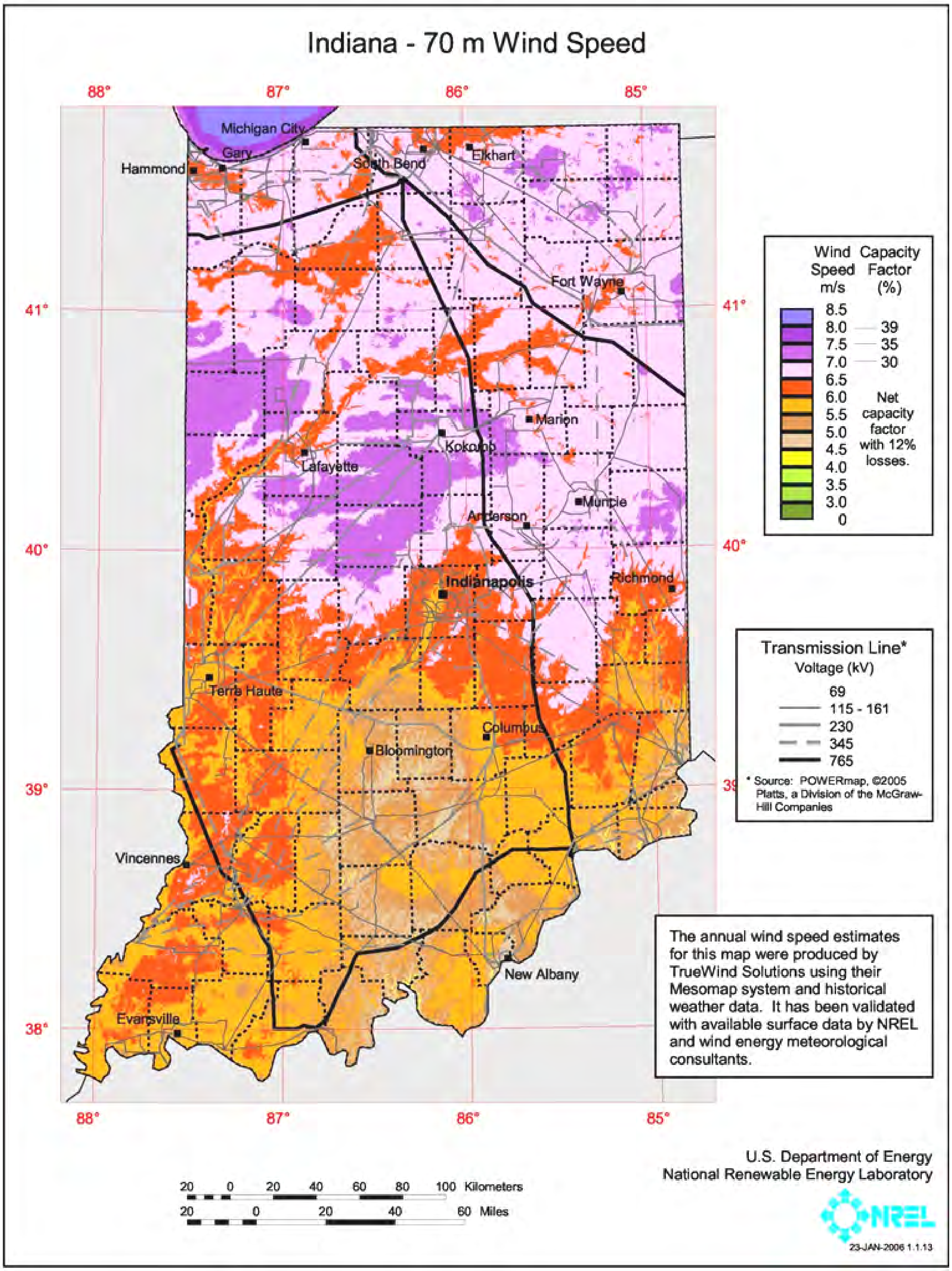


Figure 2-11: Indiana wind speed at 70 meters height (Source: OEDD [15])

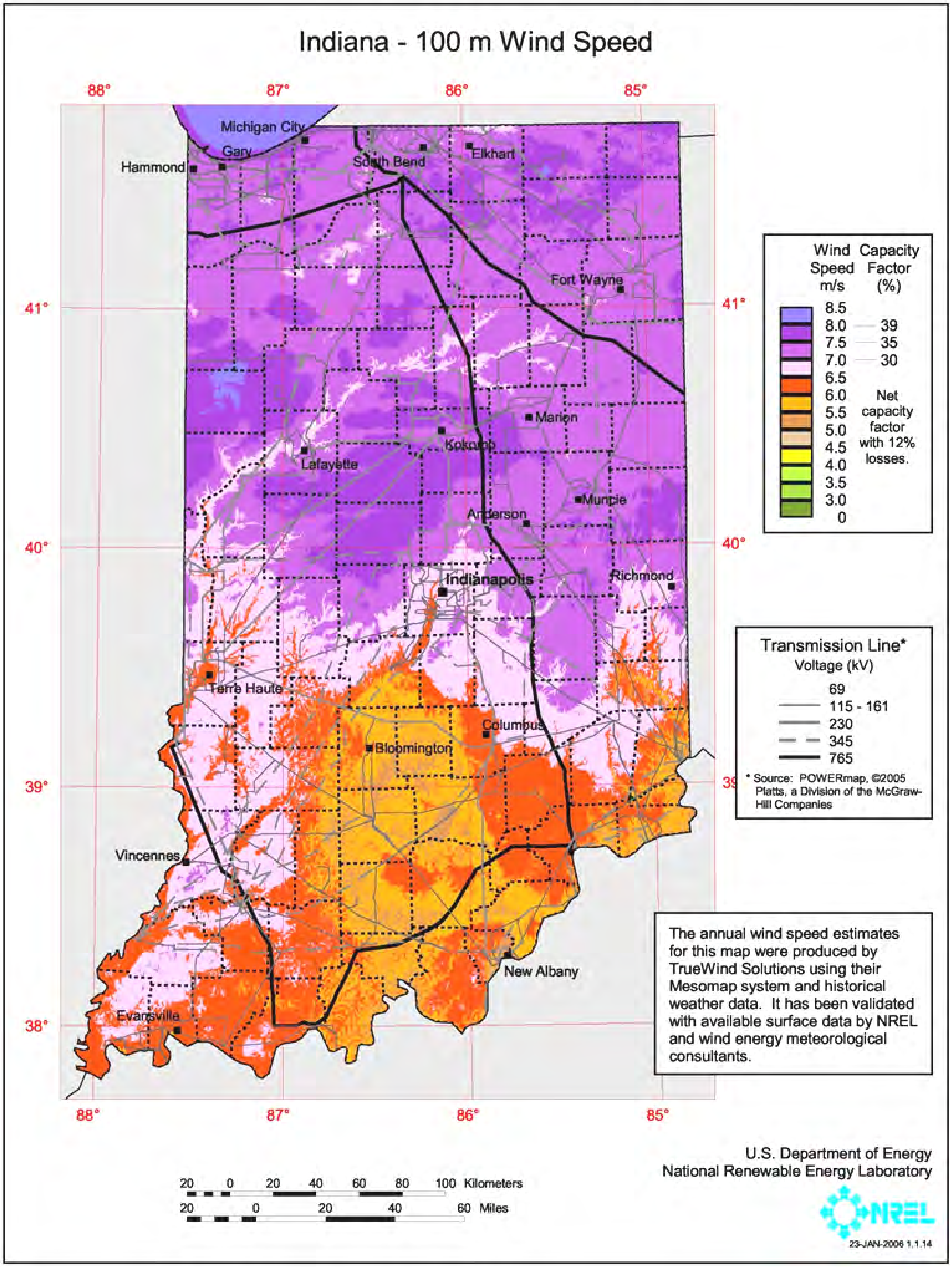


Figure 2-12: Indiana wind speed at 100 meters height (Source: OEDD [15])

Indiana's wind generating capacity has increased dramatically in the last two years from a mere 20 kW in 2007 to over 530 MW installed and operational capacity. The 530 MW capacity commissioned in 2008 and 2009 is distributed between two wind farms in Benton County: the Benton County Wind Farm, with 130 MW in operation since May 2008, and the 400 MW Fowler Ridge Wind Farm that has been operational since March of 2009. Three wind farms with a combined capacity of 506 MW are currently under construction in Benton and White Counties: the Hoosier Wind Farm (106 MW) in Benton County, the first phase of the Meadow Lake Wind Farm (200 MW) in White County and the second phase of the Fowler Ridge Wind Farm (200 MW) in Benton County. The Fowler Ridge project has an additional 350 MW proposed, while the Meadow Lake project has 800 MW proposed. Other proposed projects include a project by Invenergy in Fountain, Montgomery and Tippecanoe Counties and projects in Howard and Randolph Counties by Horizon Energy. Table 2-3 shows the status of the various Indiana wind farm projects.

Project Name	Counties	Developer	Rated Capacity (MW)	Construction Schedule	Status
Benton County Wind Farm	Benton	Orion Energy	130	Completed May 2008	Completed
Fowler Ridge Wind Farm 1	Benton	BP Alternative Energy & Dominion	400	Completed March 2009	Completed
Fowler Ridge Wind Farm II	Benton	BP Alternative Energy	200	Under Construction	Under Construction
Fowler Ridge Wind Farm III	Benton	BP Alternative Energy & Dominion	350		Pending
Hoosier Wind Project	Benton	enXco	106	Under Construction	Under Construction
Tri-County Wind Energy Center	Tippecanoe, Montgomery, Fountain	Invenergy	300-500	Begin construction 2010	Proposed
Meadow Lake Wind Farm Phase I	Benton, White	Horizon Energy	200	Under construction	Under construction
Meadow Lake Wind Farm Phase II	Benton, White	Horizon Energy	800		Proposed
	Randolph	Horizon	100-200		Proposed
	Howard	Horizon	200		Proposed
	Boone	enXco	200-400		Proposed

Table 2-3: Status of wind generation projects in Indiana

Indiana utilities have signed power purchase agreements (PPAs) to purchase electricity with the developers of wind farms in and outside Indiana. PPAs with the completed wind farms in Indiana include Benton County Farms contracts with Duke for 100MW and 30MW with Vectren and Fowler Ridge Wind Farm's contract with Indiana Michigan Power (I&M) for 100MW. PPAs with wind farms under construction in Indiana include Vectren and I&M agreements with Fowler Ridge Phase 2 for 50 MW each and Indianapolis Power and Light's 106 MW contract with the Hoosier Wind Farm. Four of Indiana's utilities have signed agreements to purchase electricity from out of state wind farms. NIPSCO has two PPAs totaling 100 MW: 50 MW from a wind farm in South Dakota and 50 MW from a wind farm in Iowa, Wabash Valley Power Association (WVPA) has an 8 MW PPA with the AgriWind project in Illinois, Indianapolis Power and Light (IPALCO) has a 201 MW PPA with Lakefield Wind Farm of Minnesota, and Hoosier Energy a 25 MW agreement with the Story County Wind Project in Iowa. Table 2-4 lists the PPAs that Indiana utilities have to purchase wind power.

Utility	Project	State	PPA (MW)	Status
Duke Energy	Benton County Wind Farm	Indiana	100	Operational
Vectren	Benton County Wind Farm	Indiana	30	Operational
WVPA	AgriWind	Illinois	8	Operational
Indiana Michigan	Fowler Ridge Wind Farm I	Indiana	100	Operational
Hoosier Energy	Story County Wind Energy Center	Iowa	25	Operational
NIPSCO	Buffalo Ridge	South Dakota	50	Approved
NIPSCO	Barton Windpower	Iowa	50	Approved
IPALCO	Hoosier Wind	Indiana	106	Approved
IPALCO	Lakefield Wind	Minnesota	201	Pending
Vectren	Fowler Ridge Wind Farm II	Indiana	50	Pending
Indiana Michigan	Fowler Ridge Wind Farm II	Indiana	50	Pending

Table 2-4: Wind energy power purchase agreements by Indiana utilities

2.5 Incentives for wind energy

The following federal and state incentives are available for wind energy projects [12].

Federal Incentives

- Renewable Electricity Production Tax Credit (PTC) credits wind energy producers with 2.1 cents/kWh during the first ten years of operation. The PTC was modified in the February 2009 Stimulus Act to allow producers who would qualify for the PTC to opt to take the federal business energy investment tax credit (ITC) or equivalent cash grant from the U.S. Department of Treasury [12].
- Business Energy Investment Tax Credit (ITC) credits up to 30 percent of expenditures on qualifying wind energy installations.
- Renewable Energy Production Incentive (REPI) provides financial incentives similar to the Production Tax Credit to wind generators owned by not-for-profit groups, public-owned utilities and other such organizations [12]. REPI payments are subject to availability of annual appropriations by congress.
- 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).
- Qualifying Advanced Energy Project Investment Tax Credit encourages the development of a U.S.-based renewable energy manufacturing sector. The tax credit is equal to 30 percent of the qualified investment required for an advanced energy project that establishes, re-equips or expands a manufacturing facility that produces equipment and/or technologies used to produce energy qualifying renewable resources [12].
- Residential Renewable Energy Tax Credit allows taxpayers to claim 30 percent of their qualifying expenditures on installation of small wind-energy systems for the dwelling in which they reside [12].
- Modified Accelerated Cost-Recovery System (MACRS): This program allows businesses to recover investments in solar, wind and geothermal property through depreciation deductions. The Federal *Economic Stimulus Act of 2008* included a 50 percent bonus depreciation provision for eligible renewable-energy systems acquired and placed in service in 2008 and was extended to include the 2009 tax year.
- 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 Energy Improvement and Extension Act of 2008 allocated $800 million for new CREBs. In February 2009, the American Recovery and

Reinvestment Act of 2009 allocated an additional $1.6 billion for new CREBs, for a total new CREB allocation of $2.4 billion [12].

- Qualified Energy Conservation Bonds (QECBs) are similar to Clean Renewable Energy Bonds except that they are not subject to the U.S. Department of Treasury application process and instead are allocated to each state based upon their state's percentage of the U.S. population. The states are then required to allocate a certain percentage to "large local governments."[12]
- 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 [12].
- Value-Added Producer Grant Program: Grants are available to independent producers, agricultural producer groups, farmer or rancher cooperatives, and majority-controlled producer-based business ventures seeking funding. Previously awarded grants 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 [16].
- Rural Energy for America Program promotes energy efficiency and renewable energy for agricultural producers and rural small businesses through the use of (1) grants and loan guarantees for energy efficiency improvements and renewable energy systems, and (2) grants for energy audits and renewable energy development assistance. The program covers up to 25 percent of costs. Congress has allocated funding for the new program in the following amounts: $55 million for FY 2009, $60 million for FY 2010, $70 million for FY 2011, and $70 million for FY 2012 [12].

Indiana Incentives

- Alternative Power and Energy Grant Program: offers grants of up to $100,000 to Indiana public, non-profit, and business sectors for the purchase and installation of alternative energy systems that offset fossil fuel usage and create jobs [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 [12].
- 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.

2.6 References

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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]:

- <u>Direct combustion</u>: 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.
- <u>Co-firing</u>: 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.
- <u>Chemical and biochemical conversion</u>: 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.
- <u>Gasification</u>: 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).

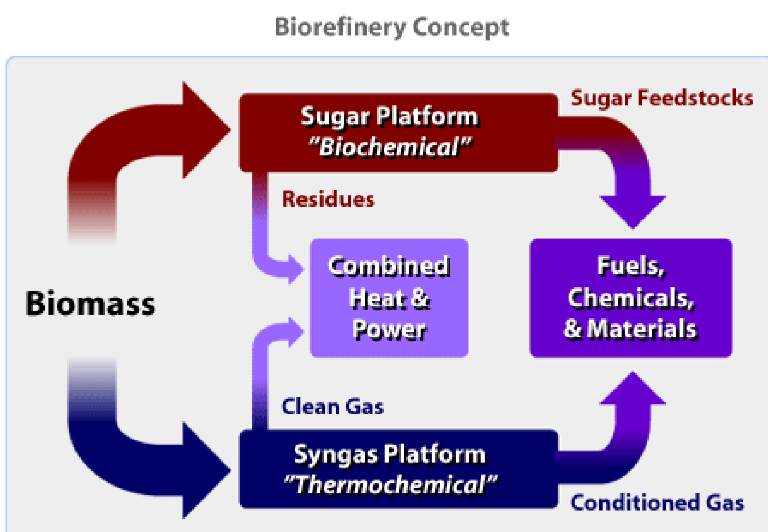

Figure 3-1: NREL biorefinery platforms (Source: NREL [8])

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]. On May 5, 2009, U. S. Secretary of Energy Steven Chu announced that the *American Reinvestment and Recovery Act* would allocate nearly $800 million for biofuels research and commercialization, which includes additional funding for commercial-scale biorefinery demonstration projects [9].

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 [10]. 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 [10].

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. [11]. 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 [12].

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 [12])

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 [13].

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 was predicted to 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 [14]. The estimated national supply curve for biomass and energy crops produced by POLYSYS for the year 2020 is shown in Figure 3-2.

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.

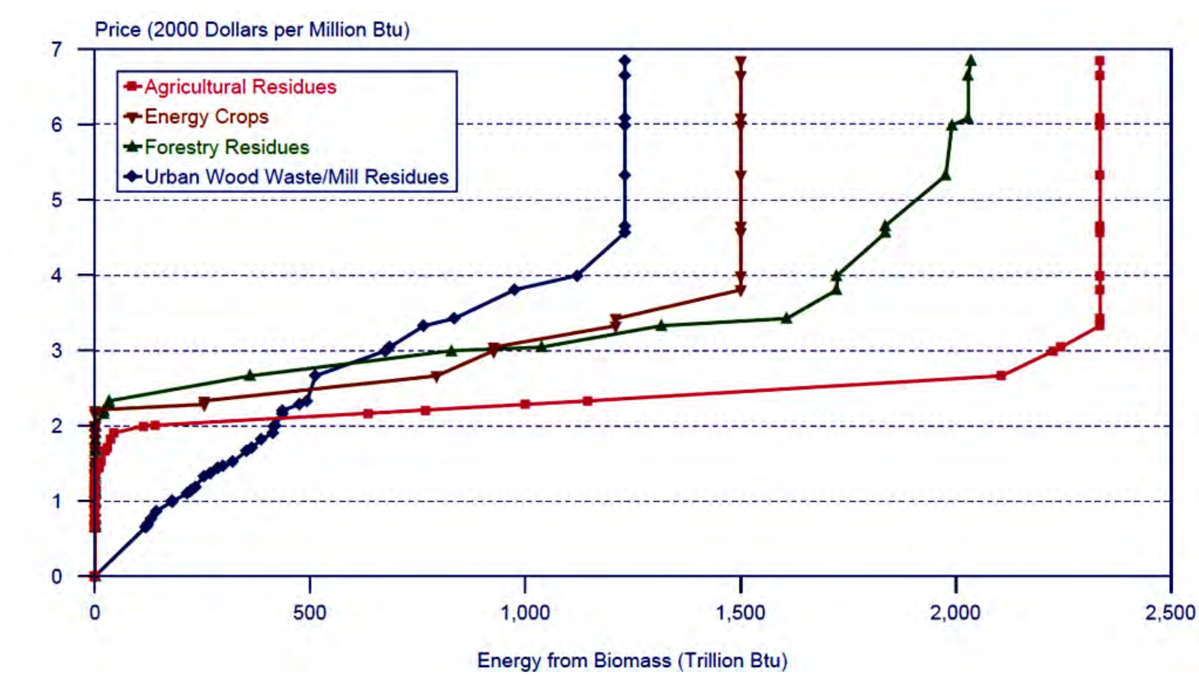

Figure 3-2: POLYSYS estimated biomass supply curve for year 2020 (Source: EIA)

Corn and soybean use for biofuel production

Although corn and soybeans do not meet the strict definition of a dedicated energy crops, their rapid rise as a feedstock for ethanol and biodiesel 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 and biodiesel is in the transportation sector. Before the construction boom in the mid 2000s Indiana's ethanol production capacity consisted of one facility, with a 102 million gallons per year (MGY) production capacity and not a single biodiesel plant. The corn-based ethanol production capacity was increased to 784 MGY by the addition of eleven ethanol plants, and biodiesel capacity increased to 118 MGY across five plants. Tables 3-2 and 3-3 show the location and capacities of the ethanol and biodiesel plants in Indiana [16, 17]. The following factors account for the rapid increase in biofuel production.

- 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 [18].
- 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 [19].
- 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 [20].

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. [21]

Company	Location	Current Capacity (MGY*)
New Energy Corp	South Bend	102
Central Indiana Ethanol	Marion	40
Iroquois Bio-Energy Co.	Rensselaer	40
POET Energy	Portland	68
POET Energy	Alexandria	68
POET Energy	North Manchester	68
The Andersons Clymers	Clymers	110
VeraSun Energy Co.	Linden	110
AltraBiofuels Indiana	Cloverdale	92
Cardinal Ethanol	Union City	100
Green Plains Bluffton	Bluffton	110
Abengoa Bioenergy Corp.	Mt. Vernon	88#

*MGY is million gallons per year. #capacity obtained from Abengoa Bioenergy Website[22].

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

Biodiesel plant Name	Year	Town/County	Estimated Capacity (MGY)
E-biofuels	2007	Middletowm/Henry	5
Evergreen Renewables	2006	Hammond/Lake	5
Integrity Biofuels	2006	Morristown/Shelby	10
Louis Dreyfus	2007	Claypool/Kosciusko	88
Xenerga	2008	Kingsbury/LaPorte	10

Table 3-3: Biodiesel plants in Indiana (Data source: ISDA [17])

3.3 State of energy crops nationally

Energy crops can be grown on most of the land classified as cropland in the U.S. [10]. 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 [23]. Figure 3-3 shows estimated biomass production potential nationally [24]. 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 marginal for conventional crop production.

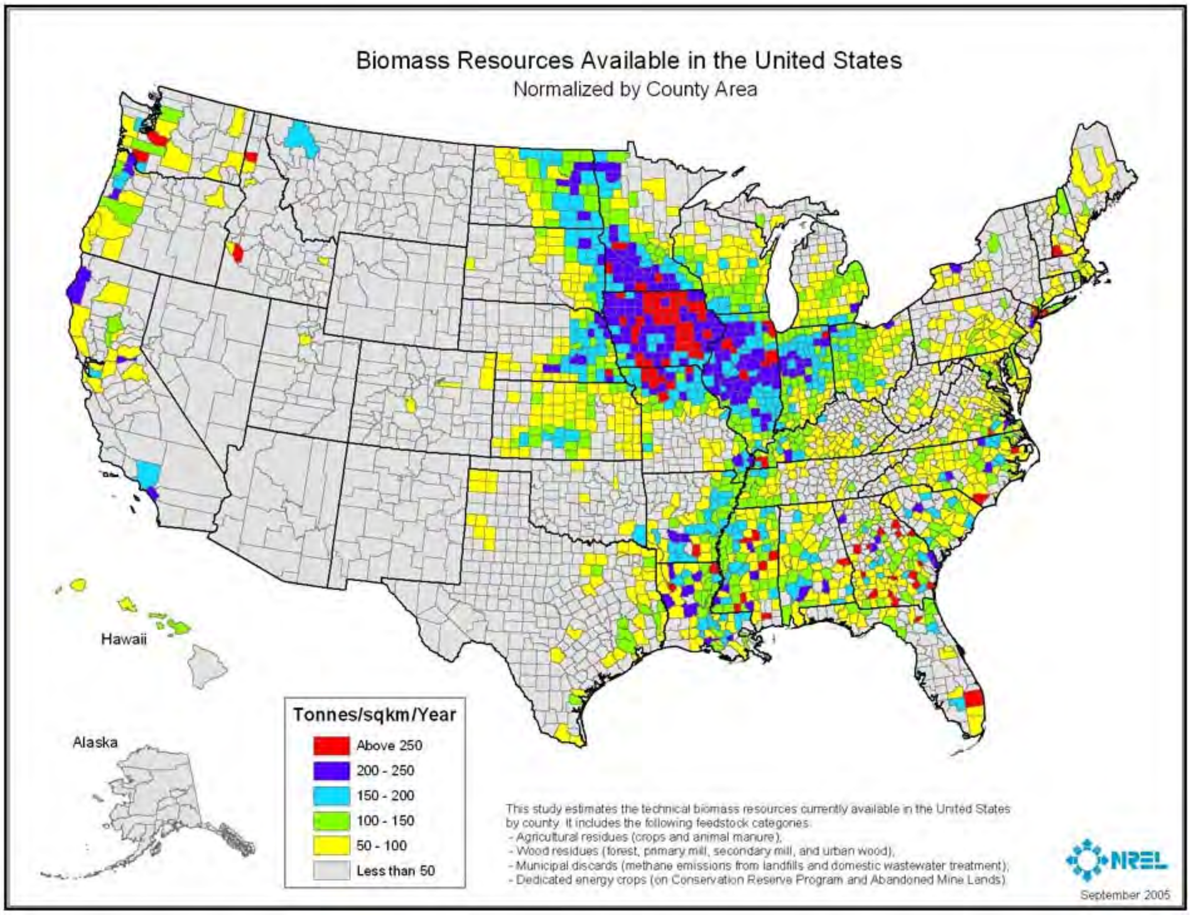

Figure 3-3: Biomass resources available in the U.S. (Source: NREL [24])

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, 25]. 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* [14].

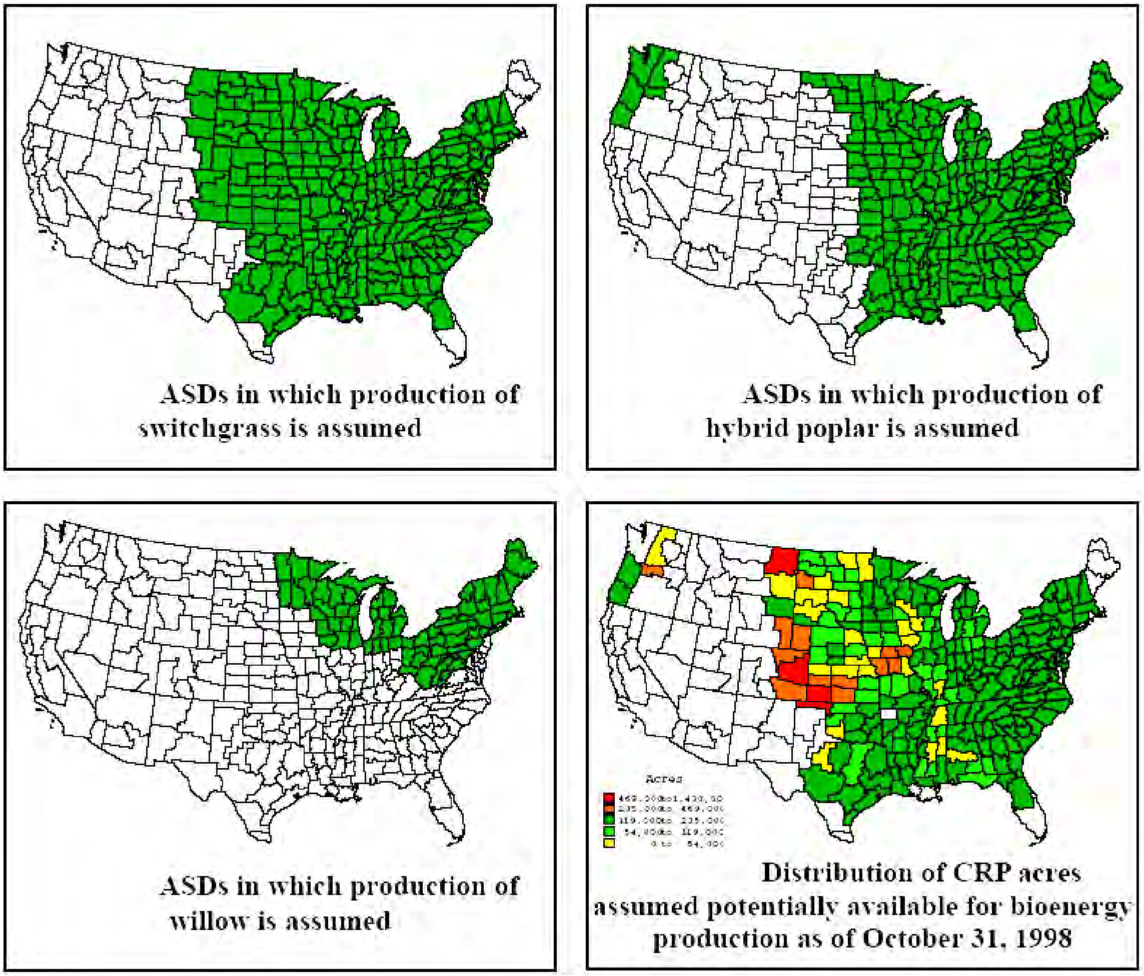

Figure 3-4: POLYSYS assumed Agricultural Statistical Districts (ASDs) for energy crop production (Source: University of Tennessee [14])

The energy crop yield assumptions that have been used for the POLYSYS model are displayed in Table 3-4. 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 switchgrass, it can be harvested 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, perhaps 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 3-4: 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 [14]. 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 [23]. Note that the CRP did not exist until 1985.

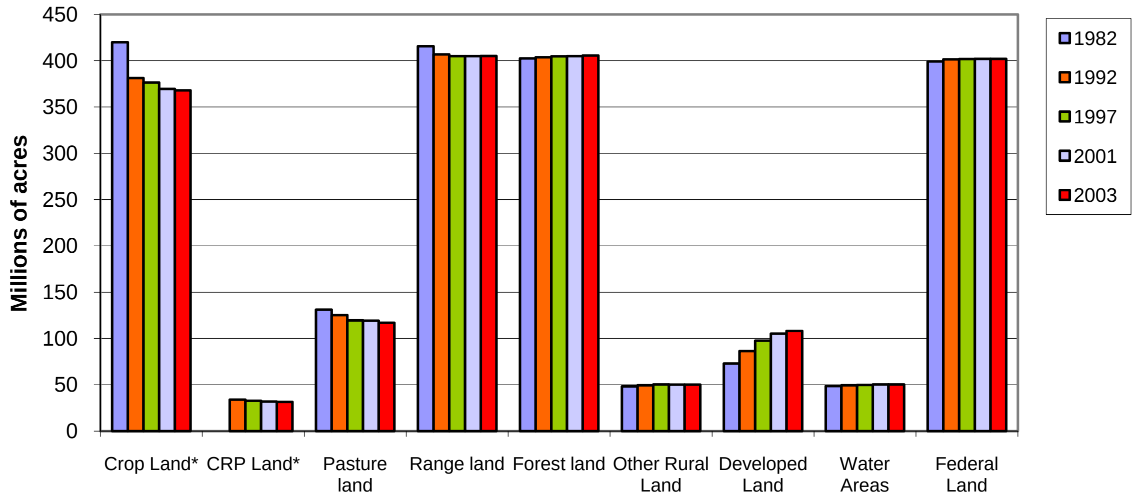

Figure 3-5: Land use in the contiguous U.S. (Source: USDA [23])

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 the Ball State 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, 26]. 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.

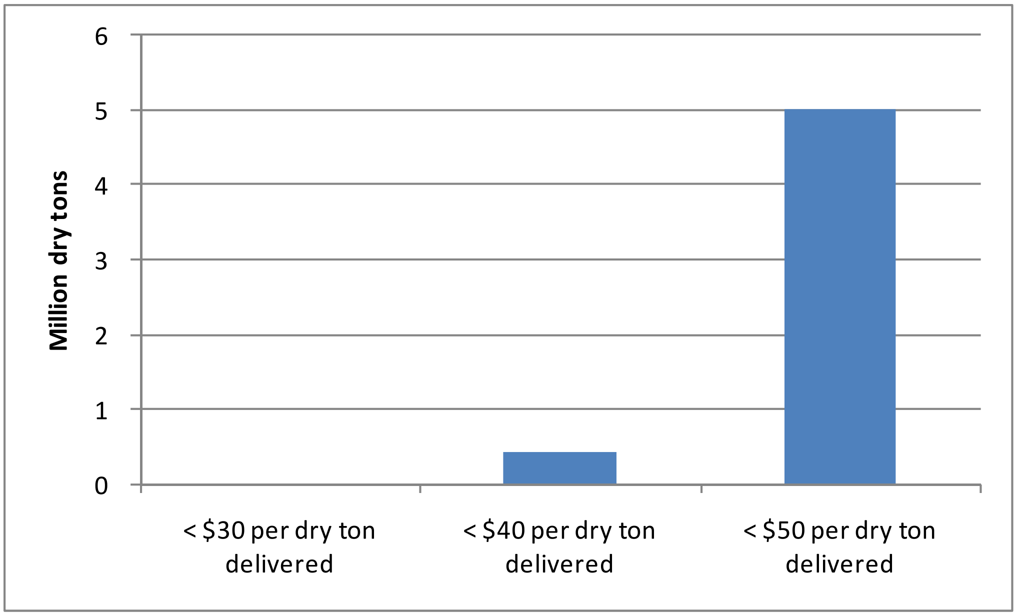

Figure 3-6: Estimated annual cumulative energy crop quantities (dry tons) by delivered price (1997 dollars) for Indiana (Data source: ORNL [1])

The estimates of switchgrass and poplar production in a 2006 ORNL [27] 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.

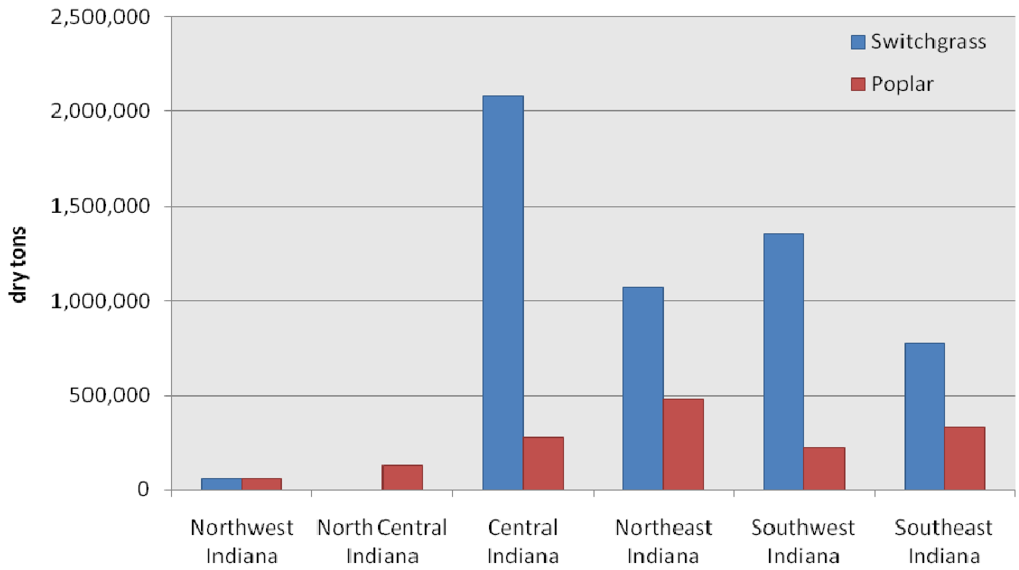

Figure 3-7: Estimated annual potential production of switchgrass and hybrid poplar (dry tons) for Indiana, USDA baseline 2001 (Source: ORNL [27])

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 3-5 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 3-5: Average cost ($/ton) for producing switchgrass in Indiana (Source: Brechbill & Tyner [28])

3.5 Incentives for energy crops

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

Federal Incentives

- Renewable Electricity Production Tax Credit (PTC) provides a 2.1 cents/kWh tax credit for wind, geothermal and closed-loop biomass and 1.1 cents/kWh for open-loop biomass, landfill gas municipal solid waste small hydroelectric and marine energy technologies. As part of the February 2009 Stimulus Act the PTC was modified to provide the option for qualified producers to take the federal business energy investment tax credit (ITC) or an equivalent cash grant from the U.S. Department of Treasury. Dedicated energy crops fall under the closed loop biomass category [29].

- Business Energy Investment Tax Credit (ITC) credits up to 30 percent of expenditures on qualified qualifying renewable energy systems [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].
- Rural Energy for America Program promotes energy efficiency and renewable energy for agricultural producers and rural small businesses through the use of (1) grants and loan guarantees for energy efficiency improvements and renewable energy systems, and (2) grants for energy audits and renewable energy development assistance. The program covers up to 25 percent of costs [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 Energy Improvement and Extension Act of 2008 allocated $800 million for new CREBs. In February 2009, the American Recovery and Reinvestment Act of 2009 allocated an additional $1.6 billion for new CREBs, for a total new CREB allocation of $2.4 billion [29].
- Qualified Energy Conservation Bonds (QECBs) are similar to Clean Renewable Energy Bonds except that they are not subject to the U.S. Department of Treasury application process and instead are allocated to each state based upon their state's percentage of the U.S. population. The states are then required to allocate a certain percentage to "large local governments" [29].
- Value-Added Producer Grant Program: Grants are available to independent producers, agricultural producer groups, farmer or rancher cooperatives, and majority-controlled producer-based business ventures seeking funding. Previously awarded grants 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 [30].

Indiana Incentives

- Alternative Power and Energy Grant Program: offers grants of up to $100,000 to Indiana public, non-profit, and business sectors for the purchase and installation of alternative energy systems that offset fossil fuel usage and create jobs. Renewable resources covered include biomass [31].

- <u>Emissions Credits:</u> 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 waste biomass 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].

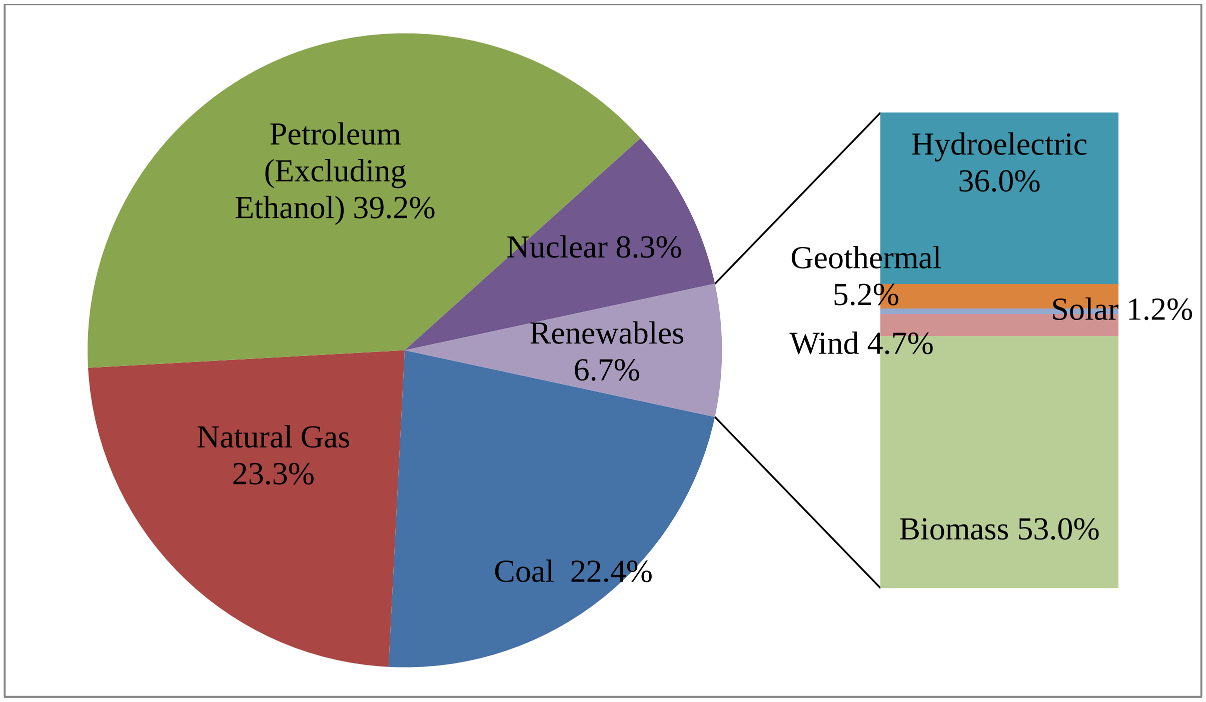

Figure 4-1: Summary of U.S. energy consumption in 2007 (Data source: EIA [1])

According to EIA's *2006 Annual Energy Outlook* [3] biomass is projected to be the largest source of renewable energy for electricity generation among the non-hydroelectric renewables. The contribution of biomass to 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.

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.

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

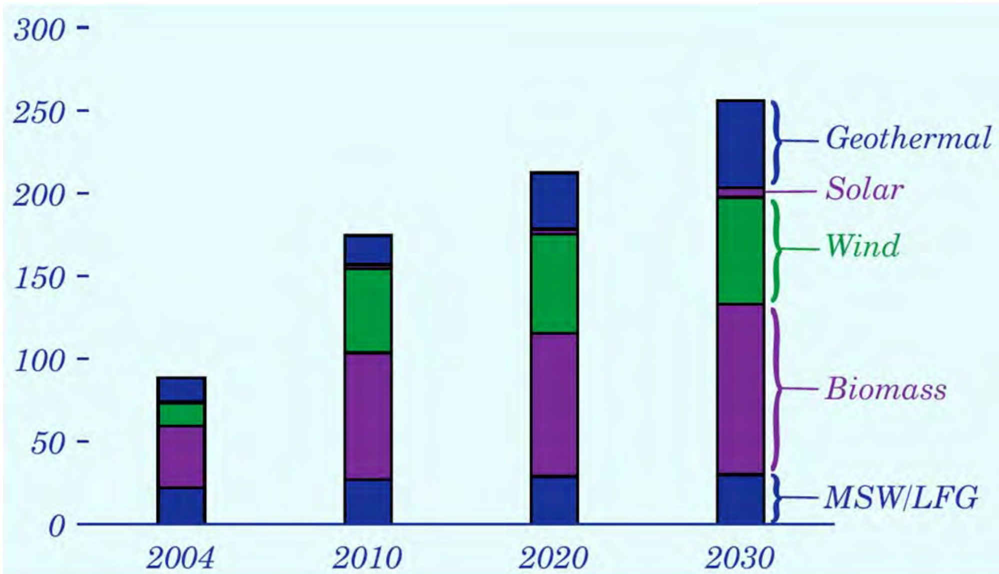

Figure 4-2: Non-hydroelectric renewable electricity generation by energy source 2004-2030 (billion kWh) (Source: EIA [3])

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 make 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 [4].

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 [5]. 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:

- 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 [6]. 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 little as two years if low-cost biomass fuel is used [5].

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 greater 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 [5].

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 [7]:

- 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 neither cheap nor effective enough for 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 [8]. 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 [5]. This translates to about 7,500 MW of additional generation capacity. Figure 4-3 shows the current biomass availability in the U.S.

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 [10]. 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 [11], 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.

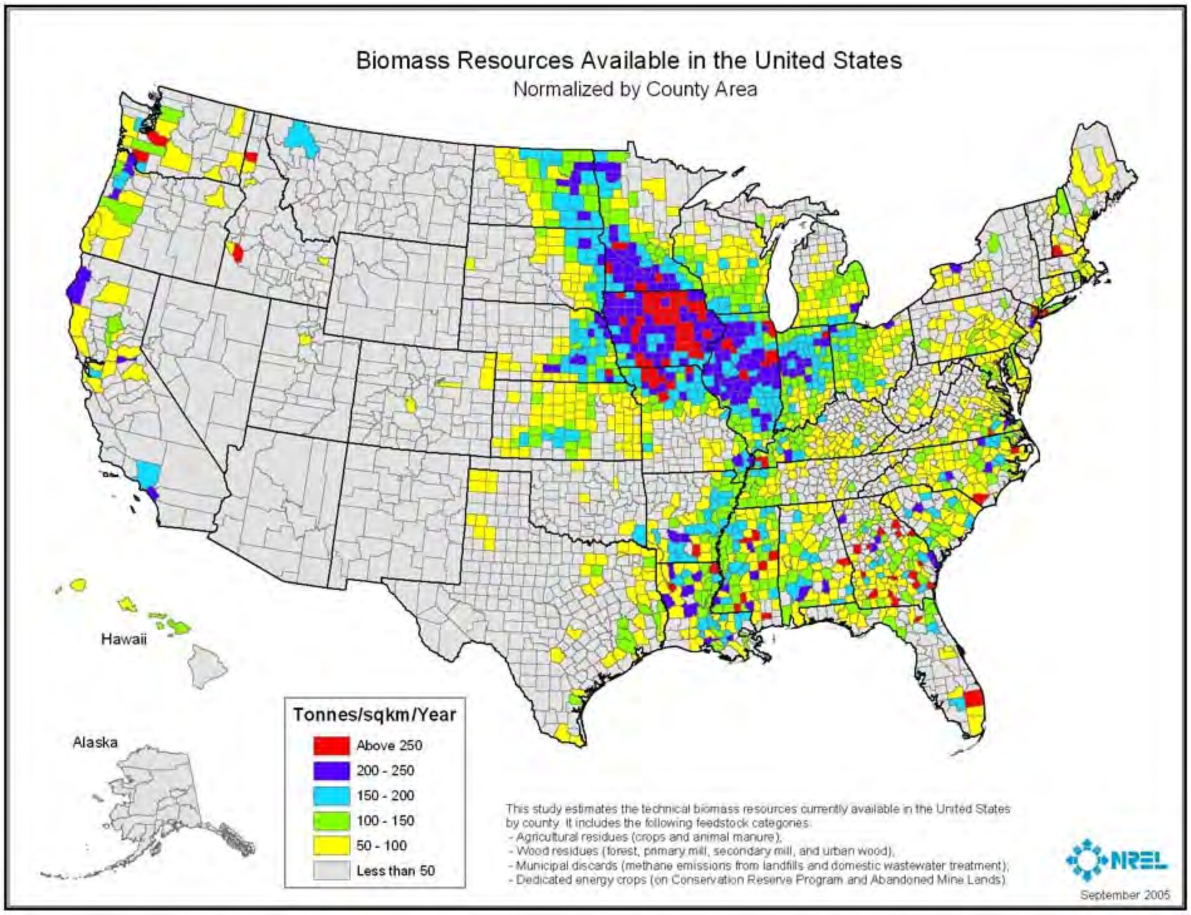

Figure 4-3: Biomass resources available in the U.S. (Source: NREL [9])

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]. The station found that co-firing causes excessive ash and slag formation, and therefore it is 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].

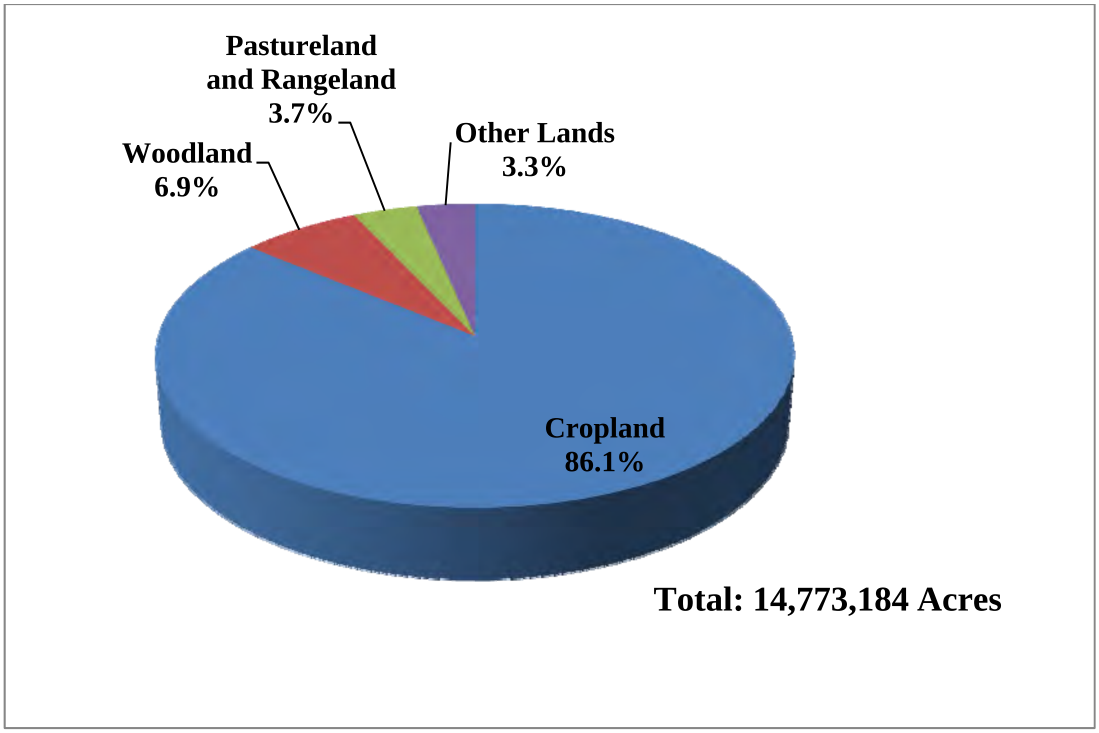

Figure 4-4: Indiana land use in 2007 (Data source: USDA [18])

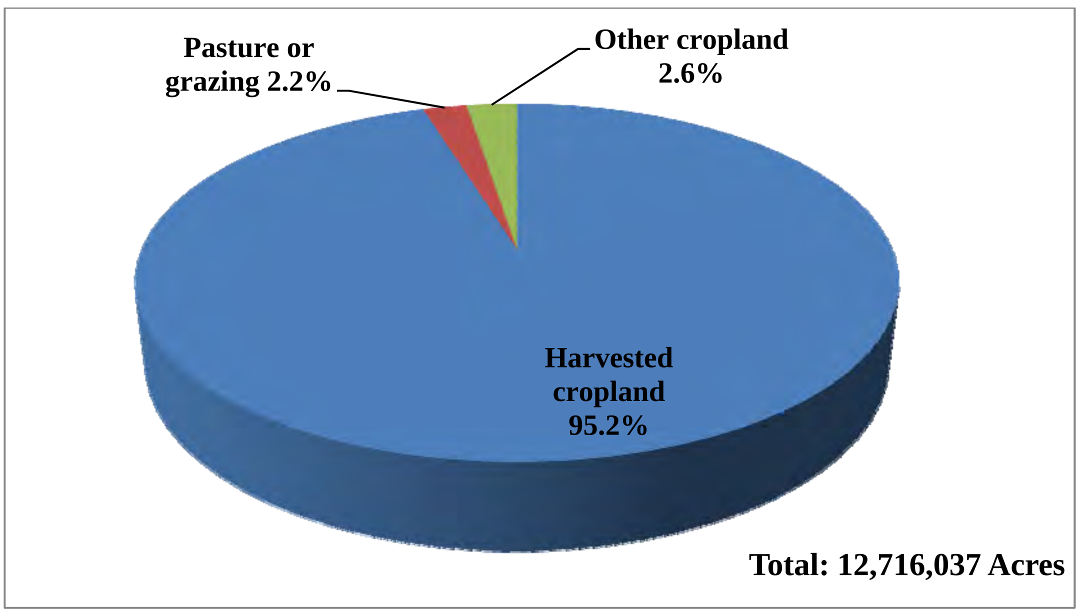

Figure 4-5: Indiana cropland use in 2007 (Data source: USDA [18])

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].

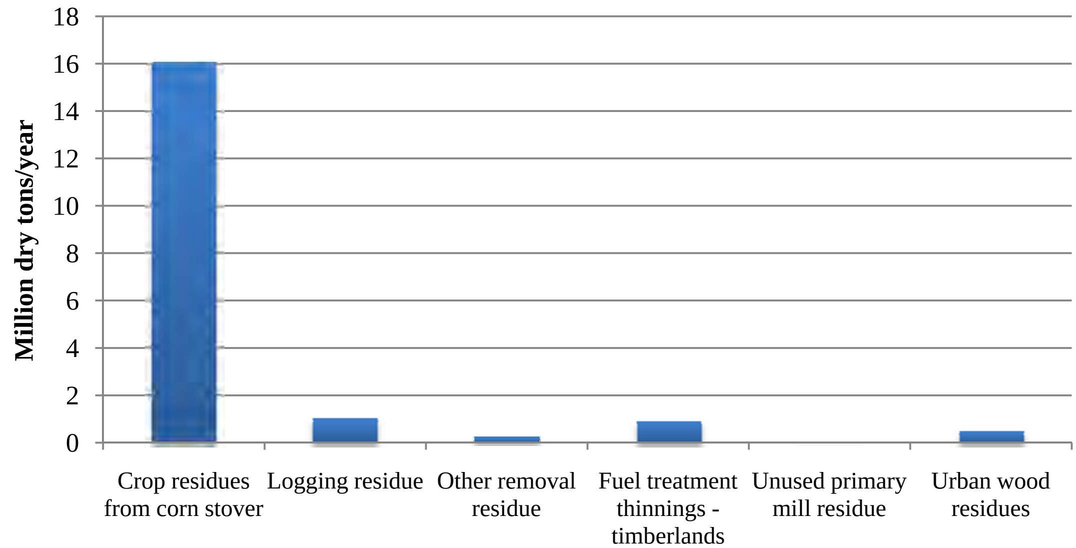

Figure 4-6: Estimated biomass production potential in Indiana (Source: ORNL [17])

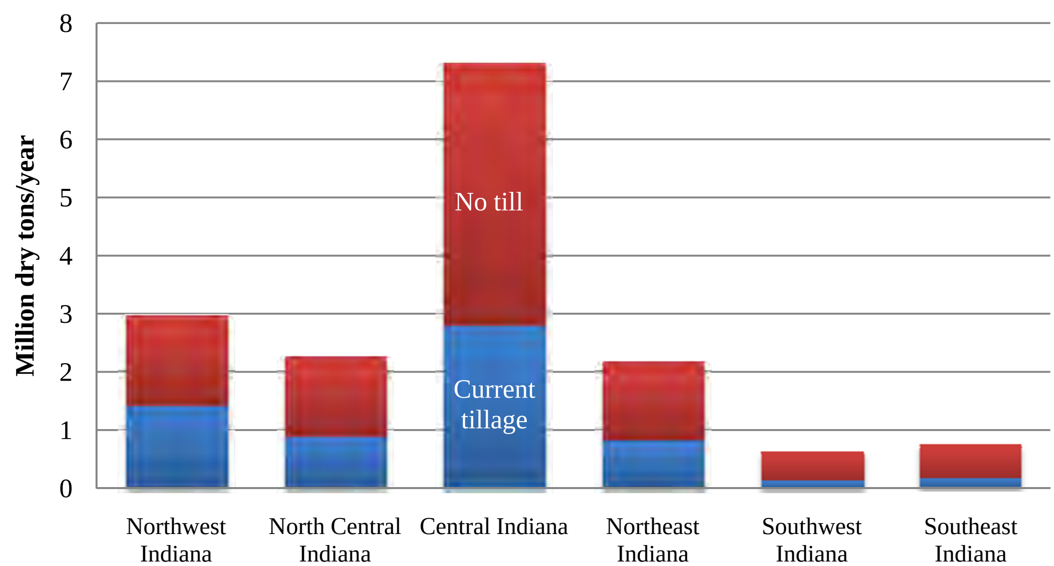

Figure 4-7: Estimated production potential of crop residues from corn stover in Indiana (Source: ORNL [17])

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 [19].

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.

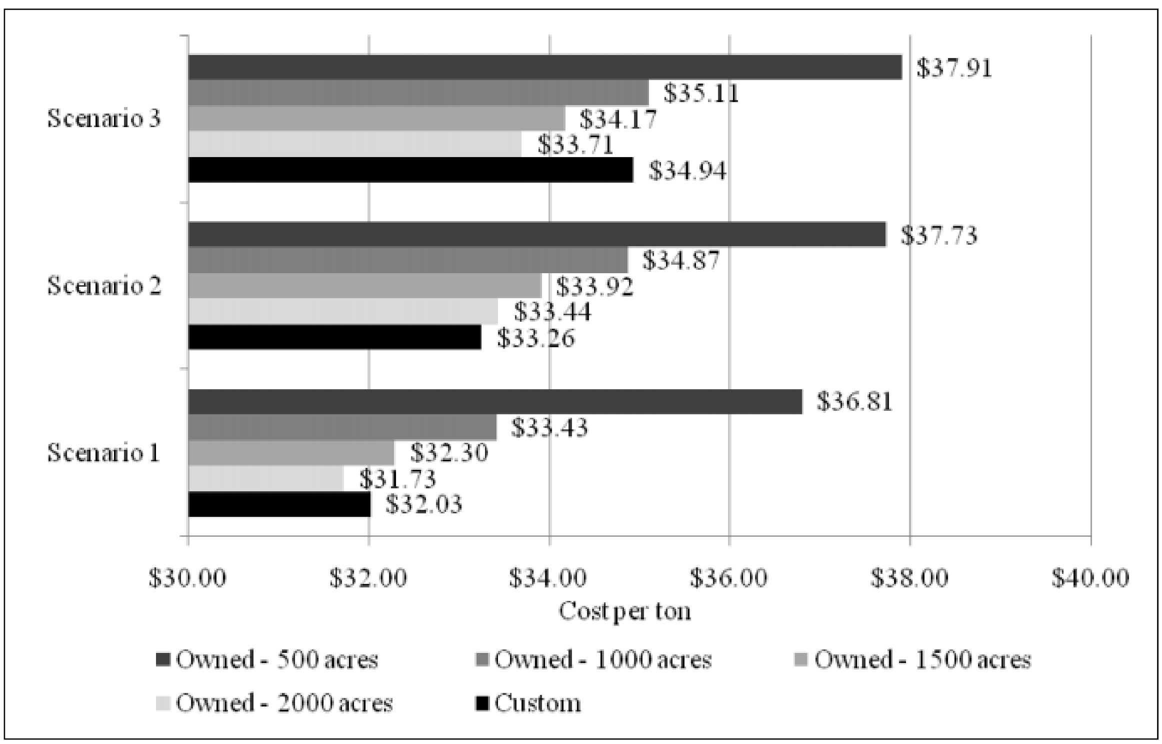

Figure 4-8: Corn stover product only costs (Source: Brechbill and Tyner [19])

According to the Electric Power Research Institute *Biomass Interest Group Technical Report for 2002* [20] 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 [21]. The total generating capacity from Indiana's landfills is 48.4 MW [22]. This includes the recently added 3.2 MW facility added by Vectren in Pike County.

Another biomass fuel use for electricity in Indiana comes from the anaerobic digesters installed at three Dairy Farms in Northwest Indiana. The three dairies are the Boss Dairy No. 4, the Fair Oaks Dairy, and the Herrema Dairy. Each of these dairies has over 700 kW of generating capacity [23].

In addition SUFG is aware of a total of 195 kW of electricity generating capacity in wastewater treatment facilities in the cities of Jasper and West Lafayette, 65 kW in Jasper and 130 kW in West Lafayette.

Covanta Energy Corporation's Indianapolis facility uses municipal solid waste to generate steam which is in turn used for district heating in downtown Indianapolis. The plant has capacity to process 2,175 tons of solid waste per day to produce at least 4,500 tons of steam per ton of solid waste [27].

4.5 Incentives for organic waste biomass

Federal Incentives

- <u>Renewable Electricity Production Tax Credit (PTC)</u> provides a 2.1 cents/kWh tax credit for wind, geothermal and closed-loop biomass and 1.1 cents/kWh for open-loop biomass, landfill gas municipal solid waste small hydroelectric and marine energy technologies. Organic waste biomass falls under the open-loop category. As part of the February 2009 Stimulus Act the PTC was modified to provide the option for qualified producers to take the federal business energy investment credit (ITC) or an equivalent cash grant from the U.S. Department of Treasury [24].
- <u>Business Energy Investment Tax Credit (ITC)</u> credits up to 30 percent of expenditures on qualifying renewable energy systems [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). 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. The program covers up to 25 percent of costs [24].
- 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 Energy Improvement and Extension Act of 2008 allocated $800 million for new CREBs. In February 2009, the American Recovery and Reinvestment Act of 2009 allocated an additional $1.6 billion for new CREBs, for a total new CREB allocation of $2.4 billion [24].
- Qualified Energy Conservation Bonds (QECBs) are similar to Clean Renewable Energy Bonds except that they are not subject to the U.S. Department of Treasury application process and instead are allocated to each state based upon their state's percentage of the U.S. population. The states are then required to allocate a certain percentage to "large local governments" [24].
- Value-Added Producer Grant Program: Grants are available to independent producers, agricultural producer groups, farmer or rancher cooperatives, and majority-controlled producer-based business ventures seeking funding. Previously awarded grants 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 [25].

Indiana Incentives

- Alternative Power and Energy Grant Program: This program offers grants of up to $100,000 to Indiana public, non-profit, and business sectors for the purchase of alternative energy systems, including biomass electricity and heating [25].
- 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 [26]. 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 [24].

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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].

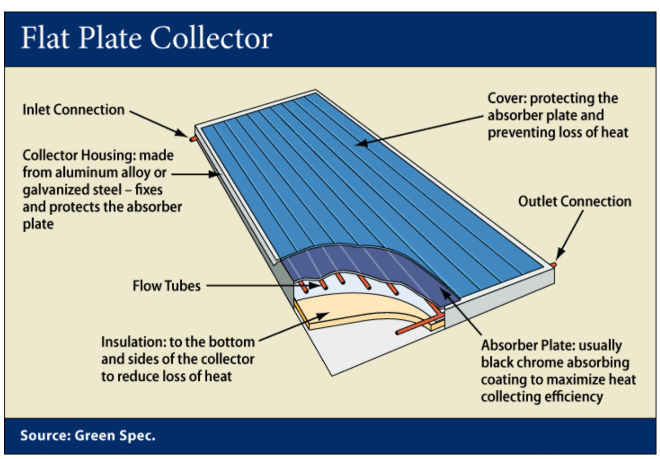


Figure 5-1: General layout of a flat-plate collector (Source: EERE [3])

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 [4], 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) [4]. 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 discussed below, 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 of the Southwest [4].
- 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 [5]. 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 [4]. 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 molten salt energy storage tanks at the base of the towers that enable them to store energy for several hours [5]. 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 temperature [4].

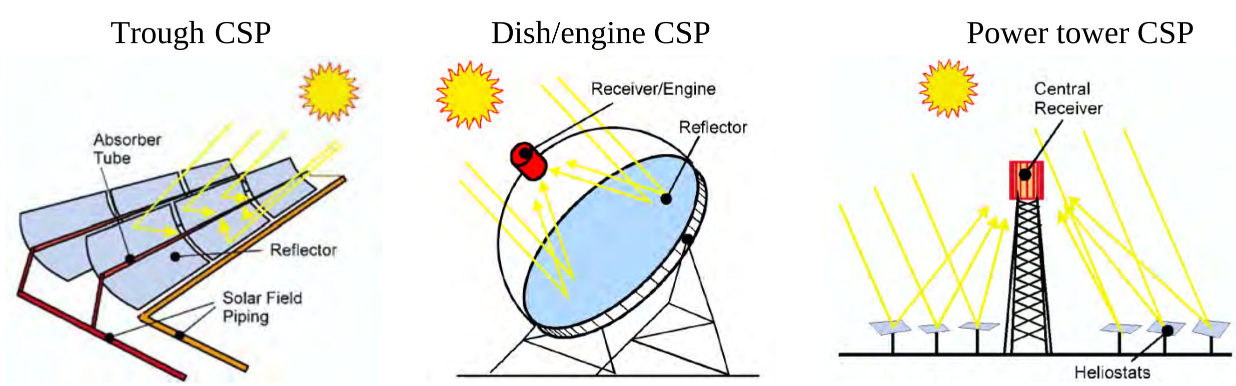


Figure 5-2: Types of concentrating solar power (CSP) collectors (Source: Sandia [4])

Table 5-1 illustrates further differences between the three types of solar thermal technologies [6].

		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 [6])

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 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. According 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 [4].

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 [7]. Table 5-2 shows the forecast costs of energy from the solar thermal technologies in areas with high solar resources [8].

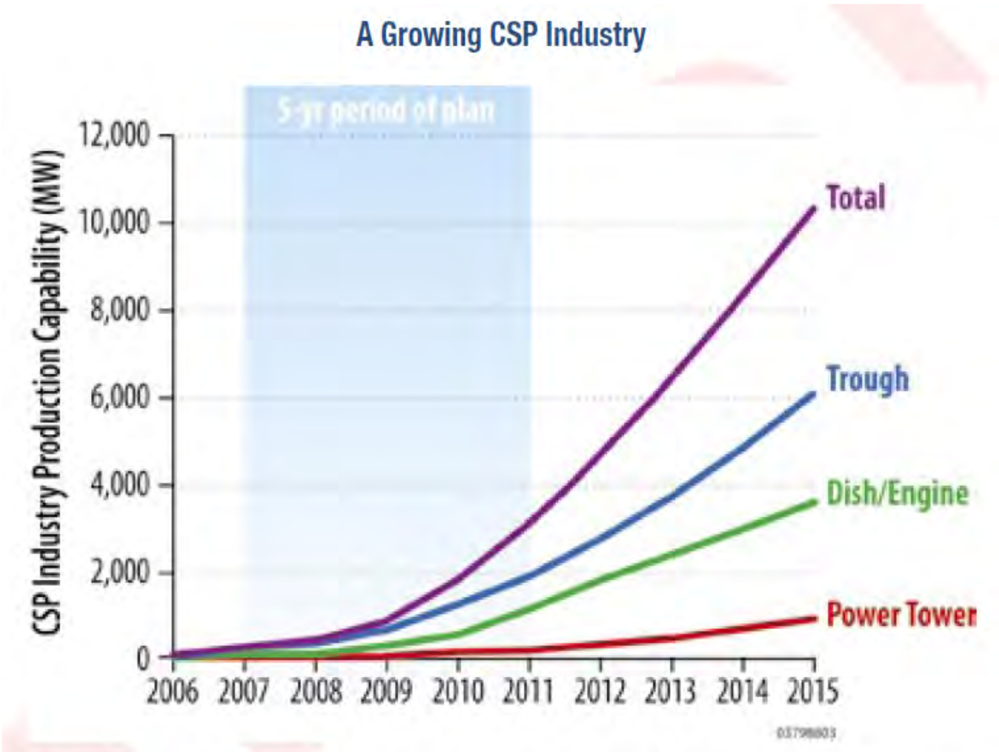
		Levelized COE *(constant 1997 cents/kWh)*				
Technology	**Configuration**	*1997*	*2000*	*2010*	*2020*	*2030*
Dispatchable Technologies						
Solar Thermal	Parabolic Trough	17.3	11.8	7.6	7.2	6.8
	Power Tower	--	13.6	5.2	4.2	4.2
	Dish Engine—Hybrid	--	17.9	6.1	5.5	5.2
Intermittent Technologies						
Solar 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 [7])

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 [9]. 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 [5].

The total domestic shipments of solar thermal collectors were 19.53 million square feet in 2006 [10]. 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 [11]. 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 [12]. Florida, California, and Nevada were the top destinations of solar thermal collectors, accounting for more than half of all domestic shipments [13]. Figure 5-4 illustrates the top states for domestic shipments of solar thermal collectors in 2007.



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 concentrating solar power (Source: EERE [5])

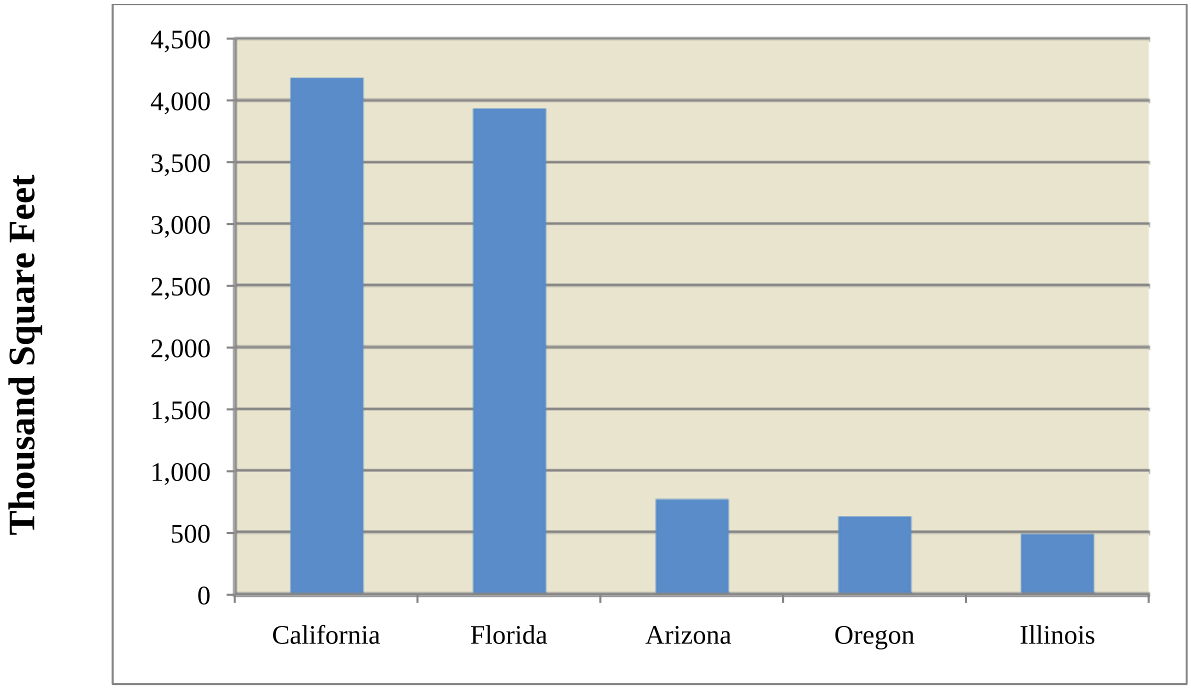


Figure 5-4: Top domestic destinations for solar thermal collectors in 2007 (Source: EIA [13])

Figure 5-5 shows annual average solar radiation with a fixed, flat-plate, collector orientation fixed at its latitude [14]. 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 [14].

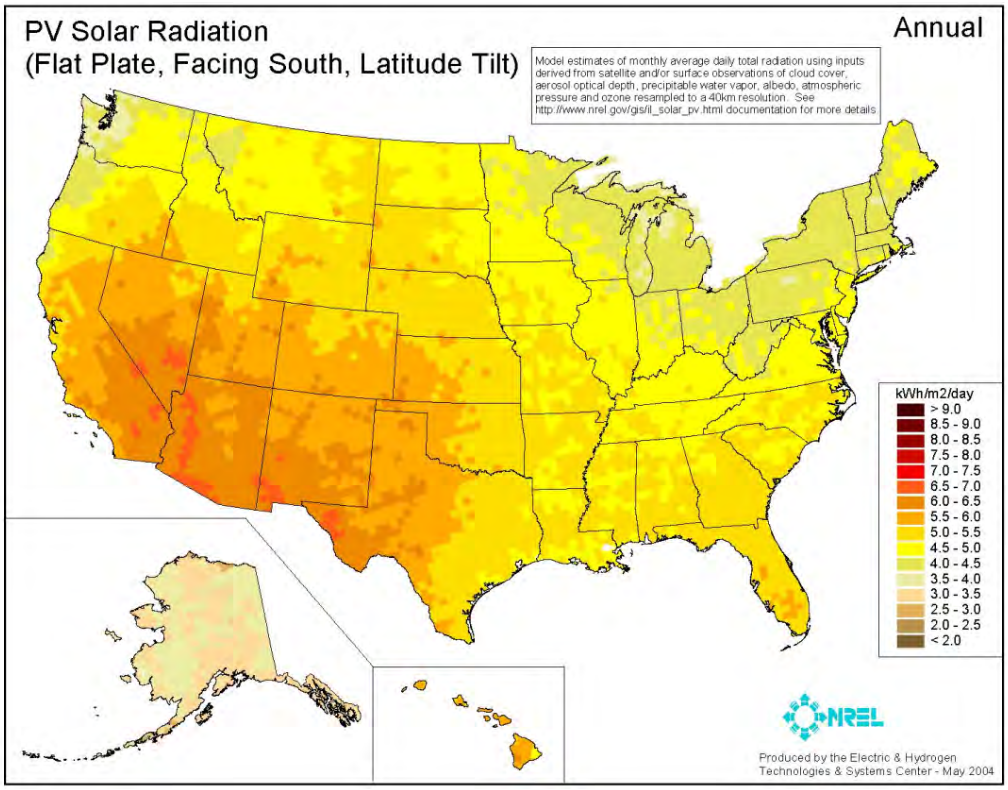


Figure 5-5: Annual average solar radiation for a flat-plate collector (Source: NREL [14])

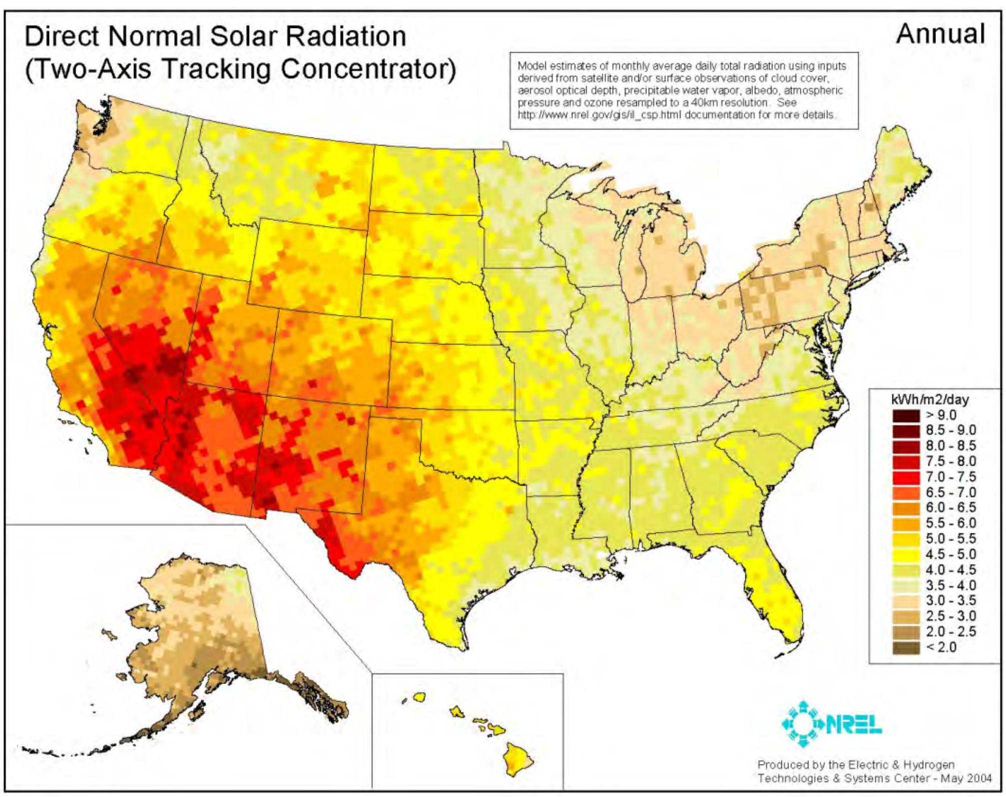


Figure 5-6: Direct normal solar radiation (two-axis solar concentrator) (Source: NREL [14])

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 [4]. SEGS consists of nine parabolic trough collectors and associated 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 [9].

There are currently no active power tower type plants in the U.S. [4]. 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 [18]:

- 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 the power plants 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 [19].

Through the Solar America Cities partnership, DOE has awarded financial and technical assistance to 25 cities pursuing city-wide solar energy initiatives. The 25 Solar America Cities are partnering with more than 180 organizations and have committed $11.9 million in funding to match $11.2 million in DOE assistance, for a combined investment of $23.1 million. Each of the Solar America Cities aims to integrate solar technology into city energy planning, streamline city-level regulations and practices, promote solar technology among residents and local businesses, and serve as a model for other cities interested in promoting the use of solar energy technologies. The two requirements for being named a Solar America City are that the population must be over 100,000, and there must be a sincere commitment to spreading the usage of solar power throughout the city [20].

On May 27, 2009, President Obama announced that over $467 million from the American Reinvestment and Recovery Act would go towards expanding and accelerating the development, deployment, and use of geothermal and solar energy throughout the United States. $117.6 million of those dollars will be allocated for solar energy with $51.5 million going towards photovoltaic technology development, $40.5 million going towards solar energy deployment, and $25.6 million going towards concentrating solar power research and development [21].

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 5-5 and 5-6 [14]. There is, however, some potential (more so in the southern part of the state) for water and building heating using flat-plate collectors. 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 [22].

5.5 Incentives for solar energy

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

Federal Incentives

- <u>Business Energy Investment Tax Credit (ITC)</u> credits up to 30 percent of expenditures on solar systems [23].

- Clean Renewable Energy Bonds (CREBs): This program, authorized by the Energy Policy Act of 2005, made a total of $1.2 billion in 0 percent bonds available through 2008 for non-profit organizations, public utilities, and state and local governments to pursue renewable energy projects. The Energy Improvement and Extension Act of 2008 added an additional $800 million and in February 2009, the American Recovery and Reinvestment Act of 2009 added $1.6 billion to bring the total up to $2.4 billion for these CREB bonds. The holders of these bonds would receive federal tax credits instead of traditional interest [23].
- Conservation Security Program: For 2008, the Conservation Security Program offers a $200 payment for each renewable energy generation system installed on an eligible farm [24, 25]. The Food, Conservation, and Energy Act of 2008 re-incorporates the program as the "Conservation Stewardship Program" in 2009 and increases funding in the program by $1.1 billion [26].
- 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 [23].
- 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 [23].
- 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 [27, 28].

- Renewable Energy Production Incentive (REPI) provides financial incentive payments for electricity produced and sold by renewable energy generation facilities owned by non-profit groups, public utilities, or state governments [23].
- 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" [23].
- 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 [23].
- Value-Added Producer Grant Program: Grants are available to independent producers, agricultural producer groups, farmer or rancher cooperatives, and majority-controlled producer-based business ventures seeking funding. Previously awarded grants 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 [29].

Indiana Incentives

- Alternative Power and Energy Grant Program: This program offers grants of up to $100,000 to Indiana public, non-profit, and business sectors for the purchase of alternative energy systems, including solar hot water and photovoltaic systems [30].
- 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 [31].
- 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 [30].
- 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 [30].
- 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 [30].

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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].

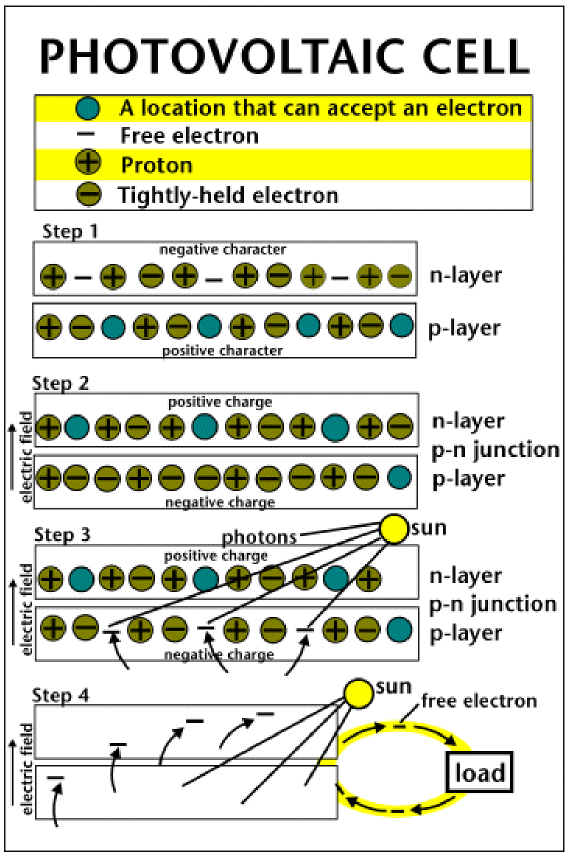

Figure 6-1: Photovoltaic cell operation (Source: EIA [1])

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].

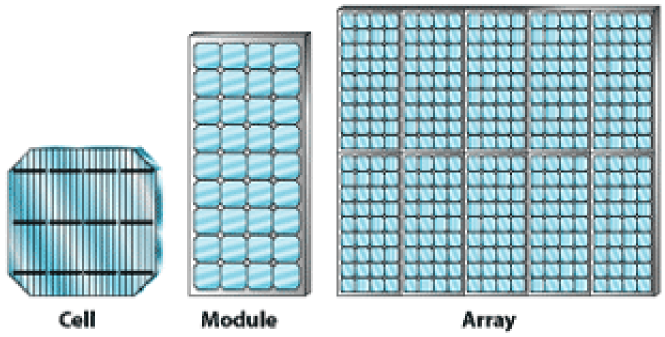

Figure 6-2: Illustration of a cell, module and array of a PV system (Source: EERE [3])

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 Chapter 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 illustrates 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].

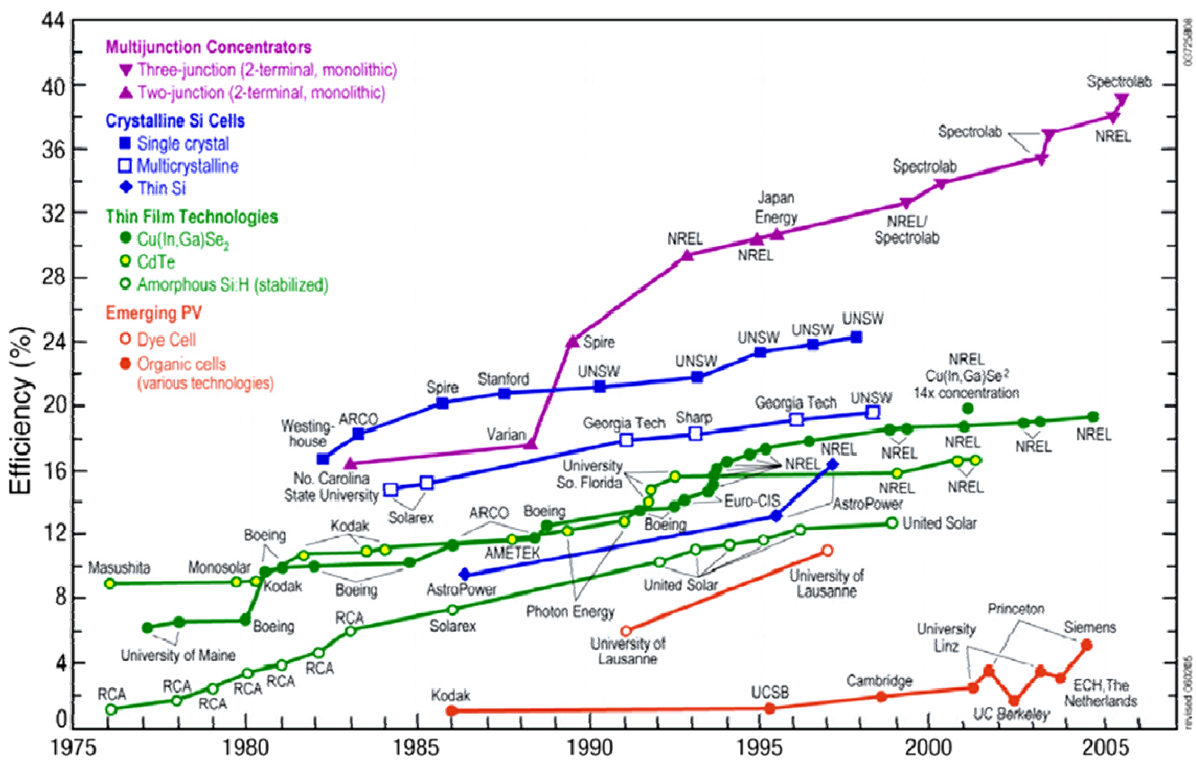

Figure 6-3: Improvements in solar cell efficiency, by system, from 1976 to 2004 (Source: DOE [7])

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 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;
- Most 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
- They have high costs relative 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/W for bulk orders of standardized systems to around $11/W 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 fuel-derived energy sources. DOE believes that increasing silicon production and greater PV manufacturing capacity should lead to markedly lower prices by 2010 [13].

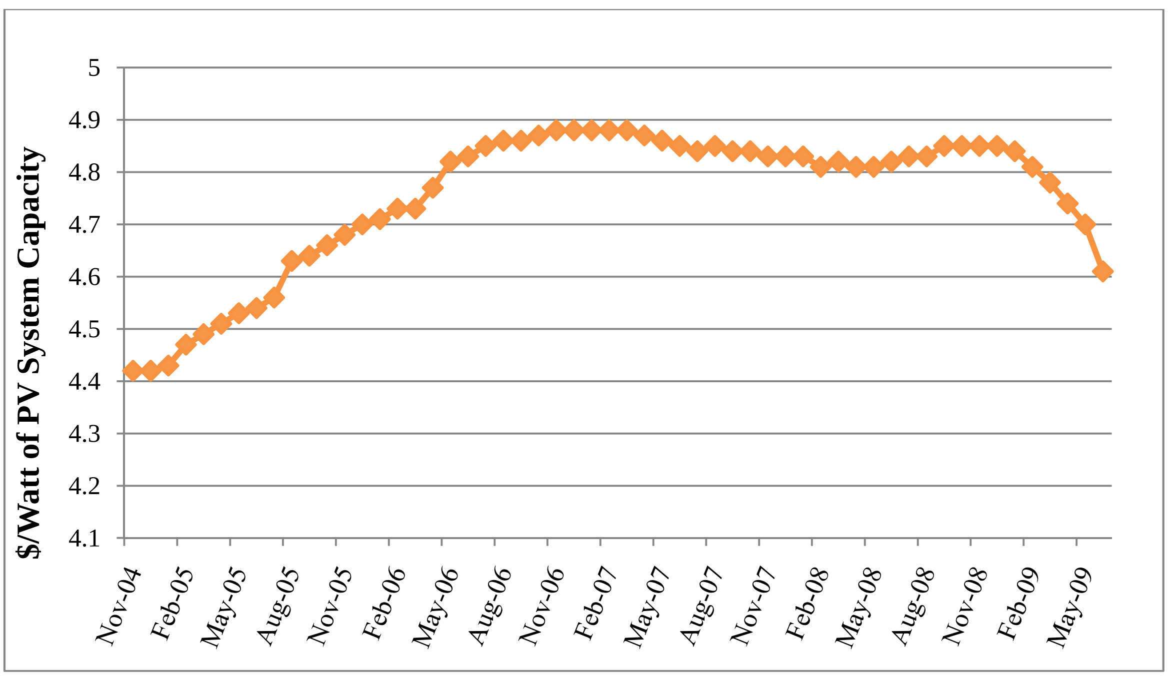

Figure 6-4: Historical PV module prices (Source: Solarbuzz [11])

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].

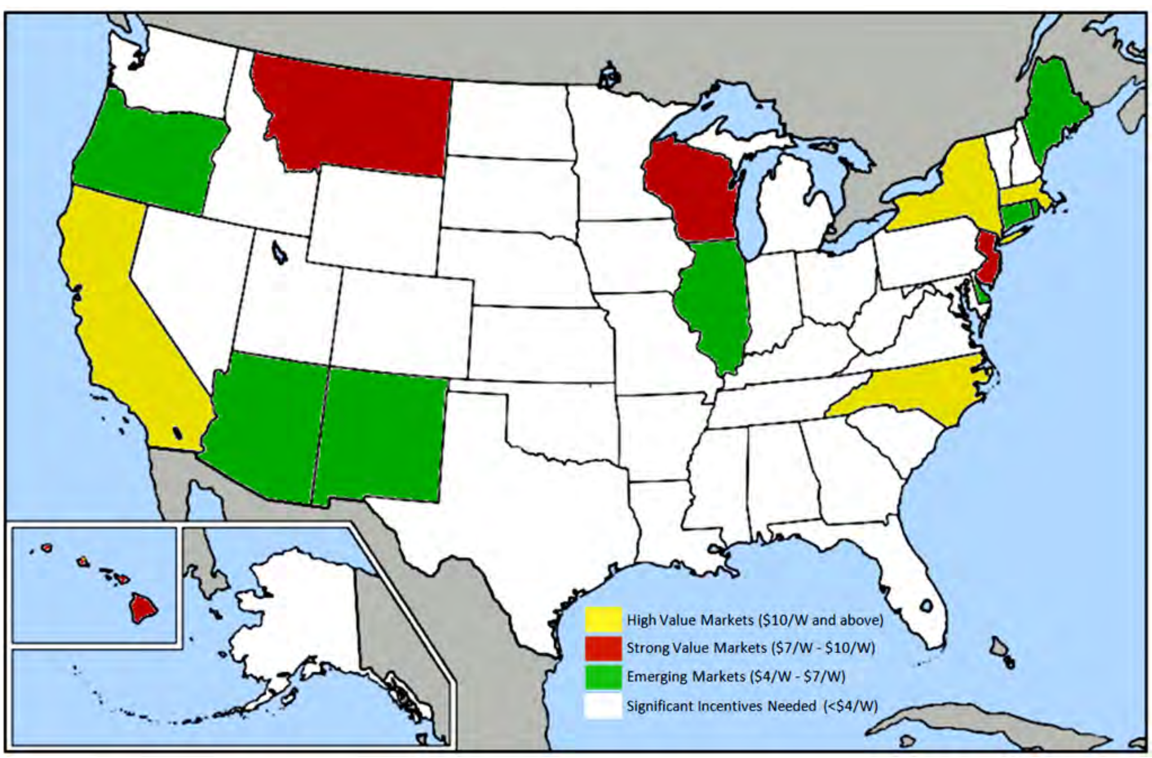

Figure 6-5: Breakeven turnkey costs by state (Source: DSIRE [15])

Table 6-1 presents a comparison of solar electricity prices compiled by the U.S. Government 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 of electricity from PV system	Avg. cost electricity	Cost electricity from PV system	Avg. cost electricity	Cost of 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
2008	10.65	37.67	9.65	27.39	6.39	21.34

Table 6-1: Solar electricity price vs. U.S. electricity price index (Source: EIA [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.

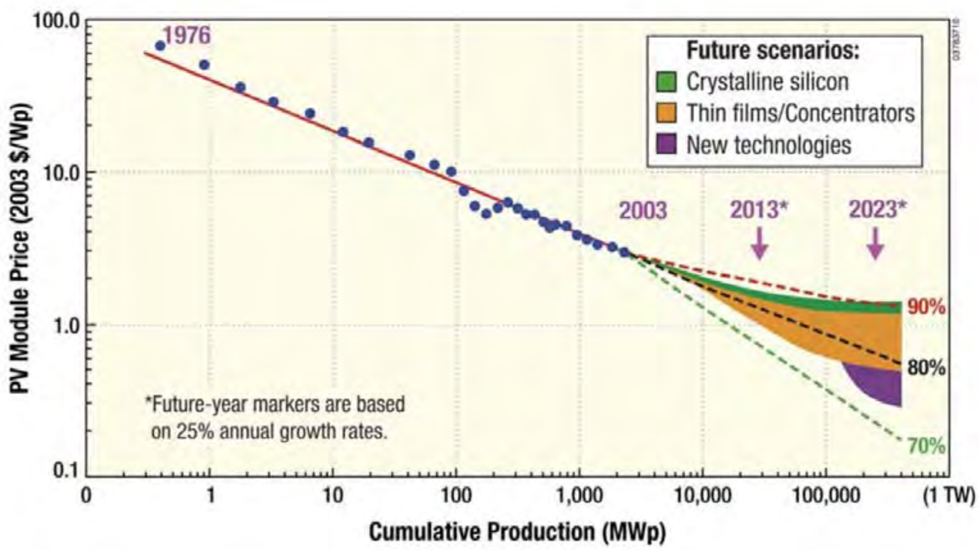

Figure 6-6: Learning curve for PV production (Source: DOE [7])

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/W, 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.

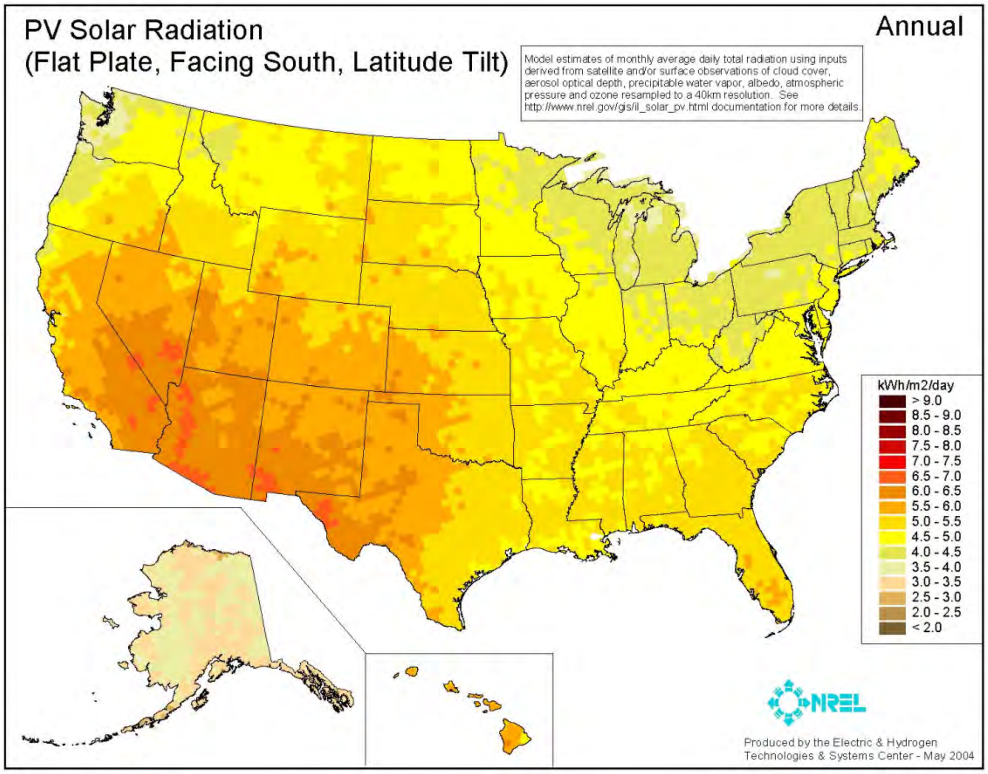

Figure 6-7: Annual average solar radiation for a flat-plate collector (Source: NREL [19])

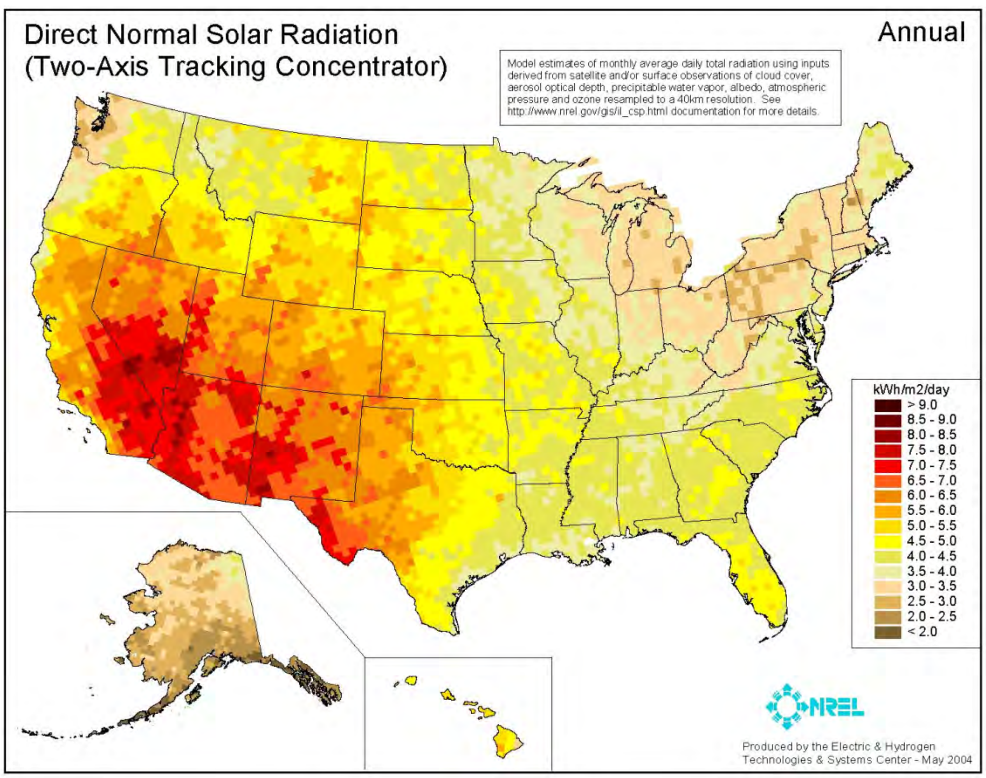

Figure 6-8: Direct normal solar radiation (two-axis solar concentrator) (Source: NREL [19])

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. 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 12 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.

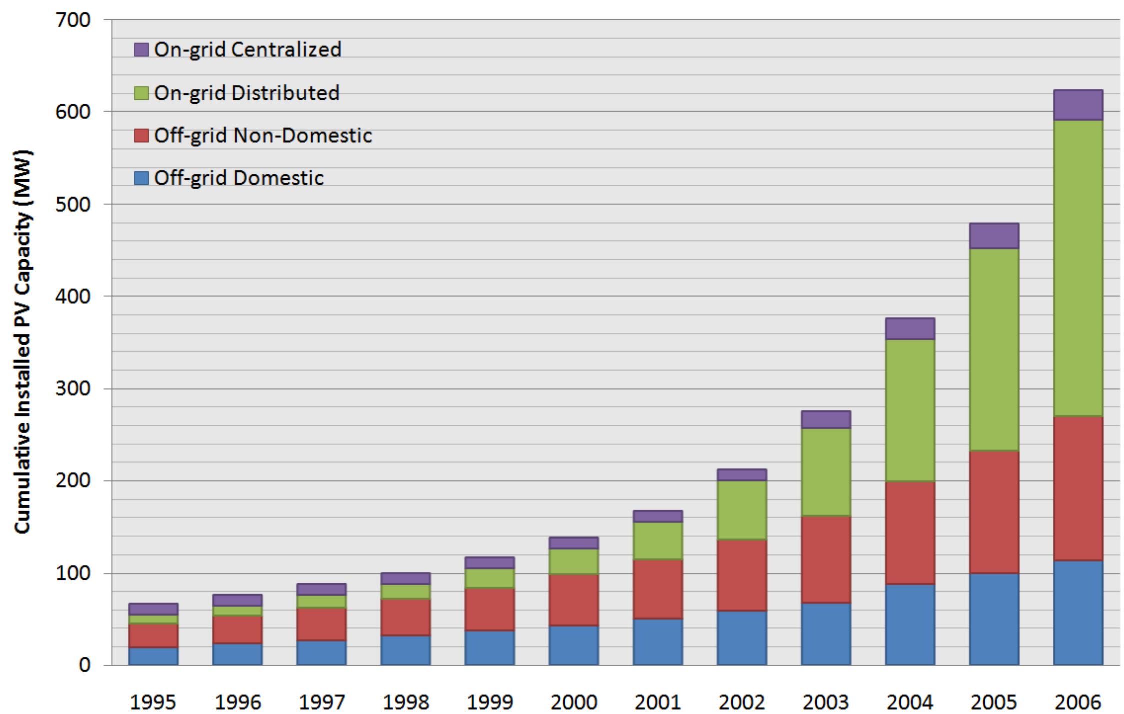

Figure 6-9: <u>Cumulative installed PV capacity in the U.S. by sub-market</u> (Source: IEA [21])

In 2008, PV installations for residential, non-residential and utility uses were growing strongly, as shown in Figure 6-10 [22].

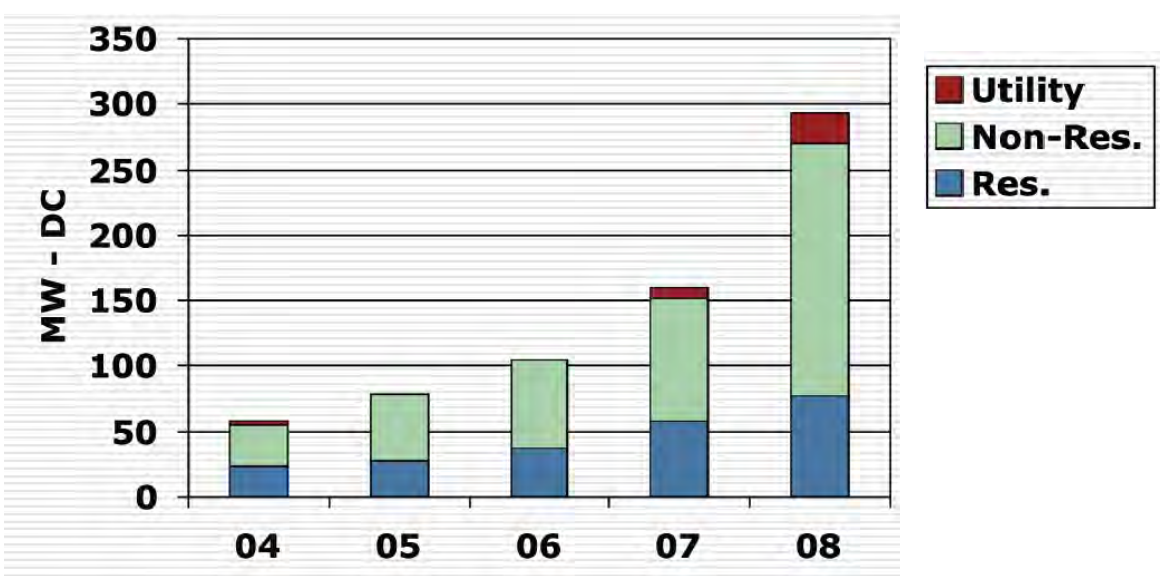

Figure 6-10: <u>Residential, non-residential and utility PV installation in the U.S.</u> (Source: IREC [22])

In 2006, President Bush proposed a new program to reduce the cost 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. Although the SAI was concluded in 2009, it had a budget nearly 80 percent larger than previous solar programs in the Department of Energy. They were responsible for accelerating the development of advanced solar electric technologies, including PV and CPV systems. Their goal was to make solar energy cost competitive with other sources of renewable electricity by 2015. Most of the programs that were created under the SAI were absorbed into the current Solar Energy Technologies Program [13, 23].

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 water 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 [24].

One such program that the SAI launched was 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 such as those shown in Table 6-3. 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 intends to add five more schools to this list by the end of 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

Owner/Developer	Rated Capacity (kW)	Location
Hoosier Energy	3	Greensburg, Decatur County
Hoosier Energy	3	Franklin, Johnson County
Hoosier Energy	3	Meron, Sullivan County
Hoosier Energy	3	Victory, Dubois County
Duke	1.92	Kokomo
Duke	8	Bloomington Solar Panel
Duke	24	Bloomington EverGreen Village Project
IPL PV program in four Indianapolis area schools	2kW In each school	Lutheran High School Brebeuf Jesuit Prep School Emmerich Manual High School Crispus Attucks Medical Magnet Middle School
Schmidt Associates (in partnership with IPL)	3	Indianapolis
The Caldwell Eco Center	0.5	Residential
The Usrey Farm	1.17	Residential
Dick Stumpner	1.765	Residential
Randolph Eastern School Corporation		Union City Community High School

Table 6-3: Grid-connected PV systems in Indiana

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. Levelized energy costs 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 and 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-fired power plants 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 which is less than 4 $/W.

6.5 Incentives for PV systems

Federal Incentives

- Business Energy Tax Credit: credits up to 30 percent of expenditures on qualifying renewable energy systems [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 Energy Improvement and Extension Act of 2008 allocated $800 million for new CREBs. In February 2009, the American Recovery and Reinvestment Act of 2009 allocated an additional $1.6 billion for new CREBs, for a total new CREB allocation of $2.4 billion. [29].
- Conservation Security Program: The Food, Conservation, and Energy Act of 2008 re-incorporates the program as the "Conservation Stewardship Program" in 2009 and increases funding in the program by $1.1 billion [30].
- 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

[6] Besides the energy from the sun.

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 [31, 32].
- 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: Grants are available to independent producers, agricultural producer groups, farmer or rancher cooperatives, and majority-controlled producer-based business ventures seeking funding. Previously awarded grants 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 [33].

Indiana Incentives

- Alternative Power and Energy Grant Program: This program offers grants of up to $100,000 to Indiana public, non-profit, and business sectors for the purchase of alternative energy systems, including solar hot water and photovoltaic systems [34].
- 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 [35].
- 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 [34].
- 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 [34].

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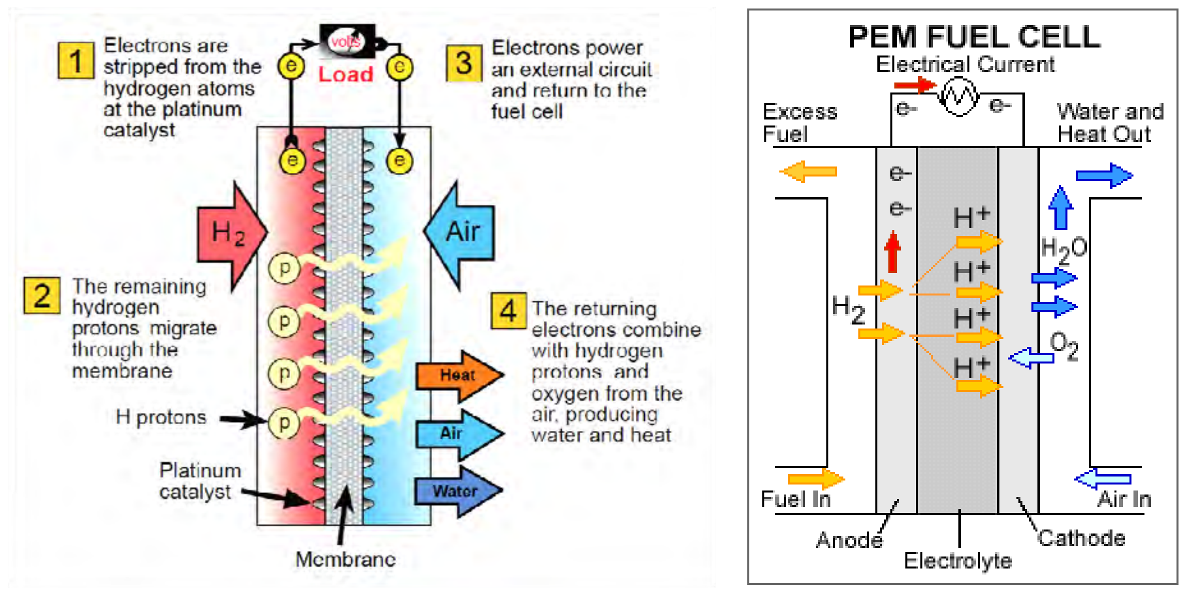
7. Fuel Cells

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.



<u>Figure 7-1:</u> <u>Schematic of basic fuel cell operation</u> (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 [5]. 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] [6].

There are five main attractive features of fuel cell technology [6]:

- 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 [5])

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

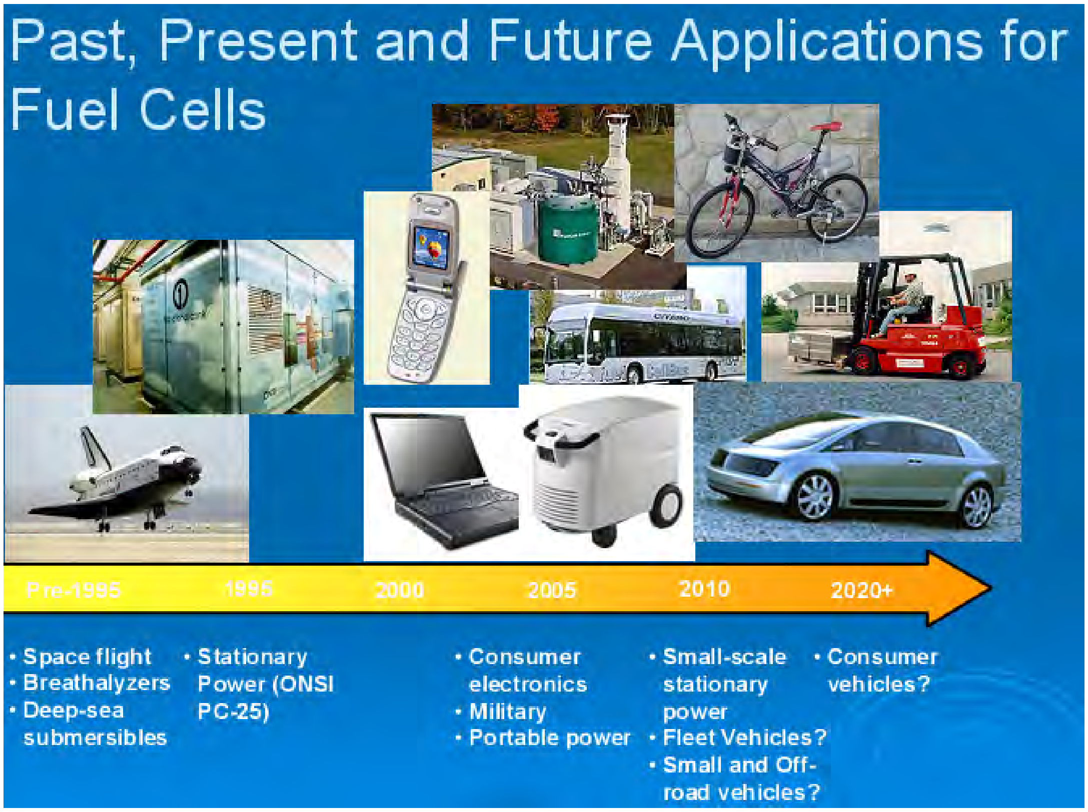
[8] H_2 gas is light enough that it will escape Earth's atmosphere and exit into space [9].

are required. There are several methods being currently pursued by DOE to produce hydrogen at an economically competitive price [8]:

- 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.
- Electrolysis: Electrolysis uses an electric current to split water into hydrogen and oxygen. The electricity required can be generated using renewable sources.
- 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 [6].

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].



<u>Figure 7-2:</u> <u>Fuel cells applications</u> (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]:

- <u>Thermal and Water Management System</u>: 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 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, in 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 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. 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 [19].

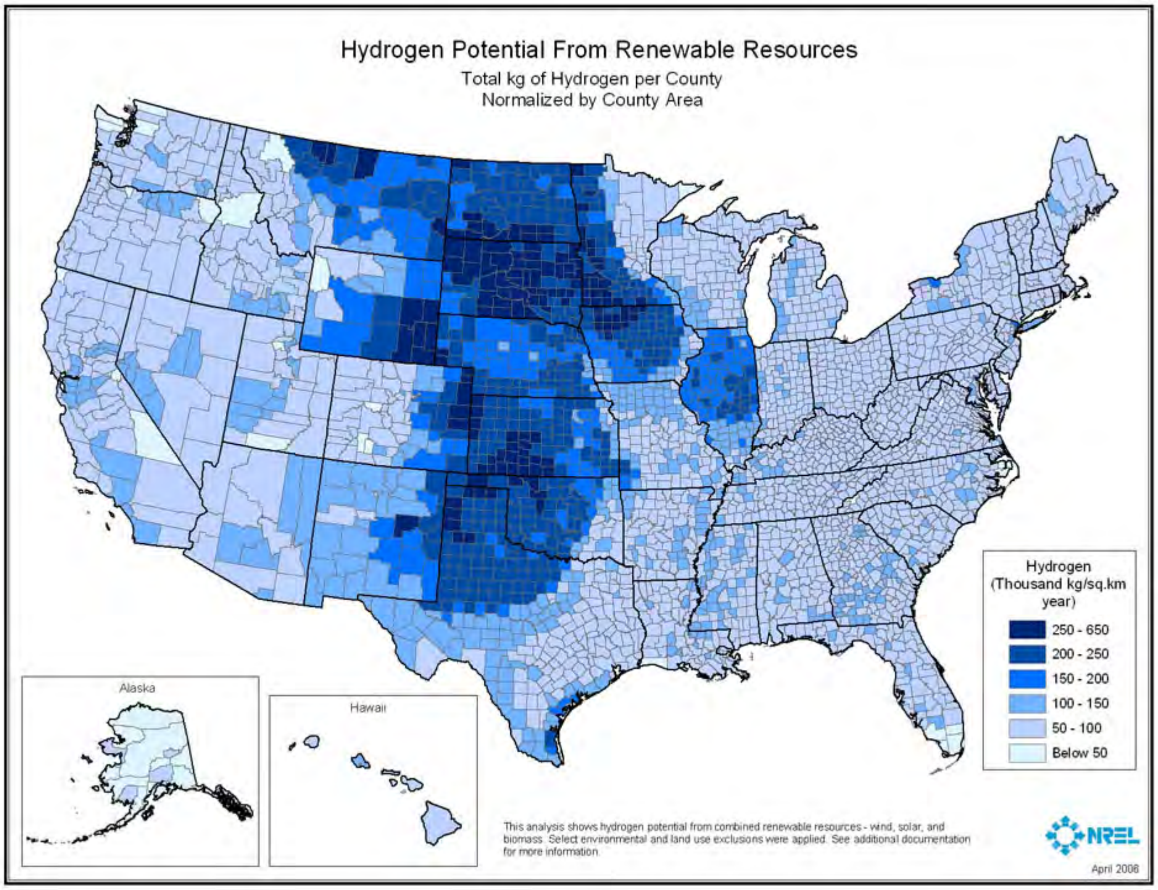


Figure 7-3: Potential for hydrogen production in the U.S. (Source: NREL [20])

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 [21]:

- 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 [22]:

- 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 [6]. In 2004, 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 [23].

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 $1,000/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 [24].

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 [25].

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 [26].

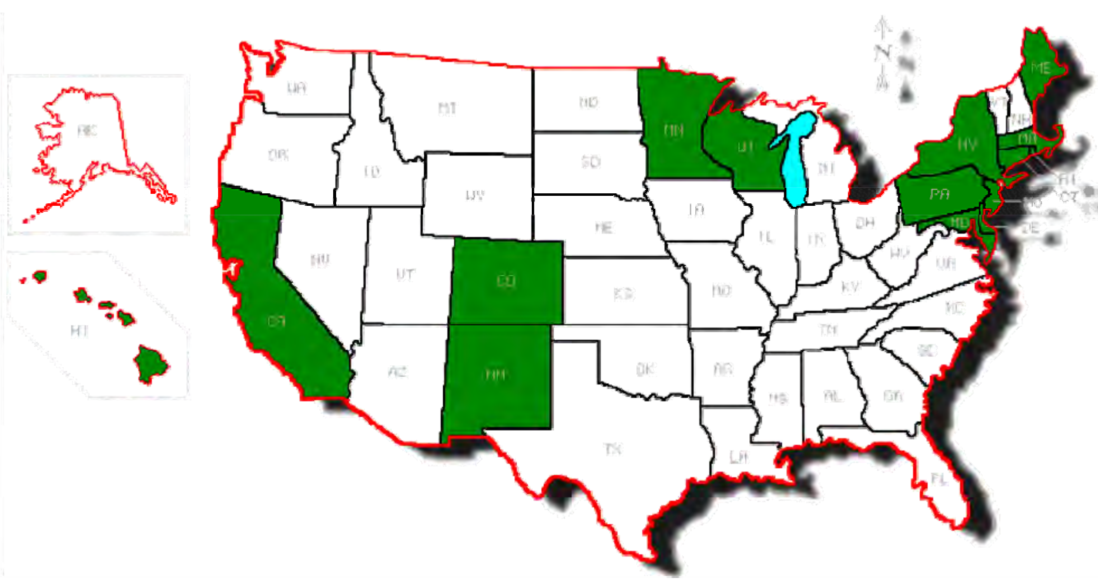


Figure 7-4: Renewable portfolio standards that include H_2/fuel cells (Source: www.fuelcells.org)

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 [6]. 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) [6]. 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.

The low cost of electricity in Indiana might provide a barrier to entry for emerging fuel cell technologies and other renewable sources. In 2007, Indiana had the 9th lowest electricity prices in the nation [27]

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 [6].

Current stationary fuel cells would use existing natural gas supplies for fuel [6]. Figure 7-5 shows the average annual residential price of natural gas in the nation and within Indiana [28]. 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.

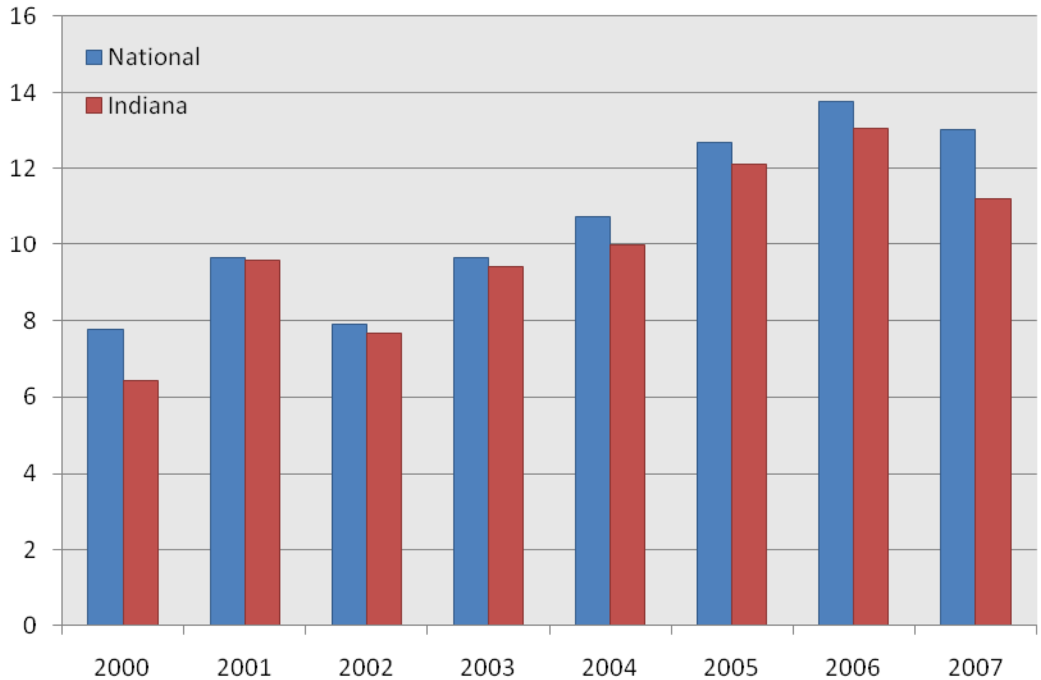


Figure 7-5: Residential natural gas prices in dollars per thousand cubic feet (Data source: EIA [28])

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 [24].

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 [29]. 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 [30].

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 on the price and efficiency of the units, and the government (federal and state) incentives focused on facilitating commercialization of this technology, and the price of electricity and natural gas.

7.5 Incentives for fuel cells

Federal Incentives

- Business Energy Investment Tax Credit (ITC) credits up to 30 percent of expenditures on qualifying renewable energy systems [31].
- Conservation Security Program: The Food, Conservation, and Energy Act of 2008 reincorporated the program as the "Conservation Stewardship Program" in 2009 and increased funding in the program by $1.1 billion [32].
- 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 [31].
- 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].
- 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 [31].

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 [34].

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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.
- 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.

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

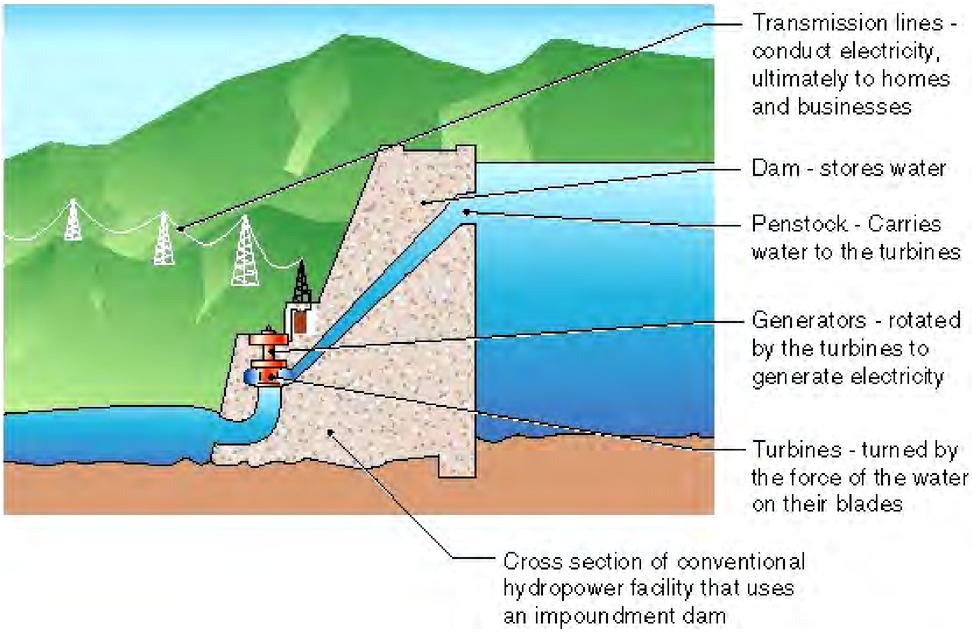

Figure 8-1: Schematic of impoundment hydropower facility (Source: INEL [2])

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.
- Hydroelectric facilities with impoundment can be used as a means of energy storage when combined with a pumped storage system.

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].

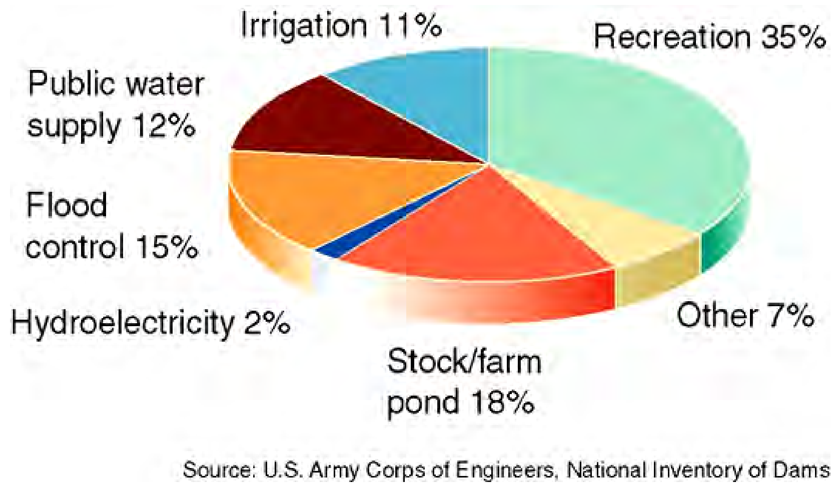

Figure 8-2: Primary function of U.S. dams (Source: NREL [7])

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 still consider the process 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.

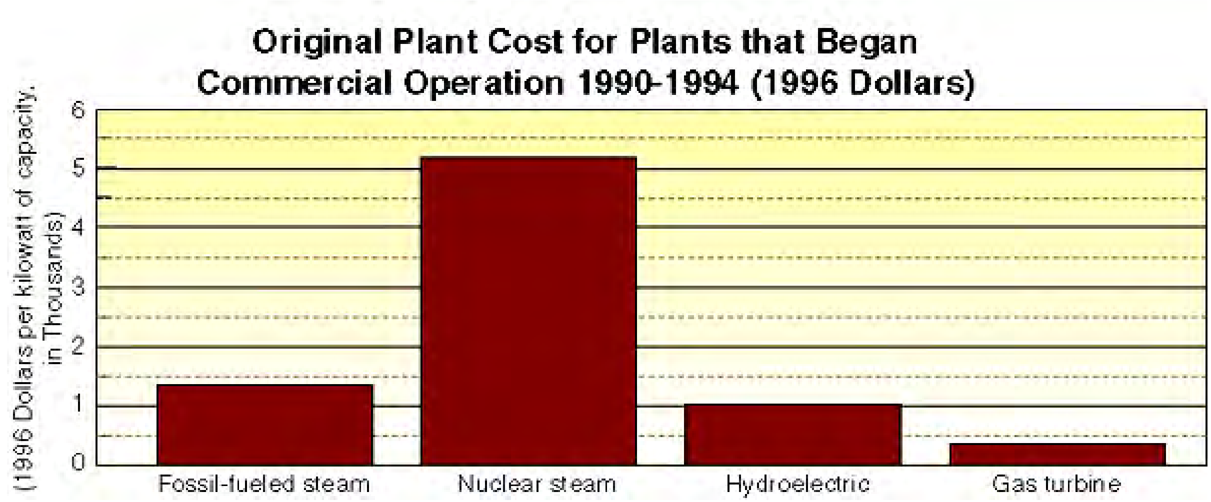

Figure 8-3: Plant costs per unit installed capacity (Source: INEL [11])

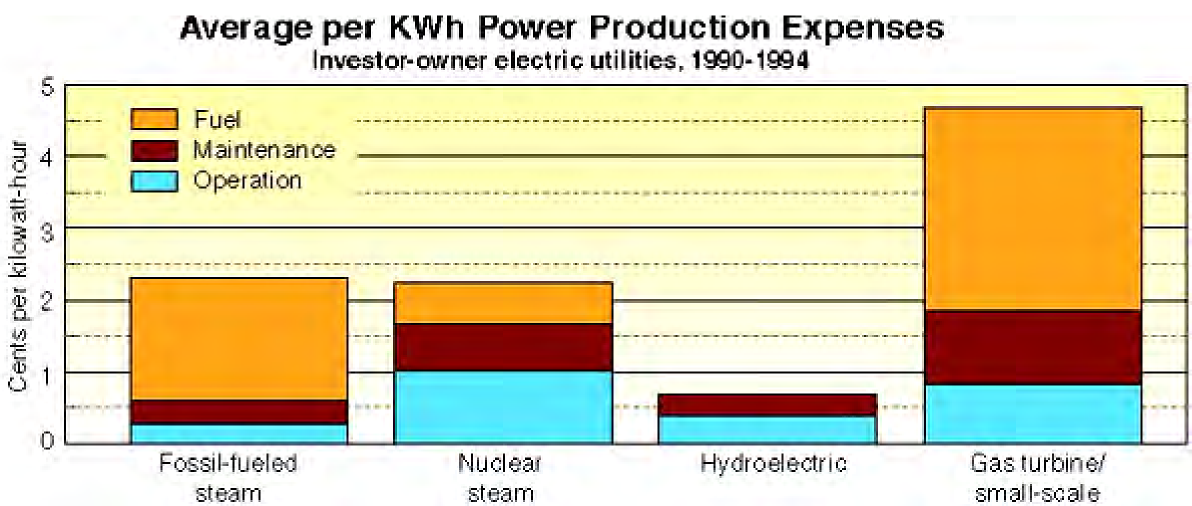

Figure 8-4: Average production costs of various types of generating plants (Source: INEL [11])

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].

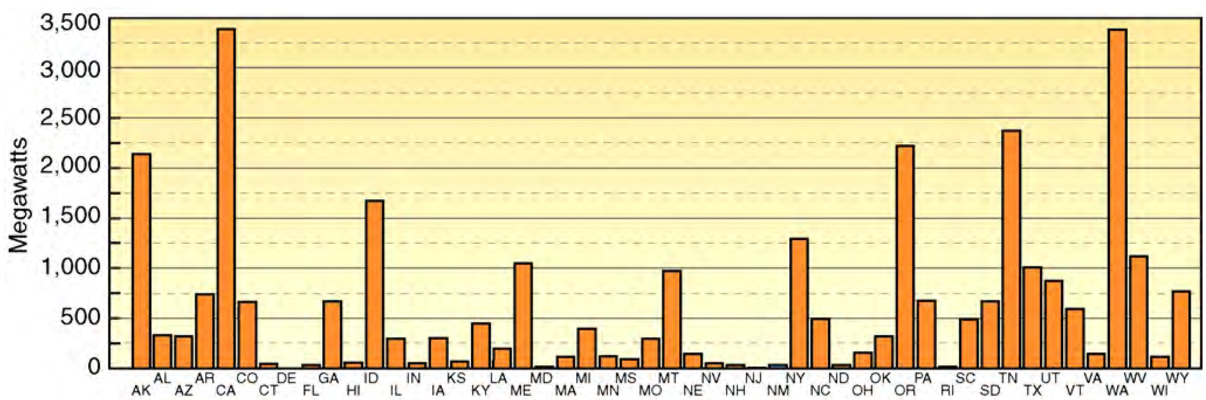

Figure 8-5: State breakdown of potential hydropower capacity (Source: INEL [16])

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 0.2 percent (231 GWh) of the total electricity generated in Indiana in 2007, 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.

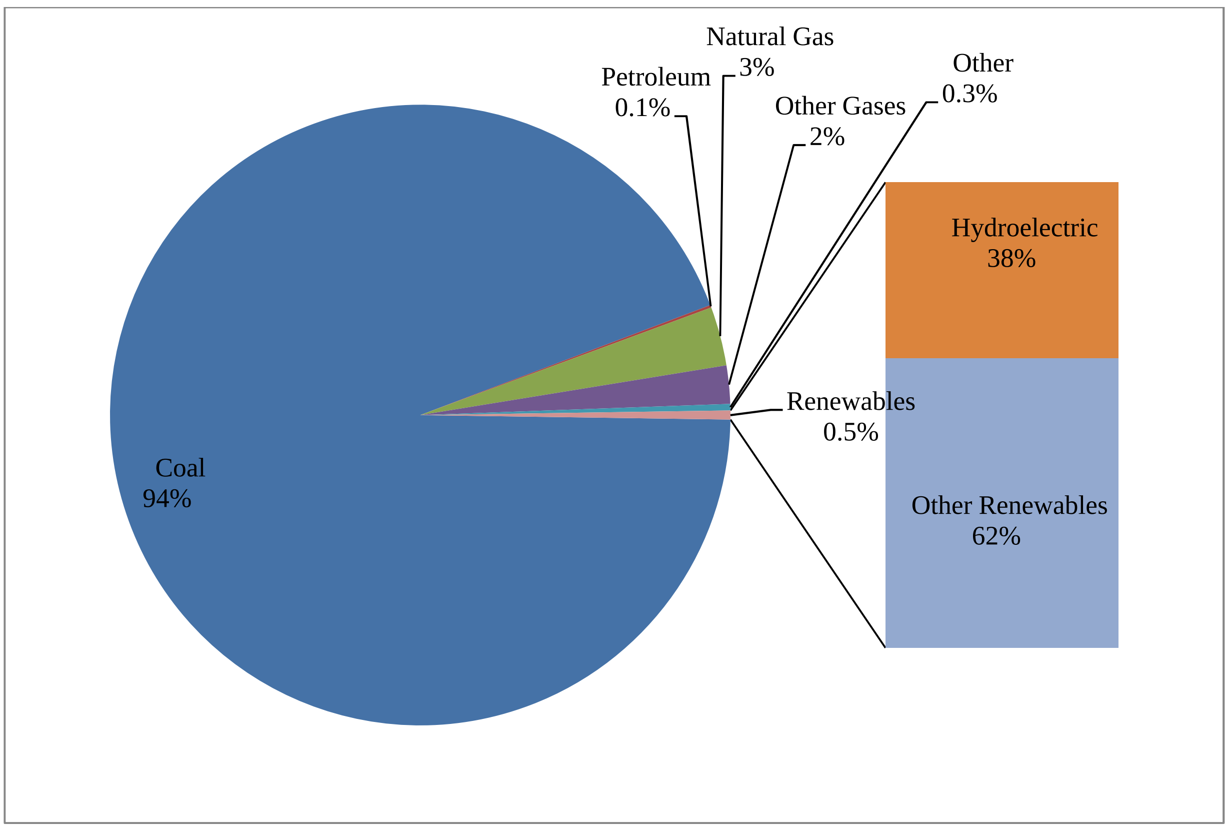

Figure 8-6: Indiana electricity generation by energy source in 2007 (Data source: EIA [19])

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. Most 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.

In August American Municipal Power broke ground on a new 84 MW run-of-the-river hydroelectric project at the Cannelton Locks and Dams on the Ohio River [21]. While the dam

[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.

spans the river between Indiana and Kentucky, the output of the facility is expected to be used for consumers in Kentucky. The facility is expected to be operational in 2013.

8.5 Incentives for hydropower

Federal Incentives

- Renewable Electricity Production Tax Credit (PTC): provides a 2.1 cents/kWh tax credit for wind, geothermal and closed-loop biomass and 1.1 cents/kWh for open-loop biomass, landfill gas, municipal solid waste, small hydroelectric and marine energy technologies. As part of the February 2009 Stimulus Act the PTC was modified to provide the option for qualified producers to take the federal business energy investment credit (ITC) or an equivalent cash grant from the U.S. Department of Treasury [22].
- 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 Energy Improvement and Extension Act of 2008 allocated $800 million for new CREBs. In February 2009, the American Recovery and Reinvestment Act of 2009 allocated an additional $1.6 billion for new CREBs, for a total new CREB allocation of $2.4 billion. [22].
- Conservation Security Program: The Conservation Security Program offers a $200 payment for each renewable energy generation system installed on an eligible farm [23, 24]. The Food, Conservation, and Energy Act of 2008 re-incorporates 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). 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 [22].

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 [26].
- Alternative Power and Energy Grant Program: This program offers grants of up to $100,000 to Indiana public, non-profit, and business sectors for the purchase of alternative energy systems, including micro-hydro electricity systems [27].
- 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].

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9. Energy from Algae

9.1 Introduction

Algae, like other plants, utilize energy from the sun through the process of photosynthesis to convert carbon dioxide from the air into biomass usable for energy production. Algae range from seaweeds growing to over 100 feet long to microscopic microalgae, and they are found both in saltwater and freshwater environments. According to the DOE Aquatic Species Program (ASP) final close-out report, microalgae are the most primitive form of plants and are generally more efficient converters of solar energy because of their simple cellular structure. Most of the algae energy research has focused on microalgae due to their generally higher content of the natural oils (lipids) needed for biofuels such as biodiesel [1]. The ASP program identified four major groupings of microalgae. They are

- The diatoms are found mainly in oceans, but also inland in fresh and saltwater environments. These store carbon mainly as oils or as a carbohydrate.
- The green algae are the most commonly seen occurring in such places as swimming pools. They store carbon mainly as starch.
- The blue-green algae are closer to bacteria in structure and play an important role in fixing nitrogen in the atmosphere.
- The golden algae can appear as yellow, brown or orange in color and occur primarily in freshwater environments. They store carbon as oils and carbohydrates.

Research on the use of microalgae as source of renewable energy started in the U.S. as early as the 1950s. At that time the focus of the research was to grow algae in wastewater treatment facilities for the production of methane gas. Between 1978 and 1996 the U.S. Department of Energy conducted the most comprehensive algae to energy research to date under the Aquatic Species Program based at the National Renewable Energy Laboratory. According to the DOE algae research draft roadmap document, while the ASP program and other subsequent research had clearly illustrated the potential for algae as a source for renewable energy, no scalable, sustainable and commercially viable algae to energy system had emerged [2].

Algae have several advantages over other biomass as source energy and especially in the production of biodiesel. These advantages include [1], [2]:

- Algae grows more rapidly and has higher photosynthetic efficiency than other biomass;
- It has a much higher oil content than other biomass (Table 9-1 shows estimated algae oil content compared to traditional oilseed crops);
- It is not a food crop;

- It can be grown in water with very high salt concentration that is not usable for other agriculture;
- It can be grown in otherwise non-arable land such as deserts;
- It has the potential for recycling of CO2 from fossil fueled power plants; and
- Both biofuels and valuable co-products can be produced from algae.

Crop	**Oil Yield (Gallons/Acre/Year)**
Soybean	48
Camelina	62
Sunflower	102
Jatropha	202
Oil palm	635
Algae	1,000-4,000

Table 9-1: Microalgae oil yield compared to oil seed crops (Data source: EERE [2])

Algae can be grown in either open ponds combined to make an algae farm or in enclosed bioreactors. An algae farm consists of shallow algae ponds combined to make a large scale farm. Algae and nutrients are circulated around a "racetrack" using paddle wheels with water, nutrients and carbon dioxide being fed continuously to the pond. The ponds are shallow to provide adequate sunlight for all the algae. The algae containing water is removed for the harvesting and processing of algae. Figure 9-1 shows the basic design of an algae pond.

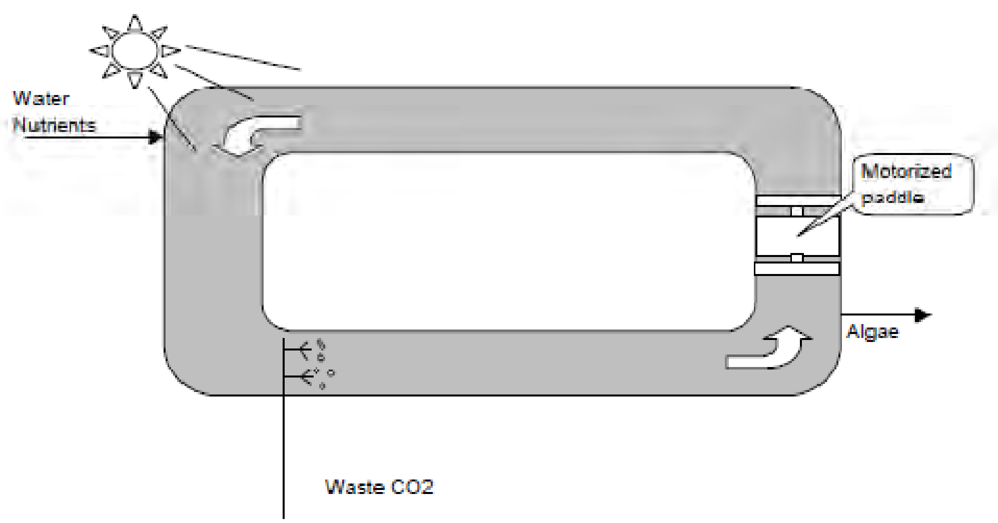

Figure 9-1: Algae pond (Source: NREL [1])

Although open pond algae farms are much more cost competitive, they are vulnerable to setbacks such as contamination of the algae in the pond by faster growing native algae, water loss through evaporation and exposure to extreme weather variations.

Enclosed bioreactors, also referred to as photobioreactors, have the algae culture entirely enclosed in greenhouses, plastic tubes, plastic bags or other transparent enclosures. They are much more expensive, but provide for better control of the algae environmental conditions and protection from biological contamination. They also provide for higher algae concentrations, thus reducing liquid handling costs [1].

Figure 9-2 shows an algae bioreactor at the Arizona Public Service Red Hawk power plant where an experiment was conducted in 2006 and 2007 to locate an algae farm next to a power plant to use the carbon dioxide exhausted by the power plant for the algae growth [3, 4].

Figure 9-2: Algae bioreactors at an Arizona Public Service power plant (Source: APS: [3])

9.2 Economics of algae-based energy

Figure 9-3 gives the estimated cost of algal oils, technically known as triacylglycerols (TAGS) from various research projects presented at the December 2008 *DOE Algal Biofuels Technology Roadmap Workshop*. The author is quick to point out that the cost estimates are very preliminary until a commercial scale algae oil production system is in place [5]. As stated in Figure 9-3 the average production cost from projects included is $109/gallon with the very wide variability represented a standard deviation of $301/gallon.

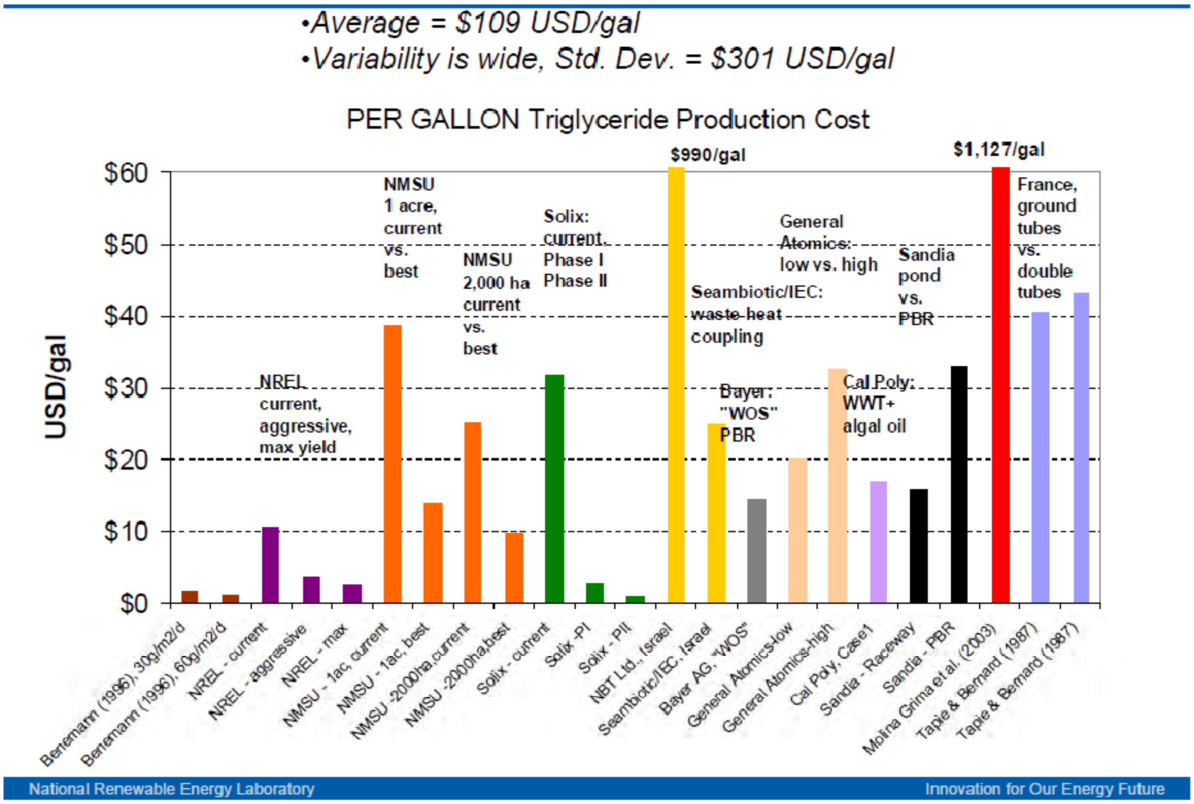

Figure 9-3: Cost comparison of various algae research projects (Source: NREL: [5])

The acronyms in Table 9-2 represent the following

- NREL – Various algae research projects at the National Renewable Energy Laboratory
- NMSU – an algae research project at the New Mexico State University in Artesia New Mexico
- Solix – closed bioreactor based algae research at the Solix Biofuels Corporation of Fort Collins, Colorado
- NBT Ltd. – algae research at the Nature Beta Technologies Corporation of Israel
- Seambiotic/IEC Israel – a joint project between the Seambiotic Corporation of Israel and the Israeli Electric Company (IEC) to grow algae using CO_2 from a coal power plant
- Bayer AG, "WOS" PBR – a photobioreactor (PBR) based algae research project by Bayer Corporation in Germany and El Paso, Texas
- Cal Poly WWT + algal oil – California Polytechnic State University microalgae research project that uses algae for the dual role of wastewater treatment and algal oil production.

The objective of the ongoing DOE algae biofuels research roadmapping effort referred to earlier in this section is to "*identify the critical barriers preventing the economical production of algal biofuels at a commercial scale*" [2].

9.3 State of algae-based energy nationally

According to DOE, while the ASP program and other subsequent research had clearly illustrated the potential for algae as a source for renewable energy, scalable, sustainable and commercially viable algae to energy system had not emerged [2].

In the last few years the use of algae as a source of biofuels has again began to receive attention. This movement is driven by factors such as the expected continued upward trend in the price of petroleum, the increased concern for energy security and increased concern about the effect carbon dioxide on global climate change [6]. Some of the recent Federal efforts in algae biofuel research include:

- Department of Defense Advanced Research Projects Agency (DARPA) jet fuel project. This project first initiated in 2006 has as an objective the development and commercialization of "*a highly efficient system for low-cost algal oil production and optimizing its conversion to JP-8 jet fuel*" [6].

- Department of Defense Air Force Office of Scientific Research (AFOSR) algal jet fuel project. A workshop to initiate this project was held in February 2008 to "develop a basic science research "roadmap" from which recommendations can be made for future scientific funding opportunities within AFOSR." This project is being done in partnership with the National Renewable Energy Laboratory [6].

- U.S. Air Force funded project carried out in 2006 by a partnership of Arizona electric utility, Arizona Public Service and National Energy Technology Laboratory to conduct field assessments of an algae farming technique to fix carbon dioxide and a conversion process to produce various liquid fuels [6].

- Starting in 2004 the DOE Small Business Innovative Research Grants program has awarded various algae production, harvesting and processing applied research projects [6].

DOE has recently launched an effort to consolidate the national algae research effort. As part of this effort DOE hosted a national *Algal Biofuels Technology Roadmap Workshop* at the University of Maryland on December 9 and 10, 2008, attended by researchers and other stakeholders in the industry. A national roadmap document that was still in draft stage at the writing of this section was issued after this workshop [2].

9.4 Algae-based energy in Indiana

The following algae developers are operating in Indiana

- Algaewheel Corporation of Indianapolis. They have carried out pilot projects in Seymour, Whitestown and at Purdue University's swine research facility. In addition they are involved in a project to incorporate algae in a proposed expansion of the wastewater treatment facility in Cedar Lake in Lake County and in a wastewater treatment algae project in Reynolds [7, 8, 9]. They have also broken ground on a wastewater treatment algae project in Reynolds.

- Stellarwind Bio Energy LLC. In March 2009 Stellarwind opened a small scale production facility and corporate headquarters in Indianapolis. [10, 11, 12]

9.5 Incentives for algae-based energy

Recent Federal Government actions have resulted in a re-energizing of algae biofuel research, including:

- <u>The 2007 Renewable Fuel Standard (RFS)</u>. The mandate for renewable fuels, first signed into law in 2005, was increased substantially and extended to 2022. In 2022 it is mandated that 21 billion gallons out of the 36 billion gallons total required biofuel be from biomass other than corn ethanol. It is expected that this 21 billion mandate gallon makes room for algae and other new generation biofuels [2].
- <u>Biomass research funds</u> made available in the 2009 American Recovery and Renewal Act – the "2009 Stimulus Act". $ 800 million in this Act was allocated to fund biofuel research, including algae biofuel, under the Biomass Program of the Department of Energy [2].

Other Federal Incentives

- <u>Renewable Electricity Production Tax Credit (PTC)</u> provides a 2.1 cents/kWh tax credit for wind, geothermal and closed-loop biomass and 1.1 cents/kWh for open-loop biomass, landfill gas municipal solid waste small hydroelectric and marine energy technologies. As part of the February 2009 Stimulus Act the PTC was modified to provide the option for qualified producers to take the federal business energy investment credit (ITC) or an equivalent cash grant from the U.S. Department of Treasury [13]
- <u>Business Energy Investment Tax Credit (ITC)</u> credits up to 30 percent of expenditures on qualifying renewable energy systems [13].

- Renewable Energy Production Incentive (REPI) provides financial incentive payments for electricity produced and sold by renewable energy generation facilities owned by non-profit groups, public utilities, or state governments [13].
- 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 Energy Improvement and Extension Act of 2008 allocated $800 million for new CREBs. In February 2009, the American Recovery and Reinvestment Act of 2009 allocated an additional $1.6 billion for new CREBs, for a total new CREB allocation of $2.4 billion [13].

Indiana Incentives

- Alternative Power and Energy Grant Program: This program offers grants of up to $100,000 to Indiana public, non-profit, and business sectors for the purchase of alternative energy systems, including biomass such as algae [13, 14].
- 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 [15].

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