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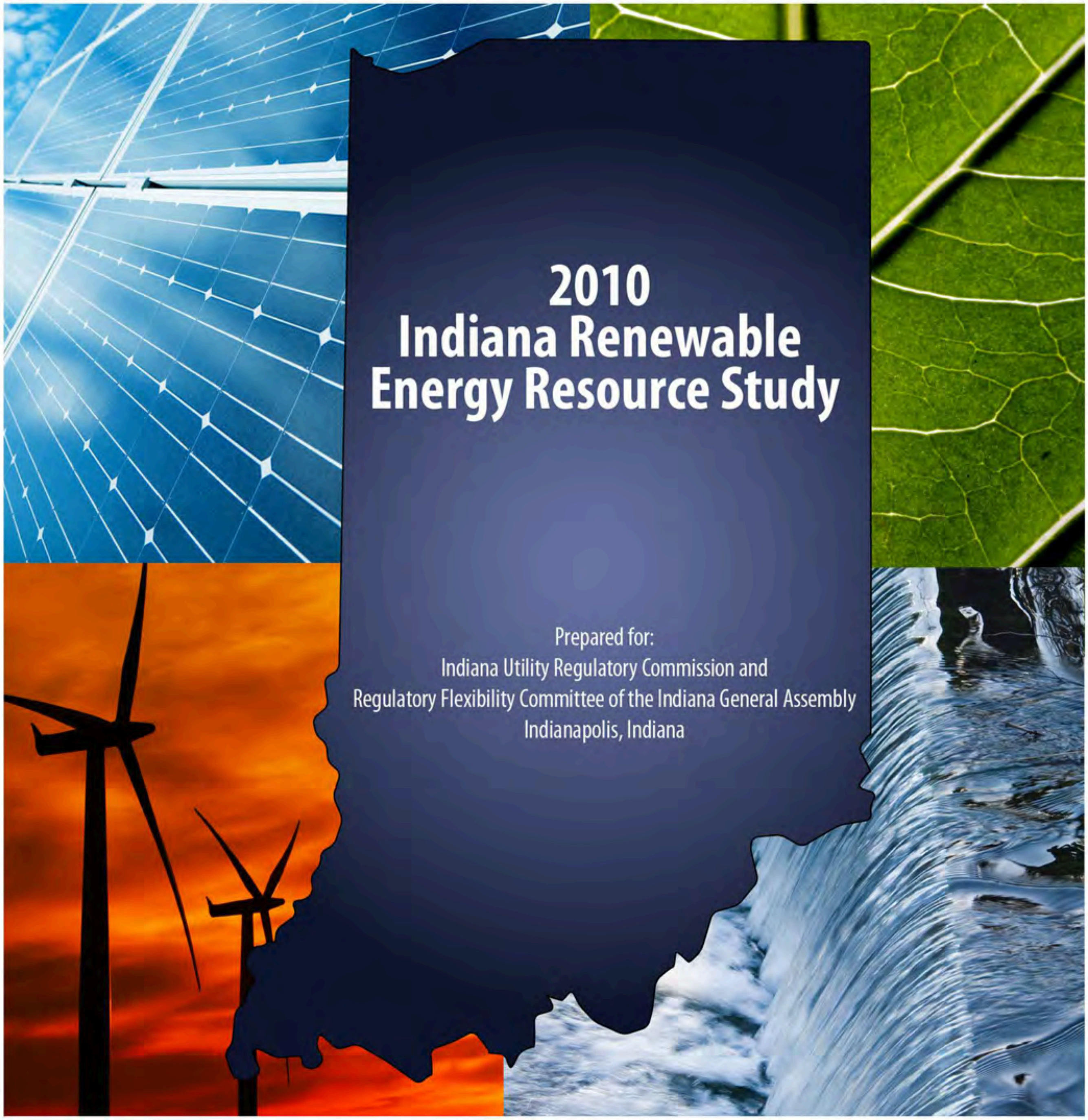

2010 Indiana Renewable Energy Resource Study

Prepared for:
Indiana Utility Regulatory Commission and
Regulatory Flexibility Committee of the Indiana General Assembly
Indianapolis, Indiana

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

2010 INDIANA RENEWABLE ENERGY RESOURCES STUDY

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Acronyms and Abbreviations

AFC	Alkaline Fuel Cell
AFOSR	Department of Defense Air Force Office of Scientific Research
ASD	Agricultural Statistical District
ASP	U.S. Department of Energy's Aquatic Species Program
APS	Arizona Public Service
AWEA	American Wind Energy Association
BIPV	Building Integrated Photovoltaics
BTC	Breakeven Turnkey Cost
Btu	British Thermal Unit
CAIR	Clean Air Interstate Rule
CHP	Combined heat and power
CPV	Concentrating photovoltaic
CREB	Clean Renewable Energy Bonds
CRP	Conservation Reserve Program
CSP	Concentrating Solar Power
DARPA	Department of Defense Advanced Research Projects Agency
DMFC	Direct methanol fuel cell
DOE	U.S. Department of Energy
DNR	Indiana Department of Natural Resources
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
ERS	U.S. Department of Agriculture Economic Research Service
GHG	Green house gases
GWh	Gigawatthour
H_2	Hydrogen
IEA	International Energy Agency
IEC	Israel Electric Company
IPL	Indianapolis Power and Light Company
INEL	Idaho National Engineering and Environmental Laboratory, U.S. Department of Energy
IREC	Interstate Renewable Energy Council
ITC	Business energy investment tax credit
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
MACT	Maximum Achievable Control Technology
MCFC	Molten Carbonate Fuel Cell
MGY	Million gallons per year
mph	Miles per hour
MSW	Municipal solid waste
MTBE	Methyl tertiary butyl ether – a gasoline oxygenating additive
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
OED	Indiana Office of Energy Development
ORNL	Oak Ridge National Laboratory, U.S. Department of Energy
PAFC	Phosphoric Acid Fuel Cell
PBR	Photobioreactor (an enclosed algae growing reactor)
PEM	Polymer electrolyte membrane
PEMFC	Polymer Electrolyte Membrane Fuel Cells
POLYSYS	Policy Analysis System
PTC	Production tax credit
PV	Photovoltaic
REAP	Rural Energy for America Program, U.S. Department of Agriculture
REP	Renewable energy production – Indianapolis Power & Light feed-in tariff for renewable energy
REPI	Renewable Energy Production Incentive
QECB	Qualified Energy Conservation Bonds
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 eighth 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 further amended in 2009, 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 of 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.

In-depth coverage of the use of woody biomass is included in this report as an appendix. Energy from wood and wood waste constitutes a significant portion of the total renewable energy produced in Indiana. The appendix examines the availability of additional energy from woody biomass, some of the limitations to accessing and using additional woody biomass, and issues associated with the carbon dioxide emissions of wood-based energy relative to fossil fuels.

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 2010 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

Figures 1-1 and 1-2 show the historical trend in renewable energy consumption in the U.S. As can be seen in Figure 1-1, biomass and hydroelectricity have been the two primary sources of renewable energy. From about 1980 until the mid 2000s, biomass and hydroelectricity have contributed nearly equal amounts of energy, except for the annual variations associated with varying levels of precipitation in the hydroelectric basins. In more recent years, corn-based ethanol has risen sharply, causing the share from biomass to be consistently higher than from hydroelectricity. Initially corn-ethanol's sharp production increase was due to its use as replacement for the gasoline oxygenating additive MTBE which began to be phased out in 2000. Production continued to increase rapidly due to the federal Renewable Fuel Standard first authorized in the 2005 Energy Policy Act.

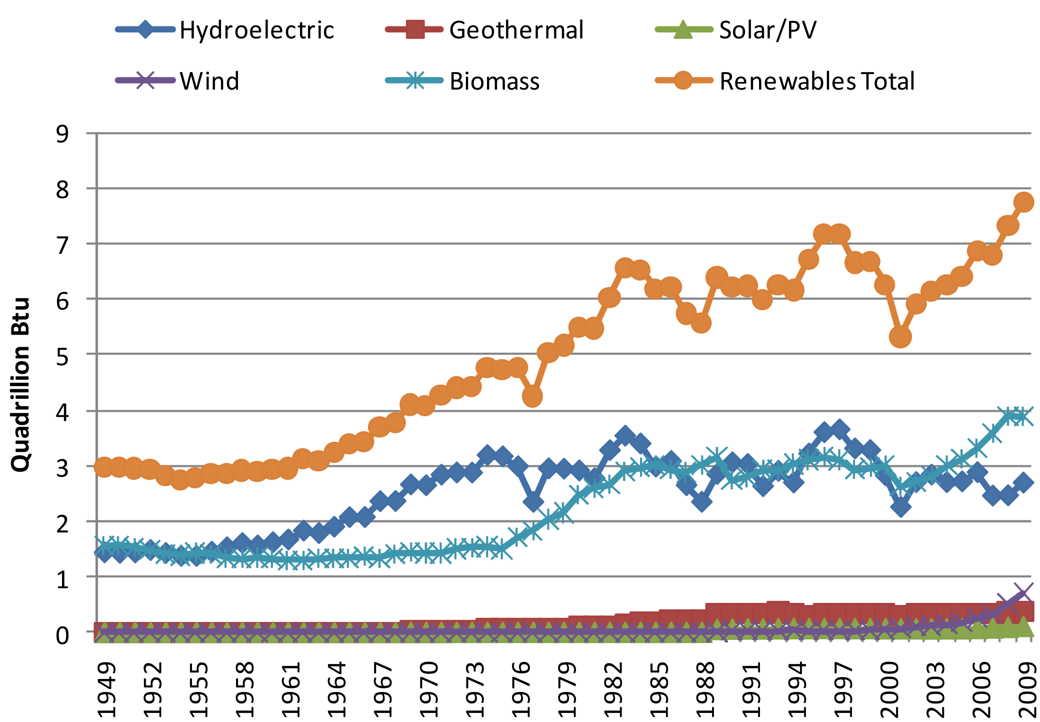


Figure 1-1: Renewable energy consumption in the U.S. (1949-2009) (Source: EIA [1, 2])

As can be seen in Figure 1-2 renewable energy's share has remained modest at less than 10 percent of the total energy consumed. In 2009 renewables contributed 8 percent of the nation's 94 quadrillion Btu of energy consumed and about 10 percent of the electricity generated.

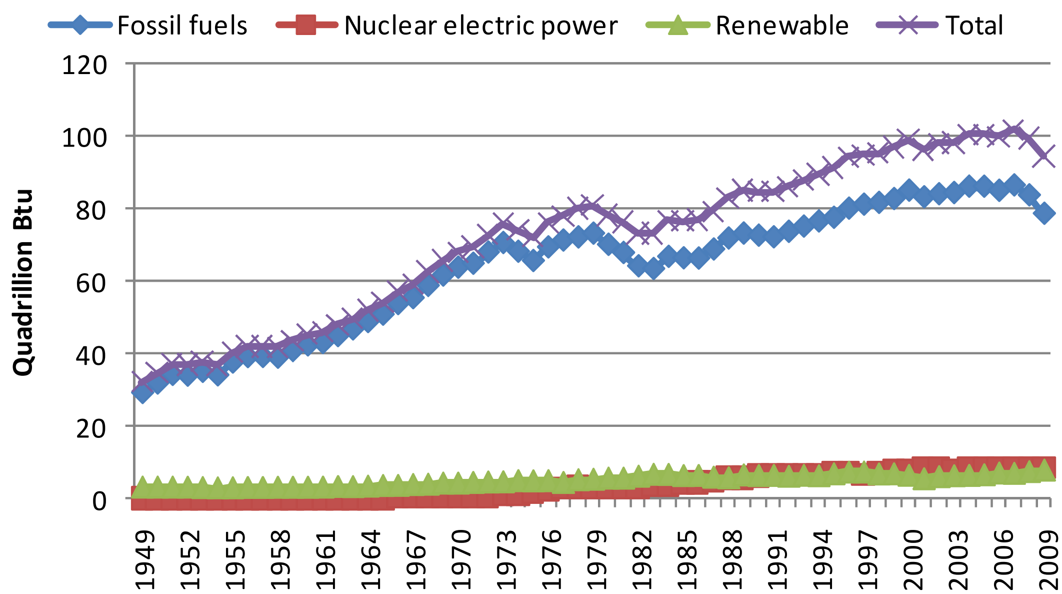


Figure 1-2: U.S. energy consumption by source (1949-2009) (Data source: EIA [1, 2])

Figure 1-3 shows the contribution of the various energy sources to the total energy consumed in the U.S. in 2009. Petroleum continues to be the dominant energy source supplying 37 percent, followed by natural gas at 25 percent and coal at 21 percent. Among the renewable resources, biomass supplied 50 percent of the renewable energy consumed, followed by hydroelectricity at 35 percent. Wind contribution increased to 9 percent from 7 percent in 2008 and geothermal maintained its 5 percent share and solar stayed at 1 percent.

When one considers renewable resources in electricity generation (Figure 1-4), hydroelectricity plays a dominant role, exceeding all the other renewable resources combined. Hydroelectricity makes up 67 percent of the renewable electricity generated. Wind energy takes second place at 17 percent and biomass drops to third place at 13 percent. Geothermal share drops to 4 percent and solar maintains a modest 0.2 percent of renewable electricity generated. As expected 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 value of the lost energy is more than compensated because low cost, off-peak electricity is converted to high cost, on-peak electricity.

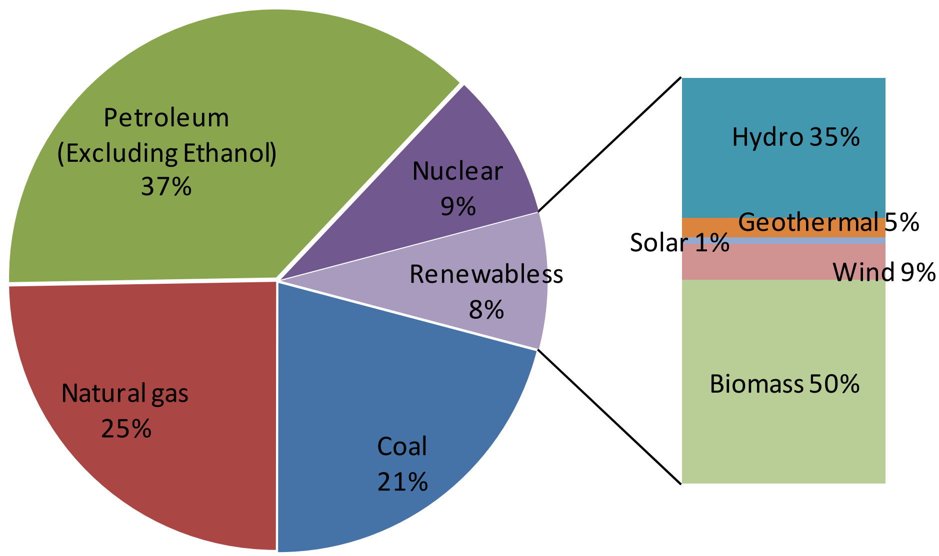


Figure 1-3: U.S. total energy consumption by energy source in 2009 (Source: EIA [2])

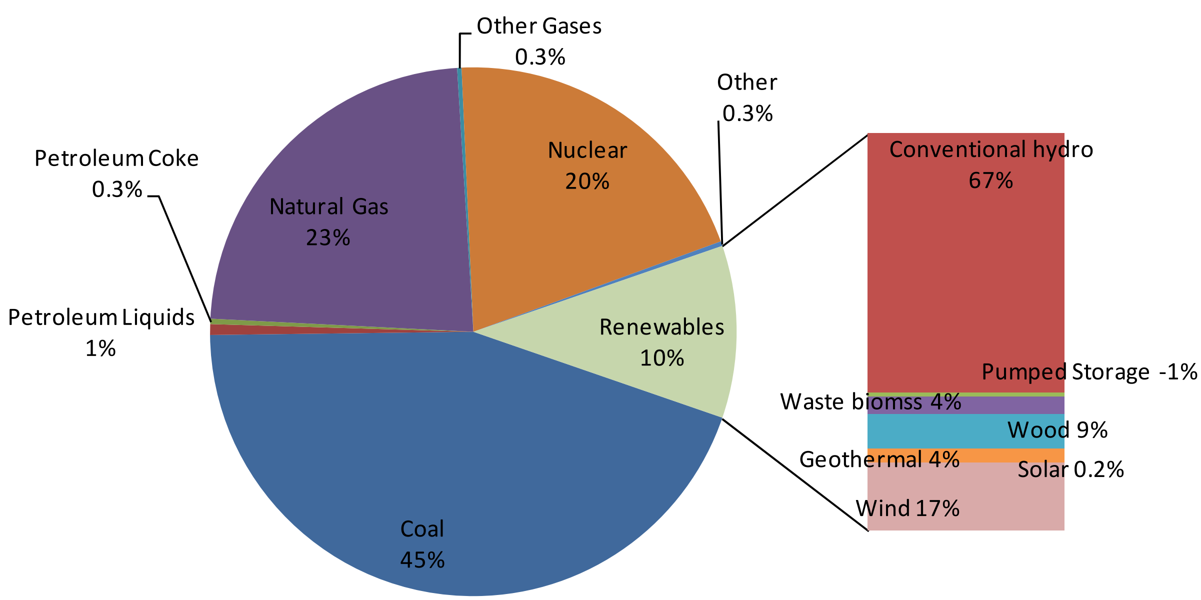


Figure 1-4: Net U.S. electricity generation by energy source in 2009 (Data source: EIA [3, 4])

1.2 Trends in renewable energy consumption in Indiana

Figure 1-5 shows renewable energy consumption in Indiana from 1960 to 2008. At the peak in the 1980s, renewable resources contributed over 3 percent of total energy consumed in Indiana. In the 1990s the share fell to below 2 percent, before the recent increase in ethanol increased it to over 3.5 percent. Woody biomass had been the main source of renewable energy in Indiana, contributing over 80 percent of the total renewable energy until the rise of corn-based ethanol.

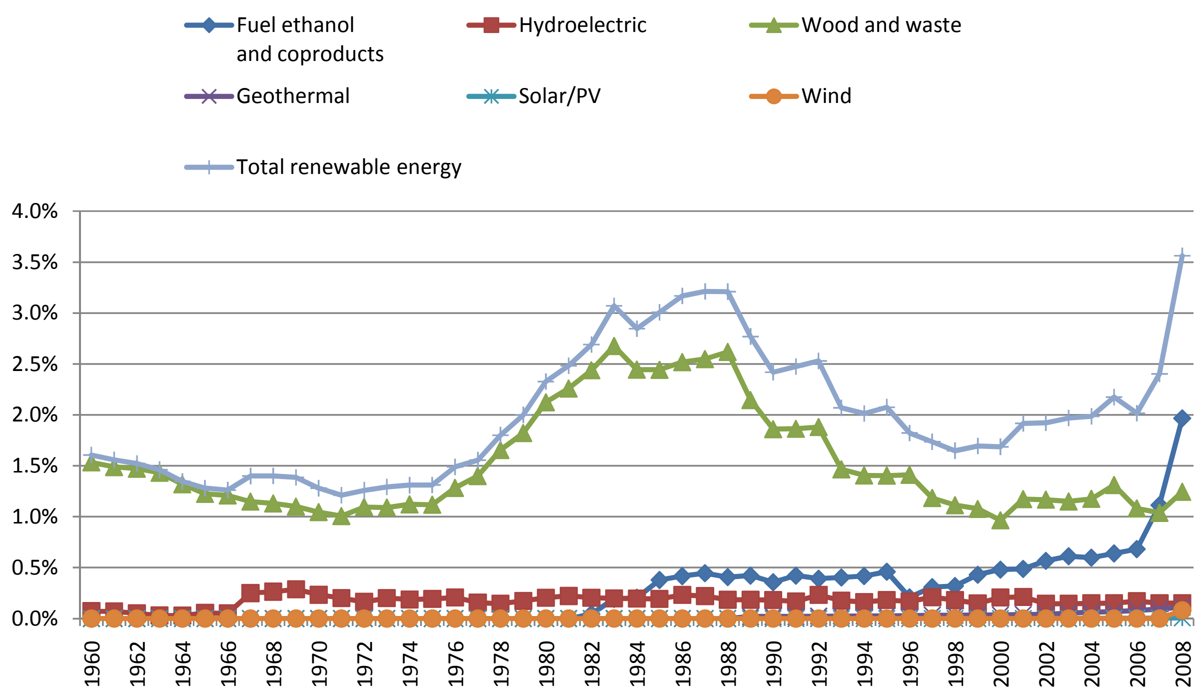


Figure 1-5: Renewables share of Indiana total energy consumption (1960-2008) (Data source: EIA [5])

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 2008. While renewable resources have contributed about 2 percent of Indiana's total energy consumption through 2007, they have contributed less than 0.6 percent of electric energy. The dramatic rise in other renewables from 2007 to 2008 is due to the development of the first commercial wind farm in Indiana, which came on line in May of that year. While 2009 data is not yet available, an even greater increase is expected due to a full year of production from that facility along with production from additional wind generators that became operational during 2009.

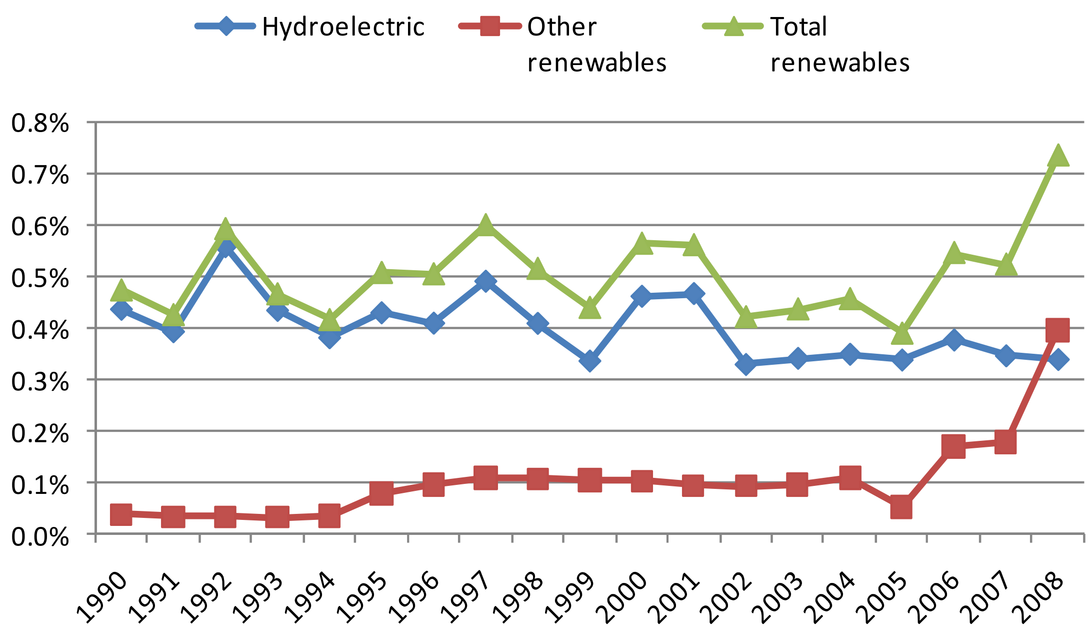


Figure 1-6: <u>Renewables share of Indiana net electricity generation (1990-2008)</u> (Data source: EIA [6])

There are two main reasons that renewable energy resources play a much smaller role in Indiana compared to the rest of the nation: Indiana has relatively modest hydroelectric resources, and the cost of electricity is relatively low. Table 1-1 shows average retail electricity prices for Indiana and the U.S. by sector and for all sectors combined for 2008. It also shows Indiana's ranking among states with respect to electricity cost.

	Indiana (cents/kWh)	*U.S. (cents/kWh)*	*Indiana Rank*
Residential	8.87	11.26	12
Commercial	7.82	10.36	17
Industrial	5.46	6.83	14
All Sectors	7.09	9.74	11

Table 1-1: <u>Indiana's 2008 retail prices comparison and ranking</u> (Data source: EIA [7])

Indiana wind capacity has increased rapidly in the last three years from a mere 20 kW in 2007 to 1039 MW at the end of 2009, with an additional 203 MW expected to be commissioned before the end of 2010. The heaviest construction was in 2009 when a total of 908 MW were brought on line. The first phase of the Fowler Ridge wind farm with a capacity of 400 MW was commissioned in March 2009 and the second phase with a capacity of 200 MW was completed in December. The first phase of the Meadow Lake wind farm with a name plate capacity of 200 MW was commissioned in October 2009 and the 106 MW Hoosier Wind project was commissioned in November. In addition a two-turbine 2 MW project in Union City, owned jointly by the city and the Randolph Eastern school district was completed the same year. In the first half of 2010 Horizon Energy commissioned the 99 MW second phase of the Meadow Lake wind farm. The third and fourth phases of the Meadow Lake project with a combined capacity of 203 MW, are expected to be completed and commissioned by October 2010. Table 2-3 shows the status of the various Indiana wind farm projects.

Project Name	**County**	**Capacity (MW)**	**Developer**	**Date Completed**	**Power Purchaser**
Benton County Wind Farm	Benton	131	Orion Energy	May 2008	Duke (101 MW) Vectren (30 MW)
Fowler Ridge Wind Farm 1	Benton	400	BP Alternative Energy & Dominion	March 2009	I&M (100 MW), Appalachian (100 MW) Dominion (2001 MW)
Fowler Ridge Wind Farm 2	Benton	200	BP Alternative Energy	December 2009	AEP (50x3 MW), Vectren (50 MW)
Hoosier Wind Project	Benton	106	enXco	November 2009	IPL (106 MW)
Union City/Randolph Eastern School Corporation	Randolph	2	Operated by Performance Services Corporation	2009	
Meadow Lake Phase 1	White	200	Horizon (EDP)	October 2009	Wholesale market
Meadow Lake Phase 2	White	99	Horizon (EDP)	Summer 2010	I&M (50 MW)
Under construction					
Meadow Lake Phase 3	White	104	Horizon (EDP)	October 2010	Wholesale market
Meadow Lake Phase 4	White	99	Horizon (EDP)	October 2010	Wholesale market
Proposed Projects					
Fowler Ridge 3	Benton	150	BP Alternative Energy		
Meadow Lake Phase 5	White	100	Horizon (EDP)		
Spartan Wind Farm	Newton	101	Duke Generation Services		

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

Indiana utilities have signed power purchase agreements to purchase electricity from these wind farms and from wind farms outside Indiana as shown in Table 1-3.

Utility	**Project**	**State**	**Power Purchase Agreement (MW)**
Duke	Benton County Wind Farm	Indiana	100
Vectren	Benton County Wind Farm	Indiana	30
Vectren	Fowler Ridge Wind Farm 2	Indiana	50
Indiana Michigan	Fowler Ridge Wind Farm 1	Indiana	100
Indiana Michigan	Meadow Lake Wind Farm 2	Indiana	50
NIPSCO	Buffalo Ridge	South Dakota	50
NIPSCO	Barton Windpower	Iowa	50
IPL	Hoosier Wind	Indiana	106
IPL	Lakefield Wind	Minnesota	201
WVPA	AgriWind	Illinois	8
Hoosier Energy	Story Counter Wind Energy Center	Iowa	25
IMPA	Crystal Lake Wind	Iowa	50

Table 1-3: Wind energy purchase agreements by Indiana utilities (Source: IURC)

1.3 References

1. Energy Information Administration (EIA). 2008 Annual Energy Review. http://www.eia.doe.gov/emeu/aer/overview.html
2. EIA. July 2010 Monthly Energy Review Table 1.3. http://www.eia.doe.gov/emeu/mer/overview.html
3. EIA. Electricity Net Generation From Renewable Energy by Energy Use Sector and Energy Source, http://www.eia.doe.gov/cneaf/solar.renewables/page/table3.html
4. EIA. Electric Power Monthly, July 2010. http://www.eia.doe.gov/cneaf/electricity/epm/table1_1.html
5. EIA. State Energy Data System (SEDS) 2008. Released June 2010. http://www.eia.doe.gov/emeu/states/state.html?q_state_a=in&q_state=INDIANA
6. EIA. Indiana Electricity Profile Table 5, Release date: March 2010. http://www.eia.doe.gov/cneaf/electricity/st_profiles/indiana.html
7. EIA. Electric Power Annual 2008 – State Data Tables, Release date: January 2010. http://www.eia.doe.gov/cneaf/electricity/epa/epa_sprdshts.html

2. Energy from Wind

2.1 Introduction

Wind turbines convert the kinetic energy in wind into mechanical energy and then into electricity by turning a generator. 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.

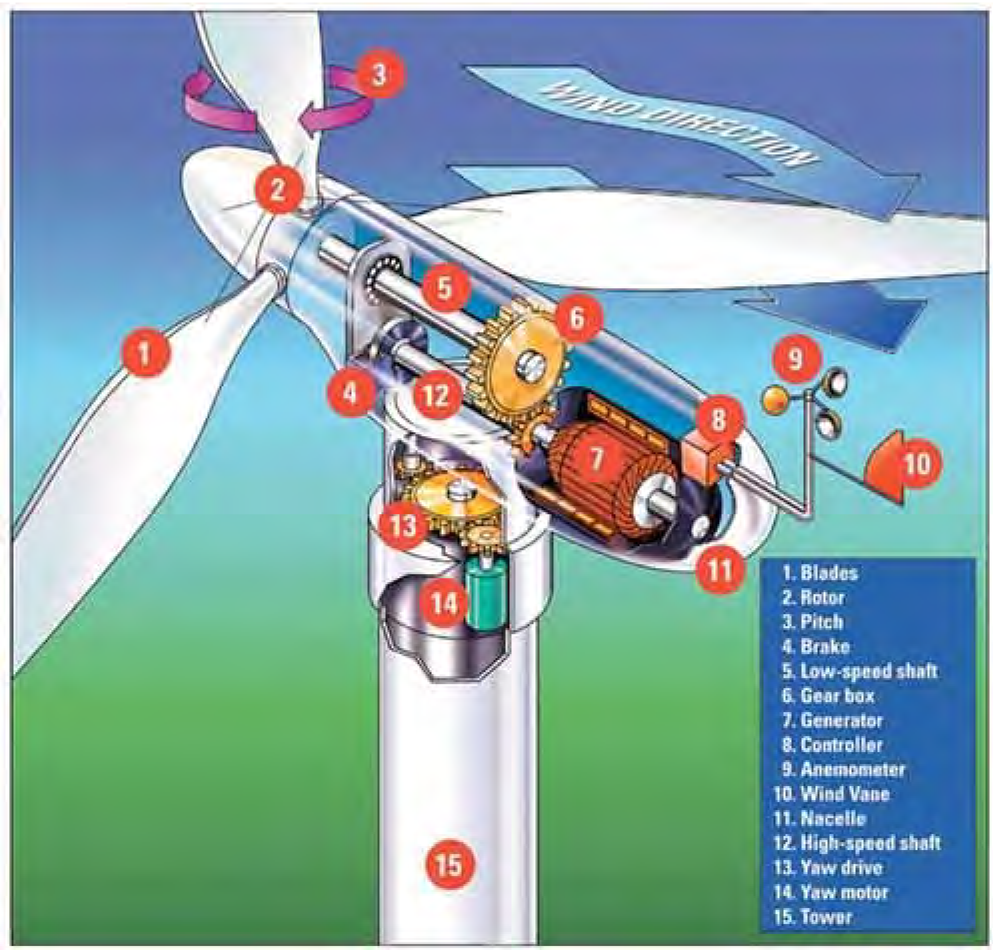


Figure 2-1: Horizontal wind turbine configuration (Source: Euro Avia Corporation [1])

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 an annual capacity factor of over 80 percent while the capacity factors of wind farms are estimated to range between 25 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 3 meters per second (m/s), or 7 miles per hour (mph), are required for small electric wind turbines not connected to the grid, whereas utility-scale wind plants require a minimum wind speed of 5 m/s (11 mph) [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" [5]. 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 [5])

In addition to its being a virtually inexhaustible renewable resource, wind energy has the advantage of being modular, that is a wind farm's size can be adjusted by simply adjusting the number of turbines on the farm. Wind technology's main disadvantage when compared to traditional fossil fuel generation is the fact that the amount of energy coming out of the turbine is solely dependent on the wind and the electric system operator cannot dispatch it to match the varying demand as is done with traditional generation.

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

2.2 Economics of wind energy

Through 2009, the installed cost of wind energy projects continued to follow an upward trend that started in the early 2000s. The 2,120 $/kW capacity-weighted average costs of projects completed in 2009 was 9 percent higher than the cost of the projects completed in 2008 and 63 percent higher than the cost of the projects completed in 2001. Figure 2-2 shows the trends in the installed projects costs from 1982 to 2009. It is expected that project costs will decline in the near future as recent decreases in the price of steel and other materials work their way through the wind industry's supply chain [6].

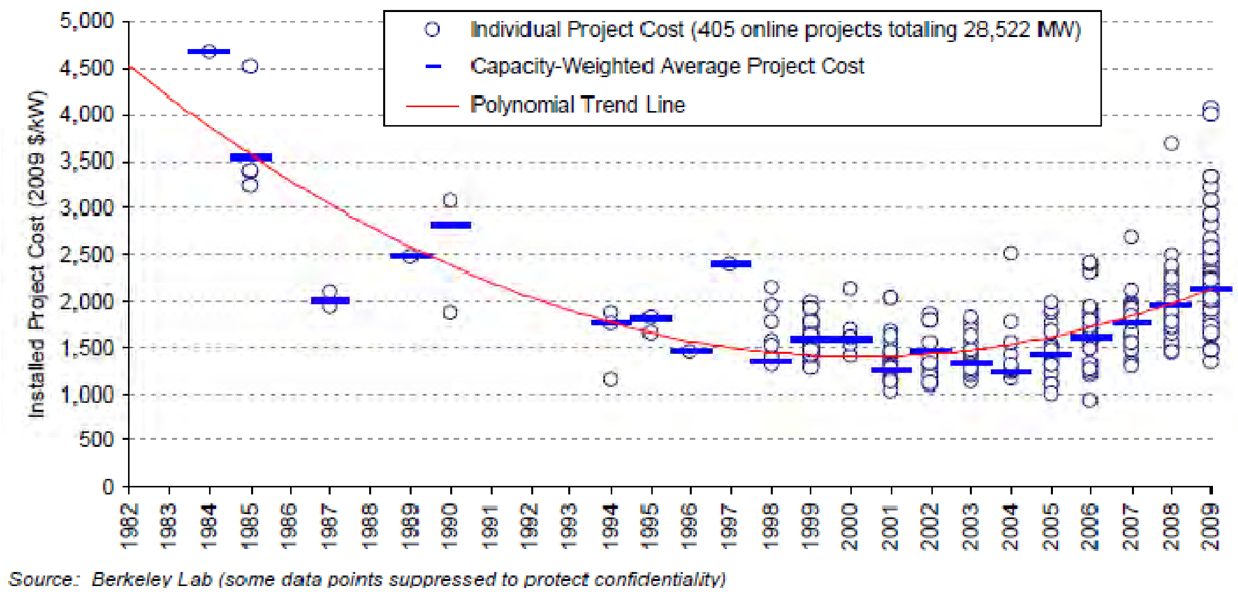
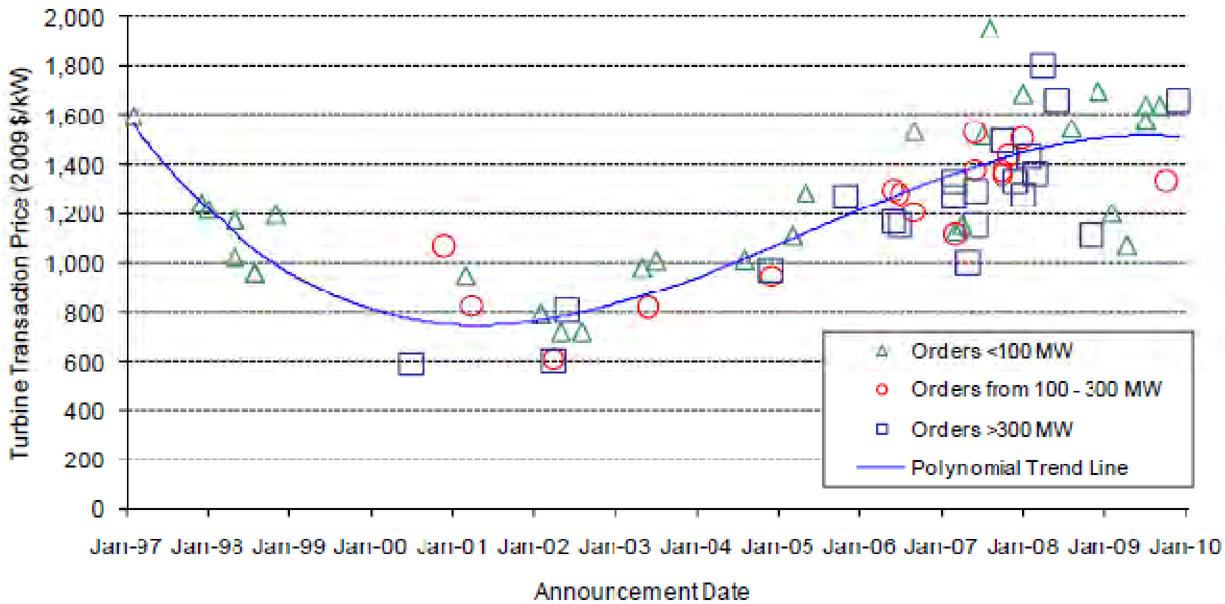


Figure 2-2: Installed wind project costs over time (Source: EERE [6])

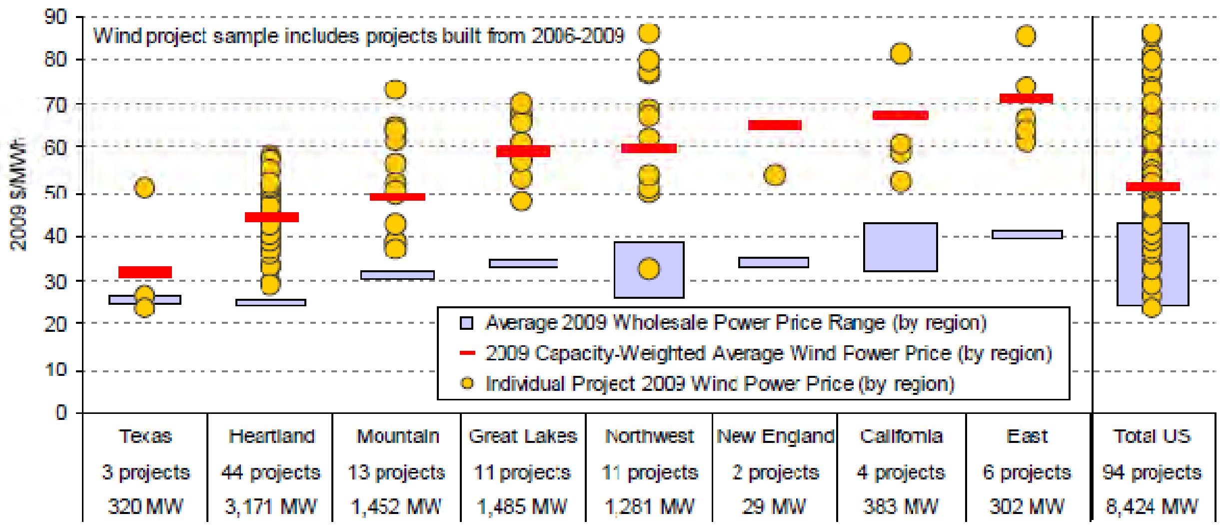
The expected decline in wind farm project costs is already being reflected by a reduction in prices of turbines in the beginning months of 2010. Figure 2-3 shows wind turbine costs over time as calculated for the projects included in the Lawrence Berkeley National Laboratory dataset used in the *2009 Wind Technologies Market Report* [6]. As illustrated in the diagram, turbine prices were in a steady increase, increasing by more than 100 percent between 2000 and 2009.



Source: Berkeley Lab

Figure 2-3: Reported U.S. wind turbine prices over time (Source: EERE [6])

Figure 2-4 shows the prices received by the wind projects in the Berkeley National Lab sample that were built between 2006 and 2009. Unlike in previous years, wind energy prices were not as competitive in 2009, with the prices received by the projects built between 2006 and 2009 being at the higher end of the wholesale electricity price range across the U.S. The drop in wholesale prices that caused this shift in wind energy's competitiveness in 2009 was primarily due to two factors: the drop in electricity demand and prices due to the economic recession and the reduced natural gas prices due to the development of substantial shale gas deposits.



Source: Berkeley Lab, Ventyx, ICE

Figure 2-4: Average cumulative wind and wholesale power prices by region (Source: EERE [6])

2.3 State of wind energy nationally

As can be seen in Figure 2-5, wind energy capacity additions increased in 2009 with over 9,994 MW of name-plate capacity installed in the year. This continued a trend of steady growth since 2005 and record breaking growth since 2007. Prior to 2005 (1999 to 2004) the industry had been characterized by boom-bust cycles attributed primarily to the recurring discontinuities in the renewal of the federal production tax credit since it was first put in place 1992. According to the DOE *2009 Wind Market Technologies Report* [6] the growth in 2009 can be attributed to the following factors.

1. The extension of the production tax credit that was set to expire at the end of 2008 caused projects that had been rushing to beat the deadline to be carried over to 2009. The tax credit has now been extended to 2012.
2. The *American Recovery and Reinvestment Act of 2009* (Stimulus Act) included a provision where wind developers could opt to take a 30 percent cash grant from the U.S. Treasury in lieu of the production tax credit.
3. Projects brought to completion in 2009 to beat the December 2009 expiration date of the first-year bonus depreciation associated with the Modified Accelerated Cost Recovery System.

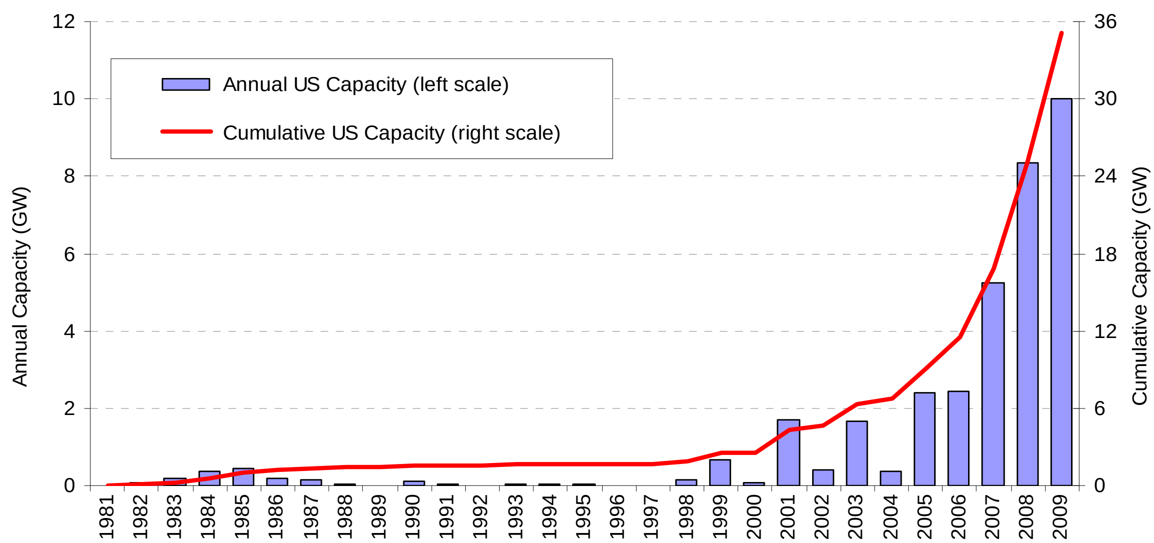


Figure 2-5: Annual capacity additions and cumulative capacity in the U.S. (Source: EERE [6])

The other drivers behind the growth in the wind and renewable energy industry in general also played a role in keeping the wind industry active. These include the renewable portfolio standards enacted and goals set by a large number of states and the uncertainty surrounding the fossil fuel industry due to concerns about future climate change legislation. Figure 2-6 is a map showing the states that have enacted some form of renewable portfolio standard or set a nonbinding goal [7].

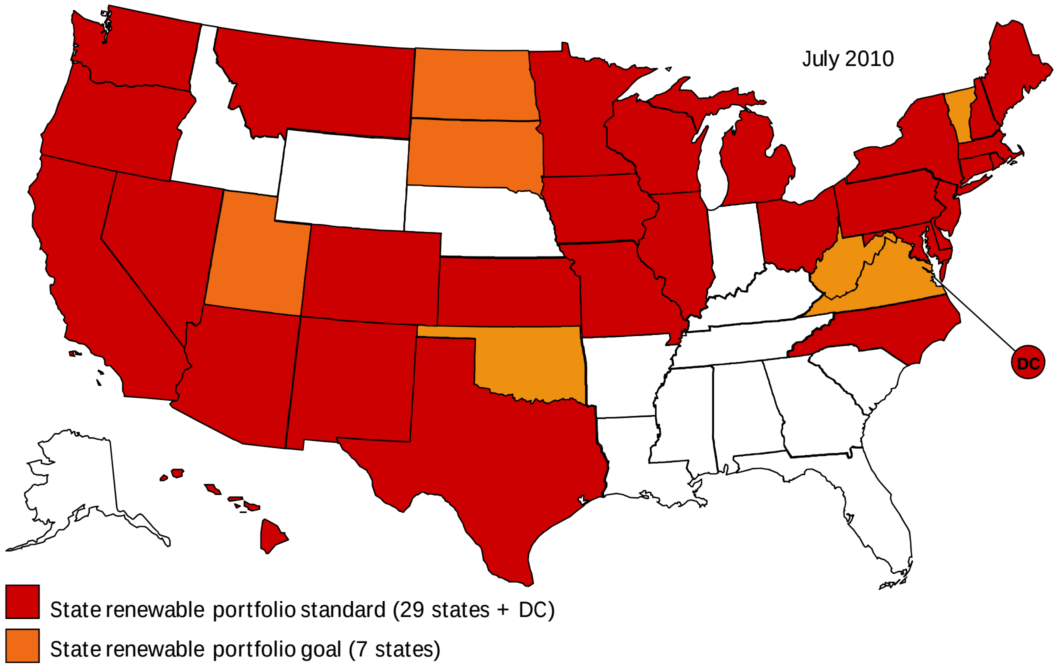


Figure 2-6: Renewable portfolio standards across the U.S. (Source: DSIRE [7])

Figure 2-7 shows the capacity of wind energy installed in states as of May 2009. Texas continued to lead with a total capacity of 9,410 MW installed followed by Iowa with 3,670 MW. The other states in the top five were California – 2,798; Washington – 1,908; Oregon-1,821. Indiana's place as a wind energy state has changed dramatically, from having no utility-scale wind project in 2007 to being ranked 13th nationally with an installed capacity of 1,036 MW at the end of 2009.

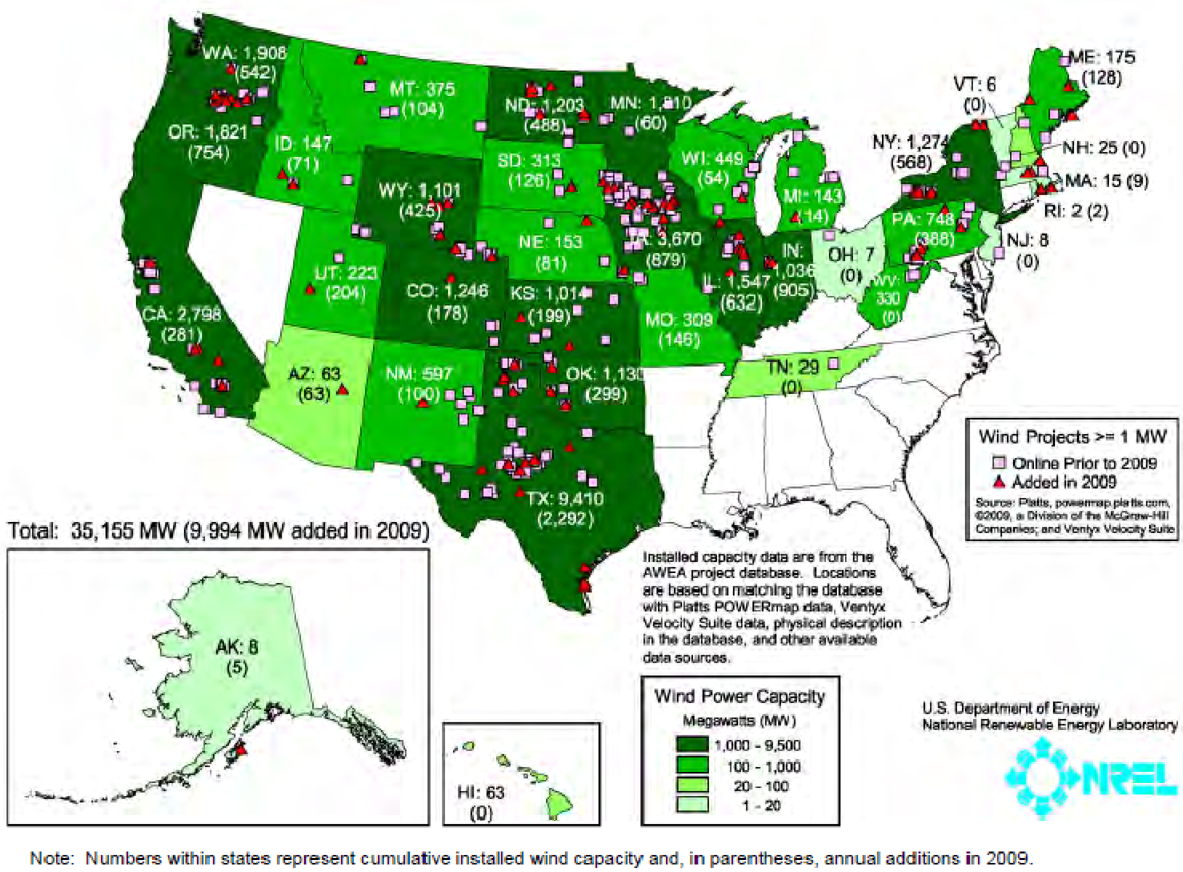


Figure 2-7: Wind power capacity by state at the end of 2009 (Source: EERE [2])

When one considers the penetration of wind energy as a percent of the total electricity generated in 2009, Texas drops to ninth place behind Wyoming whose total installed capacity at the end of 2009 was only 1,101 MW compared to Texas' 9,410 MW. The leading five states in wind energy penetration in 2009 are Iowa –18.8 percent, South Dakota – 13.6 percent, North Dakota – 11.5 percent, Minnesota – 10 percent and Oregon – 8.7 percent. Table 2-2 shows the top twenty states in capacity added in 2009, total cumulative capacity and estimated wind energy as a percentage of total electricity generated in 2009. Indiana's wind penetration ranks 17th nationally at estimated 2.7 percent of total in-state electricity generation, which is slightly above the U.S. average of 2.4 percent.

Annual Capacity (2009, MW)		Cumulative Capacity (end of 2009, MW)		Estimated Percentage of In-State Generation	
Texas	2,292	Texas	9,410	Iowa	18.8%
Indiana	905	Iowa	3,670	South Dakota	13.6%
Iowa	879	California	2,798	North Dakota	11.5%
Oregon	754	Washington	1,908	Minnesota	10.0%
Illinois	632	Oregon	1,821	Oregon	8.7%
New York	568	Minnesota	1,810	Kansas	7.2%
Washington	542	Illinois	1,547	Colorado	7.0%
North Dakota	488	New York	1,274	Wyoming	6.9%
Wyoming	425	Colorado	1,246	Texas	6.3%
Pennsylvania	388	North Dakota	1,203	Oklahoma	5.0%
Oklahoma	299	Oklahoma	1,130	Montana	4.8%
California	281	Wyoming	1,101	Washington	4.5%
Utah	204	Indiana	1,036	New Mexico	4.4%
Kansas	199	Kansas	1,014	California	3.1%
Colorado	178	Pennsylvania	748	Maine	3.1%
Missouri	146	New Mexico	597	Idaho	2.9%
Maine	128	Wisconsin	449	Indiana	2.7%
South Dakota	126	Montana	375	Hawaii	2.2%
Montana	104	West Virginia	330	Illinois	2.1%
New Mexico	100	South Dakota	313	New York	2.0%
Rest of U.S.	358	*Rest of U.S.*	1,376	*Rest of U.S.*	0.25%
TOTAL	**9,994**	**TOTAL**	**35,155**	**TOTAL**	**2.4%**

Source: AWEA project database, EIA, Berkeley Lab estimates

Table 2-2: U.S. wind power rankings: Top 20 states (Data source: EERE [2])

Transmission continued to be a major issue in wind energy development since the most abundant wind energy resource is in the Great Plains (Figure 2-8) and distant from the major population centers along the coasts. Although Figure 2-6 does not show it, the wind resources off the coasts are typically better than onshore winds, with higher wind speeds that are steadier and with less ground level interference. According to the *2009 Wind Market Technologies Report*, almost 2,500 MW of offshore wind projects have made significant advances in the permitting and development process. This includes the highly contested Cape Wind project off the coast of Cape Cod that received its federal permit from the U.S. Department of the Interior in April 2010.

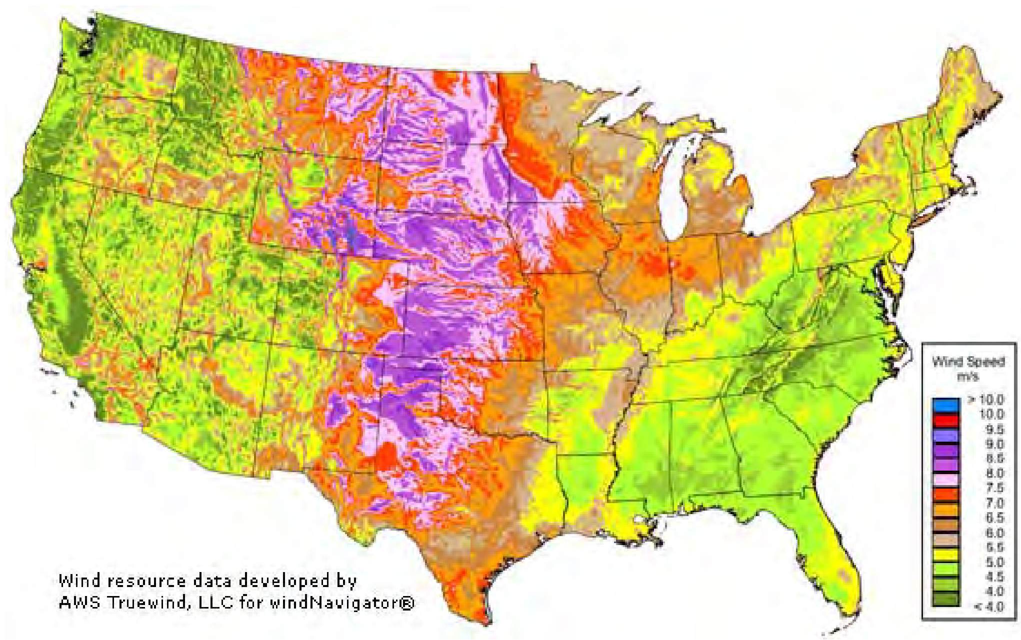


Figure 2-8: 80-meter onshore wind resource map (Source: EERE [8]

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 2-9 through 2-11 show the wind energy distribution in Indiana at 50, 70 and 100 meters, respectively [9]. 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.

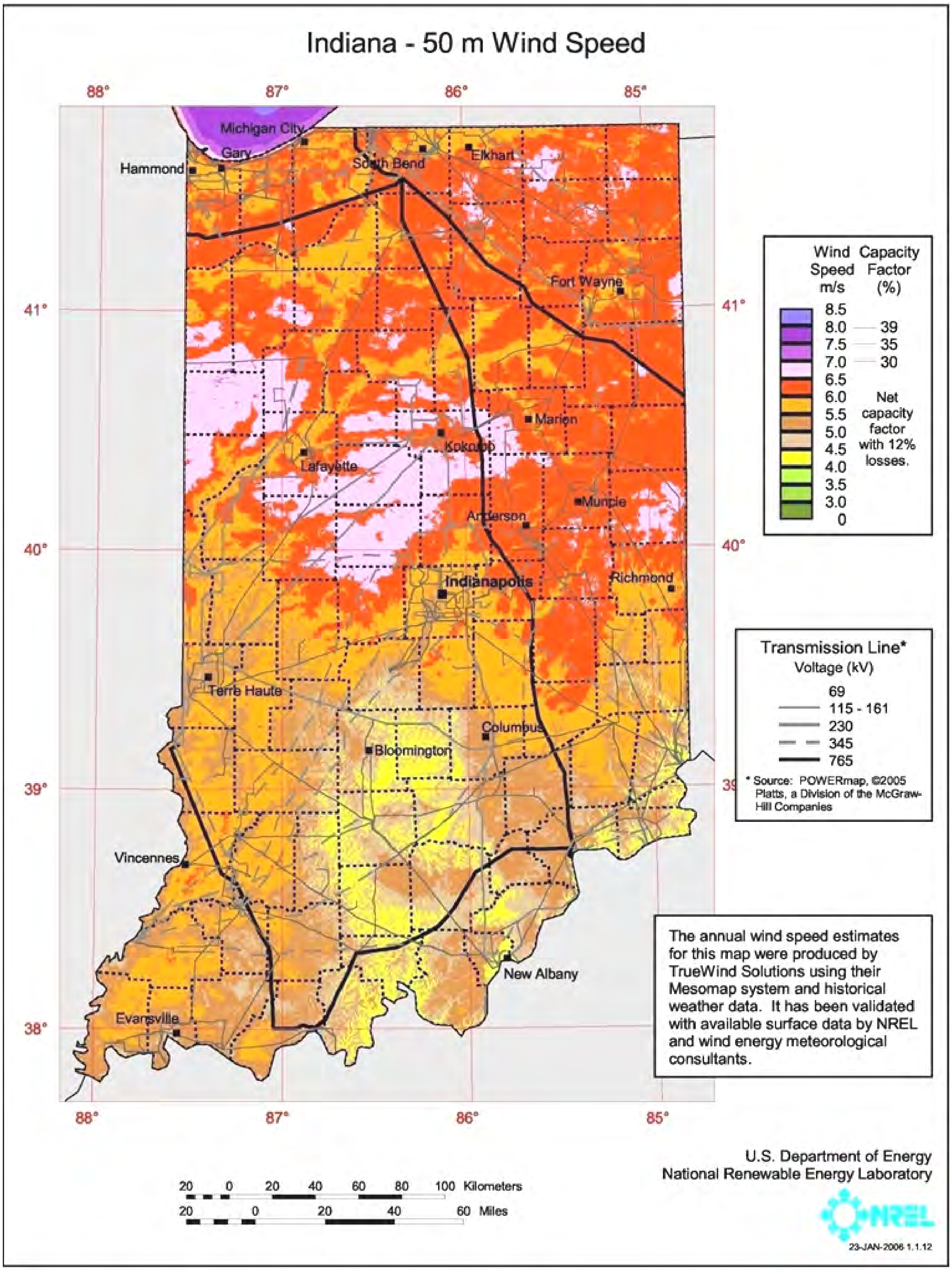


Figure 2-9: Indiana wind speed at 50 meters height (Source: OED/NREL [9])

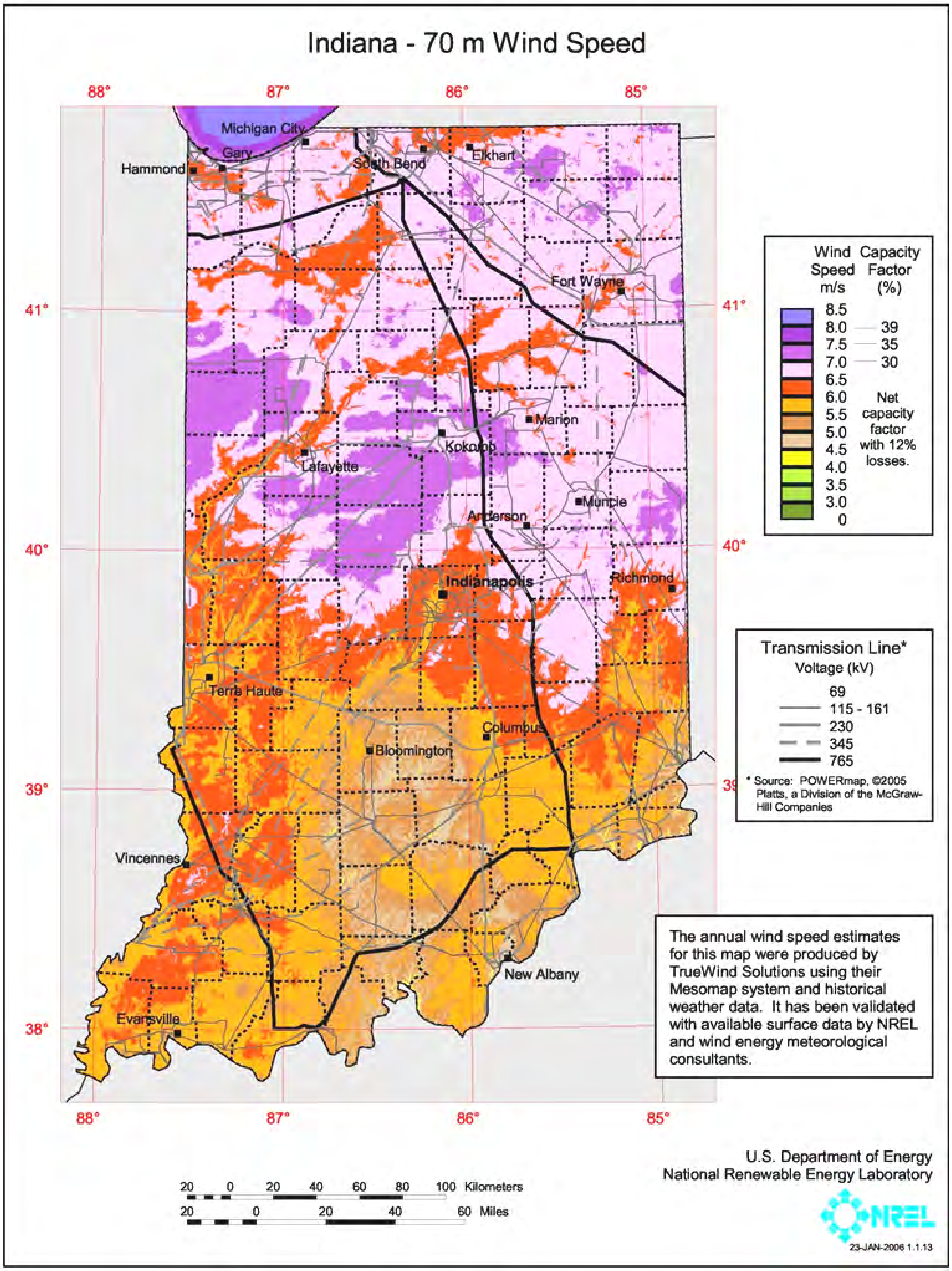


Figure 2-10: Indiana wind speed at 70 meters height (Source: OED/NREL [9])

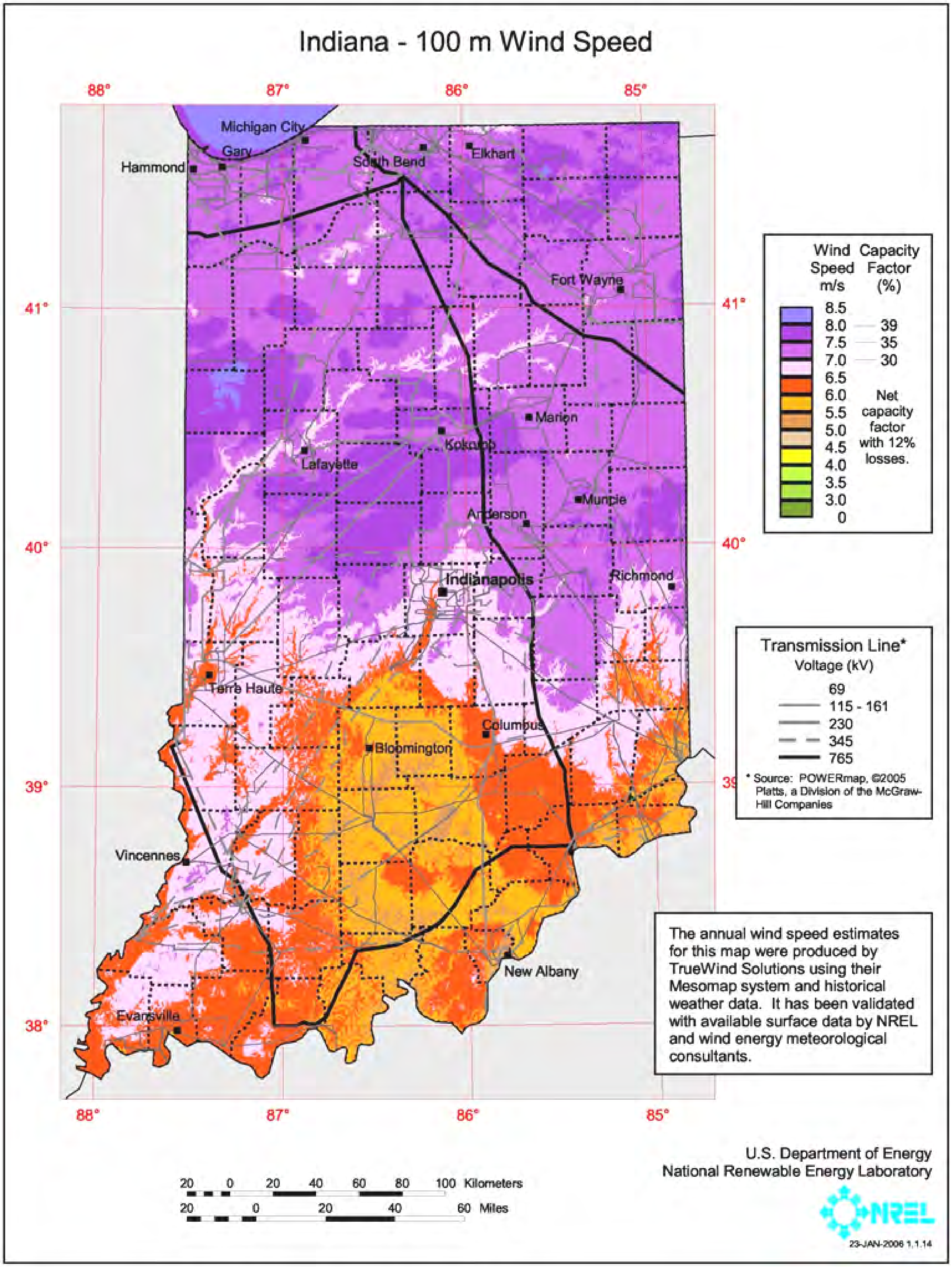


Figure 2-11: Indiana wind speed at 100 meters height (Source: OED/NREL [9])

Indiana wind capacity has increased rapidly in the last three years from a mere 20 kW in 2007 to 1039 MW at the end of 2009, with an additional 203 MW expected to be commissioned before the end of 2010. The heaviest construction was in 2009 when a total of 908 MW were brought online. The first phase of the Fowler Ridge wind farm with a capacity of 400 MW was commissioned in March 2009 and the second phase with a capacity of 200 MW was completed in December. The first phase of the Meadow Lake wind farm with a name plate capacity of 200 MW was commissioned in October 2009 and the 106 MW Hoosier Wind project in November. In addition, a two turbine 2 MW project in Union City, owned jointly by the city and the Randolph Eastern school district was completed the same year. In the first half of 2010 Horizon Energy commissioned the 99 MW second phase of the Meadow Lake wind farm. The third and fourth phases of the Meadow Lake project, with combined capacity of 203 MW, are expected to be completed and commissioned by October 2010. Table 2-3 shows the status of the various Indiana wind farm projects.

Project Name	County	Capacity (MW)	Developer	Date Completed	Power Purchaser
Benton County Wind Farm	Benton	131	Orion Energy	May 2008	Duke (101 MW) Vectren (30 MW)
Fowler Ridge Wind Farm 1	Benton	400	BP Alternative Energy & Dominion	March 2009	I&M (100 MW), Appalachian (100 MW) Dominion (2001 MW)
Fowler Ridge Wind Farm 2	Benton	200	BP Alternative Energy	December 2009	AEP (50x3 MW), Vectren (50 MW)
Hoosier Wind Project	Benton	106	enXco	November 2009	IPL (106 MW)
Union City/Randolph Eastern School Corporation	Randolph	2	Operated by Performance Services Corporation	2009	
Meadow Lake Phase 1	White	200	Horizon (EDP)	October 2009	Wholesale market
Meadow Lake Phase 2	White	99	Horizon (EDP)	Summer 2010	I&M (50 MW)
Under construction					
Meadow Lake Phase 3	White	104	Horizon (EDP)	October 2010	Wholesale market
Meadow Lake Phase 4	White	99	Horizon (EDP)	October 2010	Wholesale market
Proposed Projects					
Fowler Ridge 3	Benton	150	BP Alternative Energy		
Meadow Lake Phase 5	White	100	Horizon (EDP)		
Spartan Wind Farm	Newton	101	Duke Generation Services		

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

Indiana utilities have signed power purchase agreements to purchase electricity from these wind farms and from wind farms outside Indiana as shown in Table 2-4.

Utility	Project	State	Power Purchase Agreement (MW)
Duke	Benton County Wind Farm	Indiana	100
Vectren	Benton County Wind Farm	Indiana	30
Vectren	Fowler Ridge Wind Farm 2	Indiana	50
Indiana Michigan	Fowler Ridge Wind Farm 1	Indiana	100
Indiana Michigan	Meadow Lake Wind Farm 2	Indiana	50
NIPSCO	Buffalo Ridge	South Dakota	50
NIPSCO	Barton Windpower	Iowa	50
IPL	Hoosier Wind	Indiana	106
IPL	Lakefield Wind	Minnesota	201
WVPA	AgriWind	Illinois	8
IMPA	Crystal Lake Wind	Iowa	50

Table 2-4: Wind energy purchase agreements by Indiana utilities (Source: IURC)

2.5 Incentives for wind energy

The following federal and state incentives are available for wind energy projects [7].

Federal Incentives

- Renewable Electricity Production Tax Credit (PTC) credits wind energy producers with 2.2 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 [7].

- 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. REPI payments are subject to availability of annual appropriations by congress [7].
- 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 [7].
- 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 [7].
- Modified Accelerated Cost-Recovery System (MACRS): This program allows businesses to recover investments in solar, wind and geothermal property through depreciation deductions.
- Clean Renewable Energy Bonds (CREBs): This program, authorized by the Energy Policy Act of 2005, makes available a total of $1.2 billion in 0 percent 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 [7].
- 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."[7]
- 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 [7].
- 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: $60 million for FY 2010, $70 million for FY 2011, and $70

million for FY 2012 [7].

- High Energy Cost Grant Program administered by the U.S. Department of Agriculture (USDA) is aimed at improving the electricity supply infrastructure in rural areas having home energy costs exceeding 275 percent of the national average. Eligible infrastructure includes renewable resources generation. The USDA has allocated a total of $15.5 million for the 2010 funding cycle. The individual grants range from $75,000 to $5 million [10]

Indiana Incentives

- 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 [7].
- 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 [11].
- Indianapolis Power & Light Co. – Rate REP Renewable Energy Production: IPL is offering a "feed-in tariff" to facilities that produce renewable energy. IPL can purchase renewable energy and contract the production for up to 10 years. Compensation for small wind facilities is $0.14/kWh and for large wind facilities is $0.075/kWh [7]

2.6 References

1. Euro Avia Corporation. http://energiaeoliana.files.wordpress.com/2008/03/wind_energy.jpg
2. US Department of Energy Office of Energy Efficiency and Renewable Energy (EERE). http://www.windpoweringamerica.gov/pdfs/wpa/wpa_update.pdf
3. American Wind Energy Association (AWEA). http://www.awea.org/newsroom/releases/Annual_US_Wind_Power_Rankings_041107.html
4. American Wind Energy Association., Wind energy basics.
5. AWEA. Basic principles of wind resource evaluation. http://www.awea.org/faq/basicwr.html
6. EERE. 2009 Wind Technologies Market Report. http://www.windpoweringamerica.gov/
7. Database of State Incentives for Renewables & Efficiency (DSIRE). http://www.dsireusa.org/
8. EERE. http://www.windpoweringamerica.gov/wind_maps.asp.
9. Indiana Office of Energy Development. Indiana Wind Maps & Reports., http://www.in.gov/oed/2425.htm

10. U.S. Department of Agriculture, Rural Development, Electric Programs. http://www.usda.gov/rus/electric/hecgp/overview.htm
11. Indiana Department of Environmental Management. Clean Energy Credit. http://www.in.gov/idem/4134.htm

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, livestock manure 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 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].

Energy is extracted from biomass on a large scale either by directly burning the material or by converting the material to a substance that has efficiency or end-use benefits. Two methods are used for burning the material: direct firing and co-firing. In direct firing the biomass material is simply burned and the heat is used to create steam which can be used to create electricity. In co-firing, the biomass material is used as a supplement to coal. One advantage to using the co-firing method over using only coal is that lower net emissions of carbon dioxide and sulfates per unit of heat are obtained from the biomass material. Also, co-firing results in a smaller volume of ash than direct firing biomass [3]. One disadvantage of using biomass in coal reactors is that fouling of the reactor sides can occur due to the high amounts of alkaline impurities introduced to the reaction mix.

Apart from direct combustion of the material, biomass can be altered using thermochemical or biochemical processes. Gasification is a thermochemical process where the fuel is converted into a gaseous fuel using high temperatures. Pyrolysis is another process where the biomass material is converted into smaller compounds using heat. This technology can increase the energy transfer efficiencies [3, 4].

Other ways of handling biomass are to convert the material to a fuel using a biochemical process. The main methods of this transformation are anaerobic digestion and fermentation [3]. In digestion, enzymes are added to break down the material in order to produce biogas which is a mixture of methane and carbon dioxide. In fermentation, ethanol is produced from the material [3].

Bioenergy constituted 4.2 percent of the total energy consumed, and 51 percent of the total renewable energy consumed, in the U.S. in 2009 [5]. Of the 3.596 quadrillion British thermal units (quads) of energy supplied by biomass in 2007, 56 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 17 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 the use 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. 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[3] [6].

Analogous to a refinery for petroleum, biorefineries are facilities that use biomass to create fuels, power, and chemicals. They are able to process the high volume of raw biomass into a more easily handled product such as transportation fuel. Research occurring at NREL takes two approaches for developing biorefineries. The biochemical approach focuses on the fermentation of sugars to produce fuels and other useful products for energy generation. The thermochemical approach uses gasification technologies to obtain these products [8].

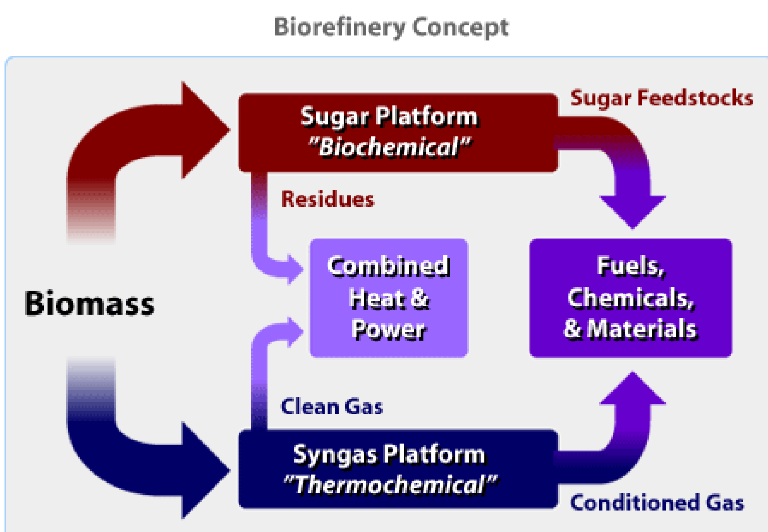


Figure 3-1: Biorefinery platforms (Source: NREL [8])

[3] A complete overview of organic waste biomass is presented in Section 4 of this report.

The advantage of a biorefinery lies in 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 to aid in biofuels research and commercialization, which includes additional funding for commercial-scale biorefinery demonstration projects [9]. On May 6, 2010, the U.S. Departments of Energy and Agriculture announced an additional $33 million for funding research to develop technologies and processes that produce biofuels, bioenergy, and high-value biobased products [10].

Energy crops have long-term advantages, such as erosion mitigation, that other sources of biomass do not have [11]. Willow and switchgrass 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" [11]. Canola, a specialized oilseed, is also a potential energy crop that is being grown in the Northern Plains region of the United States [12]. As a relatively new crop, adoption of canola is limited by farmer confidence and the large amount of land required for profitable initial production.

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. [13]. 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 [14].

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 [14])

Converting a traditional coal-fired power plant to a co-firing plant costs $150-$300 per kilowatt of biomass generation in pulverized coal boilers [15].

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. Furthermore, the proposed revision to the *Clean Air Interstate Rule* (CAIR) would reclassify biomass boilers making them subject to the *Maximum Achievable Control Technology* (MACT) to restrict emissions will likely worsen the economic viability of biomass combustion for energy. The proposed rule was issued by the U.S. Environmental Protection Agency in April 2010 and the public comment period closed in August [16].

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 [17]. 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) [18]. Therefore, the use of energy crops is not yet economical. Tighter emission standards (SO_2, NO_x, mercury, carbon etc) may significantly alter the price spread over which biomass becomes viable.

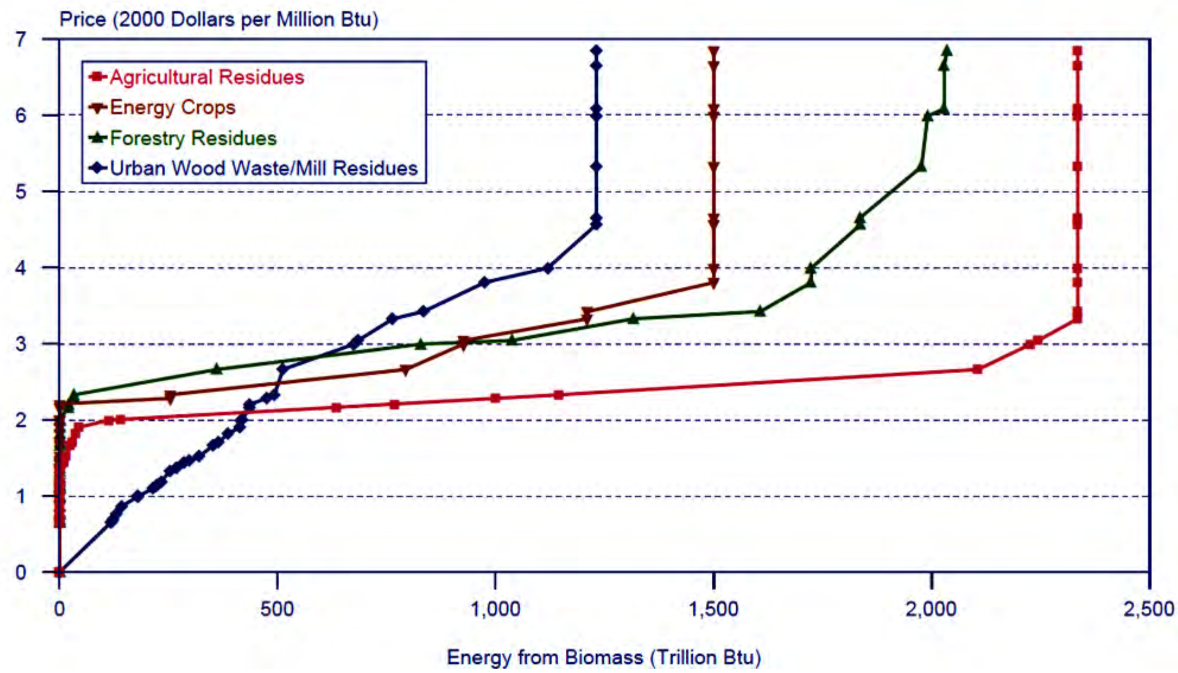


Figure 3-2: POLYSYS estimated biomass supply curve for year 2020 (Source: EIA)

Corn and soybean use for biofuel production

Although corn and soybeans do not meet the strict definition of a dedicated energy crop, their rapid rise as feedstocks 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 938 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 [19]. 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 [20].
- The renewable fuel standard (RFS) included in the 2005 Energy Policy Act. The RFS mandates the increasing use of renewable fuels by expanding to 7.5 billion gallons by 2012 [21].
- 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 45 cents/gallon

tax credit to be given to the individual who produces the mixture of gasoline and ethanol [22]. This tax credit is due to expire December 31, 2010, but legislation to extend the tax credit until 2015 has been submitted in the Senate and the House of Representatives [23].

Company	**Location**	**Current Capacity (MGY*)**
New Energy Corp	South Bend	100
Central Indiana Ethanol	Marion	40
Iroquois Bio-Energy Co.	Rensselaer	40
POET Energy	Portland	65
POET Energy	Alexandria	60
POET Energy	North Manchester	65
The Andersons Clymers	Clymers	110
Valero Energy	Linden	100
AltraBiofuels Indiana	Cloverdale	60
Cardinal Ethanol	Union City	100
Indiana Bio-Energy	Bluffton	110
Abengoa Bioenergy Corp.	Mt. Vernon	88

*MGY is million gallons per year.

Table 3-2: Ethanol plants in Indiana (Source: ISDA [19])

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

Table 3-3: Biodiesel plants in Indiana (Source: ISDA [19])

3.3 State of energy crops nationally

Energy crops can be grown on most of the land classified as cropland in the U.S. [11]. Overall, the nation's cropland acreage remains around 400 million acres with changes from year to year of harvested crop land at less than 13 percent [24, 25]. Figure 3-3 shows estimated biomass production potential nationally [26]. 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.

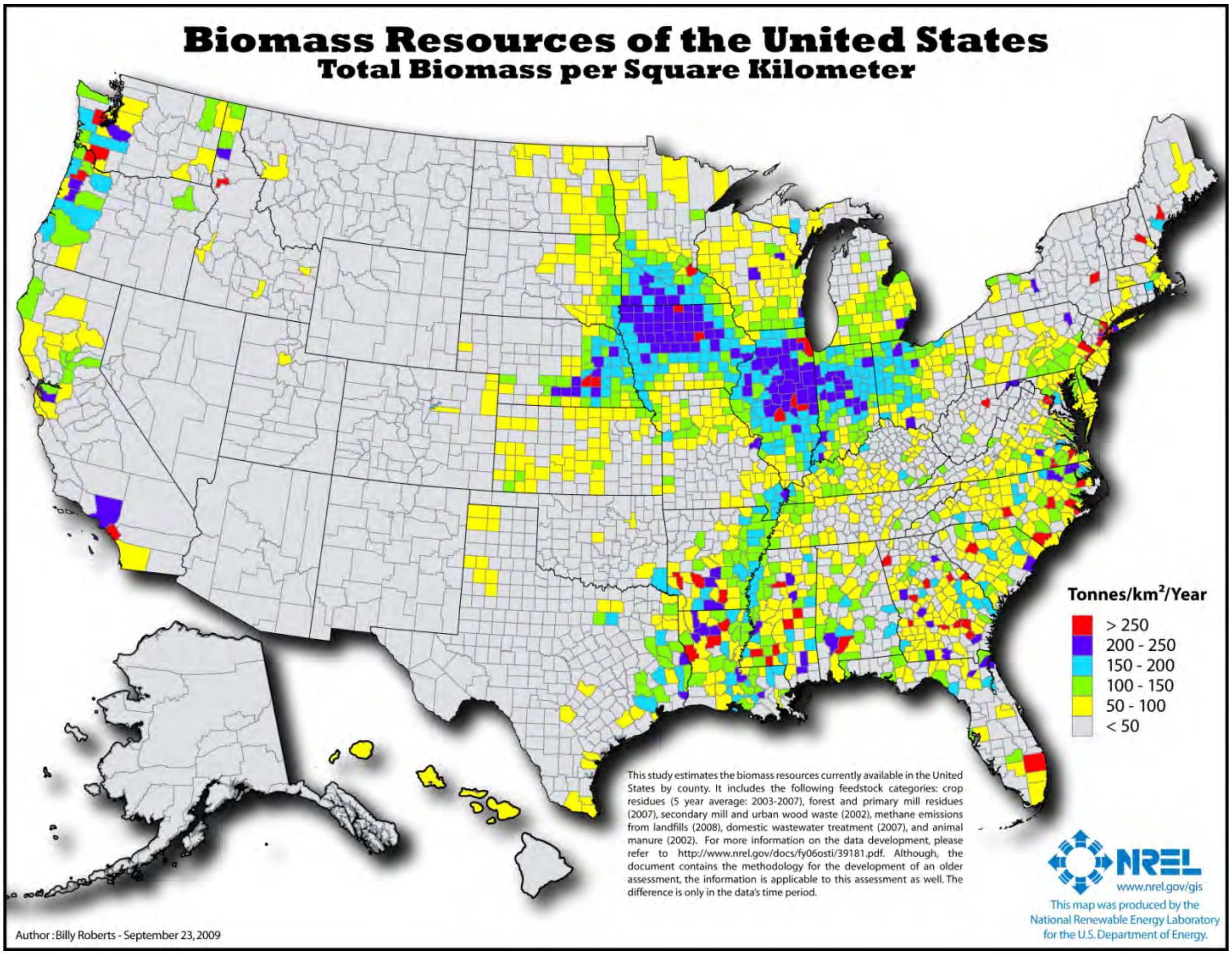
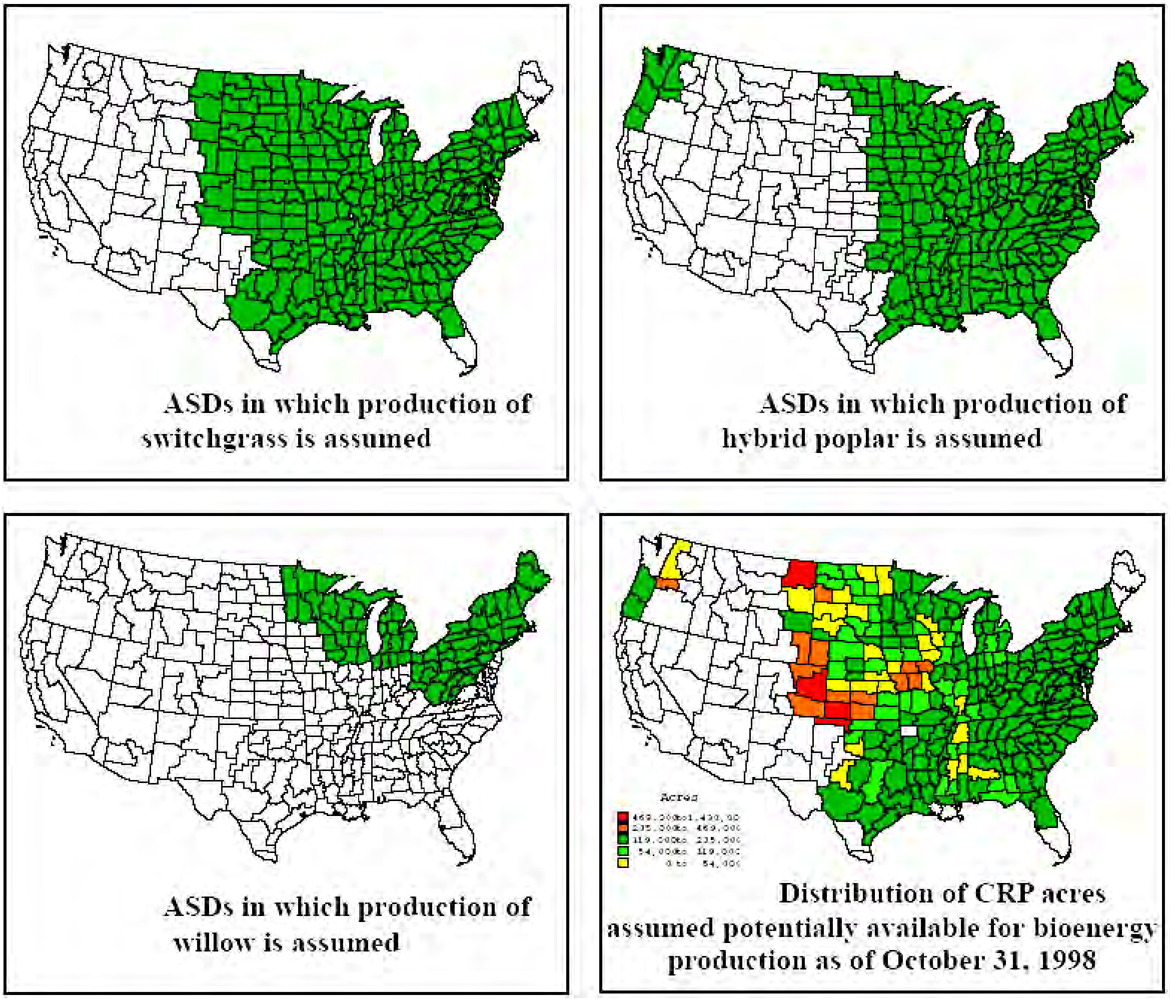


Figure 3-3: Biomass resources available in the U.S. (Source: NREL [26])

ORNL, 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, 27]. 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* [17].



<u>**Figure 3-4:** POLYSYS assumed Agricultural Statistical Districts (ASDs) for energy crop production</u> (Source: University of Tennessee [17])

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 the yield and quality of switchgrass will continually improve through genetic modification and breeding. Thus, farmers may plow under their fields and plant new varieties of switchgrass periodically, perhaps every 10 years.

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])

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 would be 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 willow trees would also be distributed as wood chips.

The USDA and DOE conducted another study in 2000 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 [17]. Harvest of CRP acres will require a significant change in the current laws, however, and likely need to 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.

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 to an increasing number of acres under cultivation.

3.4 Energy crops in Indiana

A 2002 study conducted 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 3-5 shows the levels of energy crops that would be produced in Indiana at three different biomass 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, 28]. The biomass price levels needed to achieve the production levels shown in Figure 3-5 will be higher today given that food crop price levels are much higher than they were in 1999.

The estimates of switchgrass and poplar production potential in a 2006 ORNL [29] study are shown in Figure 3-6. The study used the same agricultural sector model (POYSYS) referred to previously. As can be seen in Figure 3-6, 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.

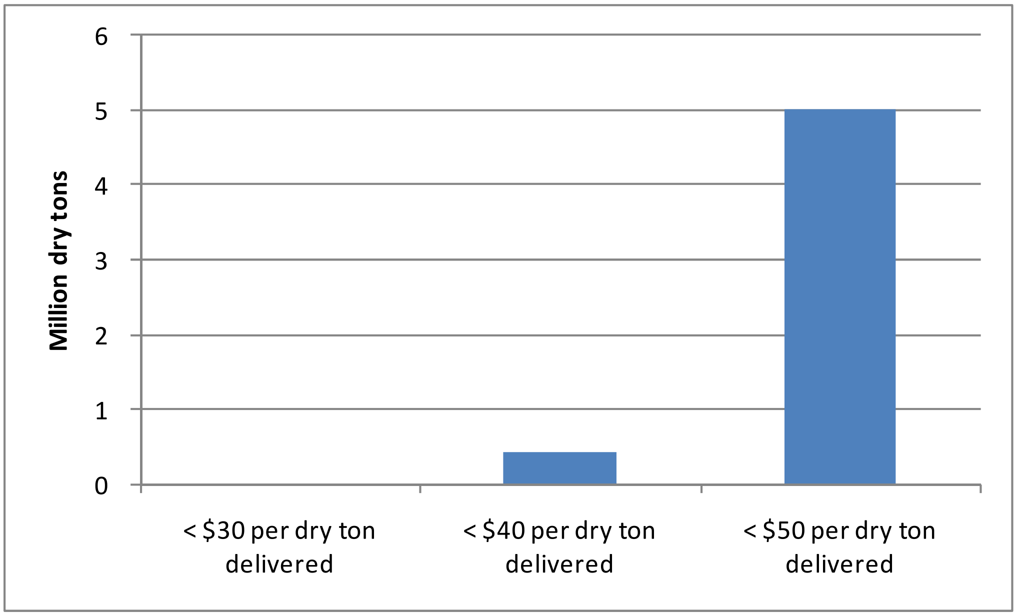


Figure 3-5: Estimated annual cumulative energy crop quantities (dry tons) by delivered price (1997 dollars) for Indiana (Data source: ORNL [1])

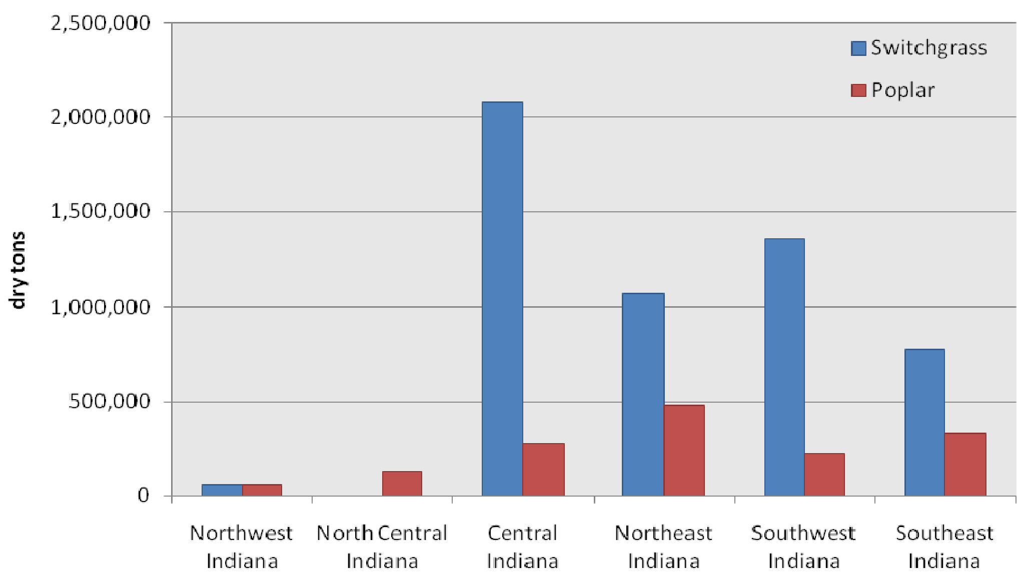


Figure 3-6: Estimated annual potential production of switchgrass and hybrid poplar (dry tons) for Indiana, USDA baseline 2001 (Source: ORNL [29])

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 [30]. 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 [30])

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 2.2 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 [31].
- Business Energy Investment Tax Credit (ITC) credits up to 30 percent of expenditures on qualifying renewable energy systems [31].
- 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 [31].
- 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 [31].
- Qualified Energy Conservation Bonds (QECBs) are qualified tax credit bonds and 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". In February 2009, these funds were expanded to $3.2 billion [31].

- 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 [32].
- High Energy Cost Grant Program administered by the U.S. Department of Agriculture (USDA) is aimed at improving the electricity supply infrastructure in rural areas having home energy costs exceeding 275 percent of the national average. Eligible infrastructure includes renewable resources generation. The USDA has allocated a total of $15.5 million for the 2010 funding cycle. The individual grants range from $75,000 to $5 million [33]

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 [34]. These credits can be sold on the national market.
- Indianapolis Power & Light Co. – Rate REP Renewable Energy Production: IPL is offering a "feed-in tariff" to facilities that produce renewable energy. IPL can purchase renewable energy and contract the production for up to 10 years. Biomass compensation is $6.18/kW per month plus $0.085/kWh [31, 35].

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 [36]. 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. [36].

3.6 References

1. Walsh, Marie E., et al. Oak Ridge National Laboratory (ORNL). Biomass feedstock availability in the United States: 1999 State Level Analysis. Updated January 2000. http://bioenergy.ornl.gov/resourcedata/index.html
2. Cook, Jim, and Jan Beyea. An analysis of the environmental Impacts of energy crops in the USA: Methodologies, conclusions and recommendations. November 1996. http://www.panix.com/~jimcook/data/ec-workshop.html

3. H.J. Brown, Eflin, J. C. and D.L. Ferguson. 2002. Biomass: Connecting Biomass Producers with Users: Biomass Production on Marginal Lands in Indiana. (Final Report to Indiana Department of Commerce for an EPA Grant).
4. Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE), Thermochemical Conversion Processes, April 2008. http://www1.eere.energy.gov/biomass/thermochemical_processes.html
5. Energy Information Administration (EIA). Monthly Energy Review, May 2008. http://www.eia.doe.gov/mer/
6. EIA., Renewable Energy Annual 2007. April 2009. http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/rea.pdf
7. Haq, Zia. EIA. Biomass for Electricity Generation. July 2002. http://www.eia.doe.gov/oiaf/analysispaper/biomass/pdf/biomass.pdf.
8. National Renewable Energy Laboratory (NREL). What is a biorefinery? April 2007. http://www.nrel.gov/biomass/biorefinery.html
9. U.S. Department of Energy. Biomass Program: Recovery Act. Funding for biomass projects. May 5, 2009. http://www1.eere.energy.gov/biomass/news_detail.html?news_id=12488.
10. U.S. Department of Energy. Biomass Program. DOE, USDA Announce Funding for Biomass Research and Development Initiative. May 6, 2010. http://www1.eere.energy.gov/biomass/news_detail.html?news_id=15995.
11. Walsh, Marie E., ORNL. BIOCOST: a Tool to estimate energy crop costs. http://bioenergy.ornl.gov/papers/misc/biocost.html
12. Raymer, P.L. 2002. Canola: An emerging oilseed crop. p. 122–126. In: J. Janick and A. Whipkey (eds.), Trends in new crops and new uses. ASHS Press, Alexandria, VA. http://www.hort.purdue.edu/newcrop/ncnu02/v5-122.html
13. Perlack, Robert D., Lynn L. Wright, Anthony F. Turhollow, et al. U.S. Department of Energy and U.S. Department of Agriculture. Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply. April 2005. http://feedstockreview.ornl.gov/pdf/billion_ton_vision.pdf
14. Scurlock, Jonathan, ORNL. Bioenergy feedstock characteristics. http://bioenergy.ornl.gov/papers/misc/biochar_factsheet.html
15. NREL. Biomass Cofiring: A Renewable Alternative for Utilities. www.nrel.gov/docs/fy00osti/28009.pdf
16. U.S. Environmental Protection Agency. http://www.epa.gov/ttn/atw/boiler/boilerpg.html
17. De La Torre Ugarte, et al. Tennessee Agricultural Policy Analysis Center. The economic impacts of bioenergy crop production on U.S. agriculture. 2000. http://www.p2pays.org/ref/17/16277.pdf
18. EIA. Electric Power Monthly, May 2008. http://www.eia.doe.gov/cneaf/electricity/epm/epm.pdf

19. Indiana State Department of Agriculture. Fact Sheet: Biofuels plants in Indiana. http://www.in.gov/isda/biofuels/factsheet.pdf
20. Texas State Energy Conservation Office. 2010. http://www.seco.cpa.state.tx.us/re_ethanol_mtbe.htm
21. EPA.Renewable Fuel Standard. May 2010. http://www.epa.gov/otaq/fuels/renewablefuels/index.htm
22. RFA. VEETC. 2005. http://www.ethanolrfa.org/pages/federal-tax-incentives-veetc
23. Ethanol Producer Magazine. Ag leaders, RFA push for VEETC extension. May 26, 2010. http://www.ethanolproducer.com/article.jsp?article_id=6659
24. USDA Economic Research Service. ERS state fact sheet: United States. July 2010. http://www.ers.usda.gov/statefacts/us.htm
25. U.S. Department of Agriculture, Economic Research Service (ERS). Estimating U.S. Cropland Area. July 2006. http://www.ers.usda.gov/Amberwaves/July06SpecialIssue/Indicators/BehindData.htm
26. NREL. Biomass Maps, September 2005. http://www.nrel.gov/gis/biomass.html
27. Environmental Law & Policy Center. Repowering the Midwest: the clean energy development plan for the Midwest, 2001, http://www.repoweringthemidwest.org/reports/repowering-the-midwest
28. Walsh, Marie; Graham, Robin; Urgate, Daniel; Slinsky, Stephen; Ray, Daryll; and Shapouri, Hosein. Economic analysis of energy crop production in the U.S. location, quantities, price and impacts on traditional agricultural crops, 1998.
29. Oak Ridge National Laboratory, Indiana's counties energy crops estimates. Data provided by Dr. Wallace Tyner, 2006.
30. Brechbill, Sarah and Tyner, Wallace. Department of Agricultural Economics, Purdue University. The economics of biomass collection, transportation, and supply to Indiana cellulosic and electric utility facilities. working paper #08-03, April 2008.
31. Database of State Incentives for Renewables & Efficiency (DSIRE). Federal Incentives for Renewable Energy. http://www.dsireusa.org/
32. U.S. Department of Agriculture. Value-added producer grants, 2008. http://www.rurdev.usda.gov/rbs/coops/vadg.htm
33. U.S. Department of Agriculture, Rural Development, Electric Programs. http://www.usda.gov/rus/electric/hecgp/overview.htm
34. Indiana Department of Environmental Management. Indiana Clean Energy Credit Program. http://www.in.gov/idem/4134.htm
35. Indianapolis Power and Light Company. Renewable Energy Production. http://www.iplpower.com/ipl/index?page=IPLGeneral&Menu=01000000&DocID=020391af33d6012801538fc10057cb
36. Clemmer, Steve. Harnessing the Upper Midwest's bioenergy potential. Upper Midwest renewable energy and agriculture summit, February 2002. http://www.ef.org/documents/Bioenergy.pdf

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 energy for their own processes.
- 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: Processing of biomass yields byproducts and waste streams that 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 2009 renewable energy constituted 8.1 percent of the total energy consumed in the U.S. [1]. Of that, 50 percent was from biomass, making biomass the single largest source of renewable energy (Figure 4-1). More than 70 percent of biomass in 2007 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 54 percent of biomass electricity generation in the U.S. in 2007. During 2009, biomass accounted for approximately 10 percent of renewably generated electricity, 99 percent of industrial renewable energy use, 76 percent of residential renewable energy use, and 86 percent of commercial renewable energy use [1].

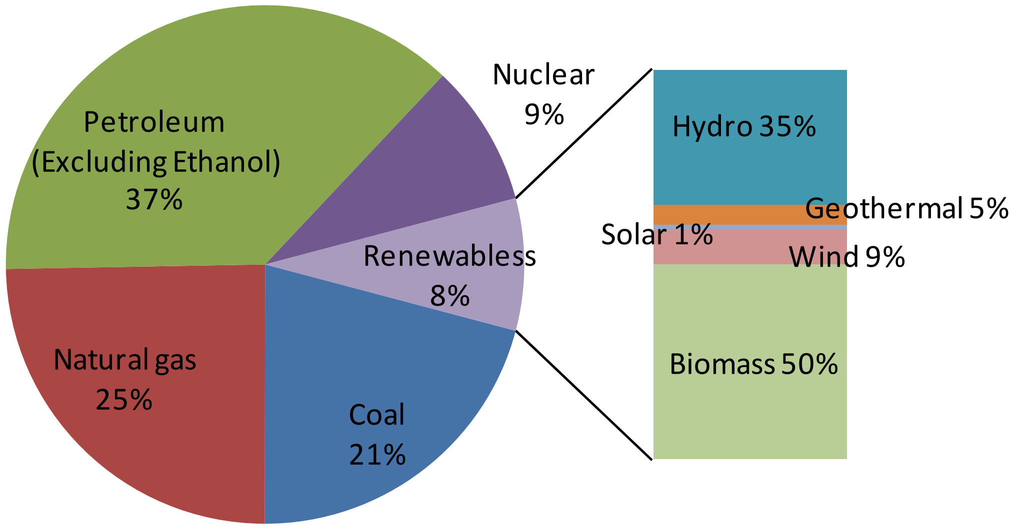


Figure 4-1: Summary of U.S. energy consumption in 2009 (Data source: EIA [1])

Figure 4-2 shows the projected growth in non-hydro renewable electricity generation in the 2010 EIA *Annual Energy Outlook* reference case [3]. Biomass and wind are forecast to remain the main suppliers of non-hydro renewable electricity with biomass growing from its current 1.4 percent share to 5.5 percent in 2035 and wind growing from its current 1.9 percent to 4.1 percent in 2035.

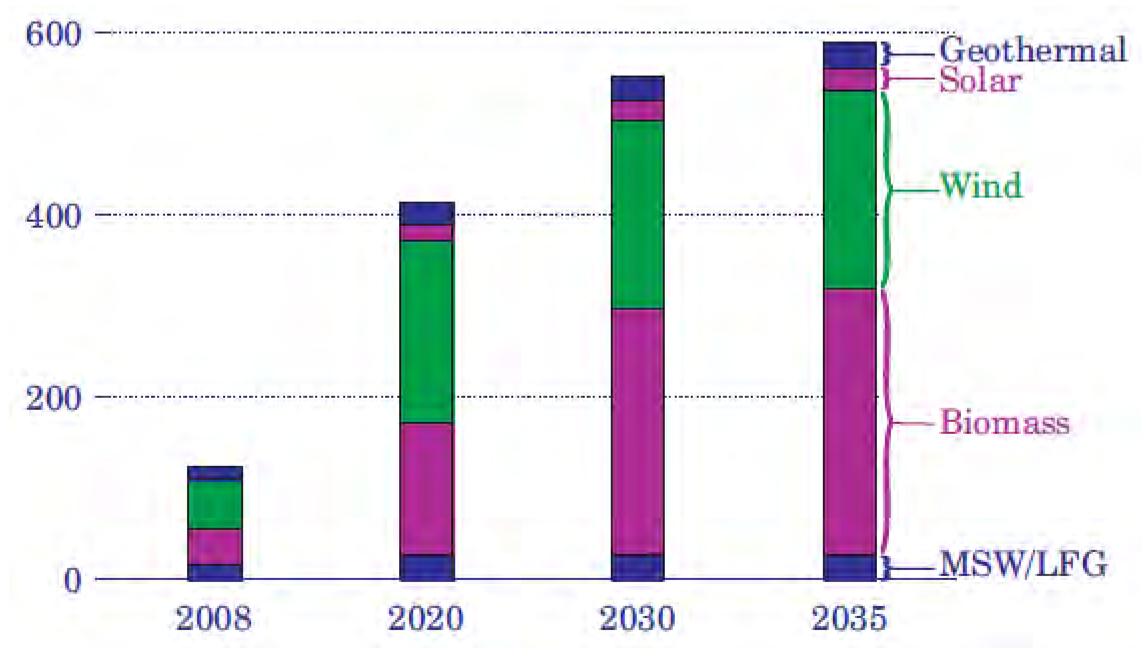


Figure 4-2: Non-hydroelectric renewable electricity generation by energy source 2008-2035 (billion kWh) (Source: EIA [3])

Biomass can be converted into energy in one of the following ways[4]: direct combustion, co-firing in conventional coal power plants, chemical conversion, and gasification. Direct combustion and co-firing are the two most common methods used in converting biomass into energy. In direct combustion the biomass material is burned to produce heat. This heat can either be used directly or can be used to produce steam which is then passed through a turbine to produce electrical energy. According to the March 2003 report by NREL, *Biopower Technical Assessment: State of the Industry and Technology*, direct combustion to 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. Combustion efficiencies range from 17-25 percent. However with cogeneration, where both steam and heat are utilized, much greater efficiencies are obtained at around 85 percent. Producer gas from gasification contains up to 70-80 percent of the original energy contained in the feedstock [5]. Although gasification technologies have been

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

successfully tested in demonstration projects, they still have some technical barriers before they can be widely deployed at a commercial scale [6].

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

Fuel Type	***Heat Content***	
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 Liquor	12.720	Million Btu/Short Ton
Utility Poles	12.500	Million Btu/Short Ton
Waste Alcohol	3.800	Million Btu/Barrel

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

4.2 Economics of organic waste biomass

Co-firing with biomass fuels utilizes existing power plant infrastructure to minimize costs while maximizing environmental and economic benefits [7]. Up to 20 percent of the input fuel mix can be biomass in typical co-firing applications. 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 is between one and eight years [8].

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 [9]. The economic viability of burning biomass for energy will likely be negatively impacted by the proposed revision of the *Clean Air Interstate Rule* (CAIR) that has been proposed by the Environmental Protection Agency (EPA). The proposed rule would reclassify biomass fired boilers in such a manner that they would now be subject to the *Maximum Achievable Control Technology* (MACT) to restrict the emission of mercury, carbon monoxide and other non-mercury metals. The MACT proposal was published in April 2010 with a public comment period that ended in August [10].

Biomass gasification is a technology that is still under development and has not been fully 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 [6]:

- 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.
- Available gas cleanup and conditioning systems 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.
- 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 2008, the total biomass-based electricity generation capacity in the U.S. was 11,050 MW [11]. Of this installed capacity, 6,864 MW was dedicated to generation from wood and wood derived fuels, 4,186 MW was attributed to generation capacity from all other biomass including municipal solid waste (MSW) and landfill gas supplies.

The United States has a tremendous capacity for biomass. 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 (10^{15} Btus) of energy [12]. About 7.2 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 [13], 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.

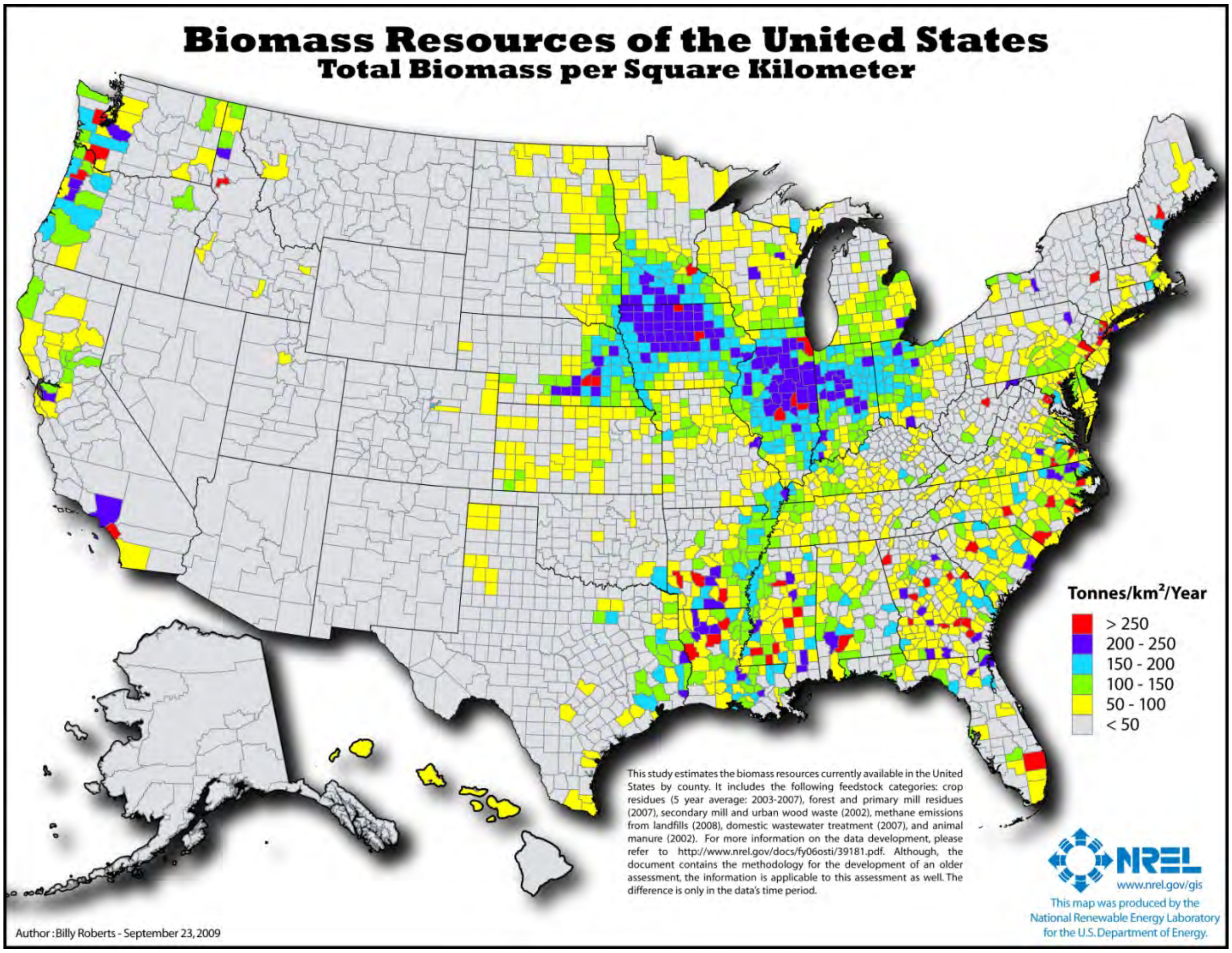


Figure 4-3: <u>Biomass resources available in the U.S.</u> (Source: NREL [14])

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 [15].

Research into thermochemical conversion technologies focuses on biomass gasification and the subsequent production of syngas which is a mixture of carbon monoxide and hydrogen [16]. 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 are being researched by the Carbona Corp. and the Community Power Corp. in association with NREL. This technology is especially appropriate for remote communities that do not have access to electricity, but have supplies of biomass available. Electricity for these areas can be produced using small modular gasifiers [9].

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 40 co-firing stations in the U.S. [17]. 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 [18]. 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 [18].

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 may become more competitive economically as technology improvements cause costs to drop [19].

4.4 Organic waste biomass in Indiana

In 2008 biomass contributed 0.2 percent of the 129,510 GWh of total electrical energy generated in Indiana while all renewable resources combined contributed a total of 0.7 percent [20]. 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 [21].

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 [21, 22].

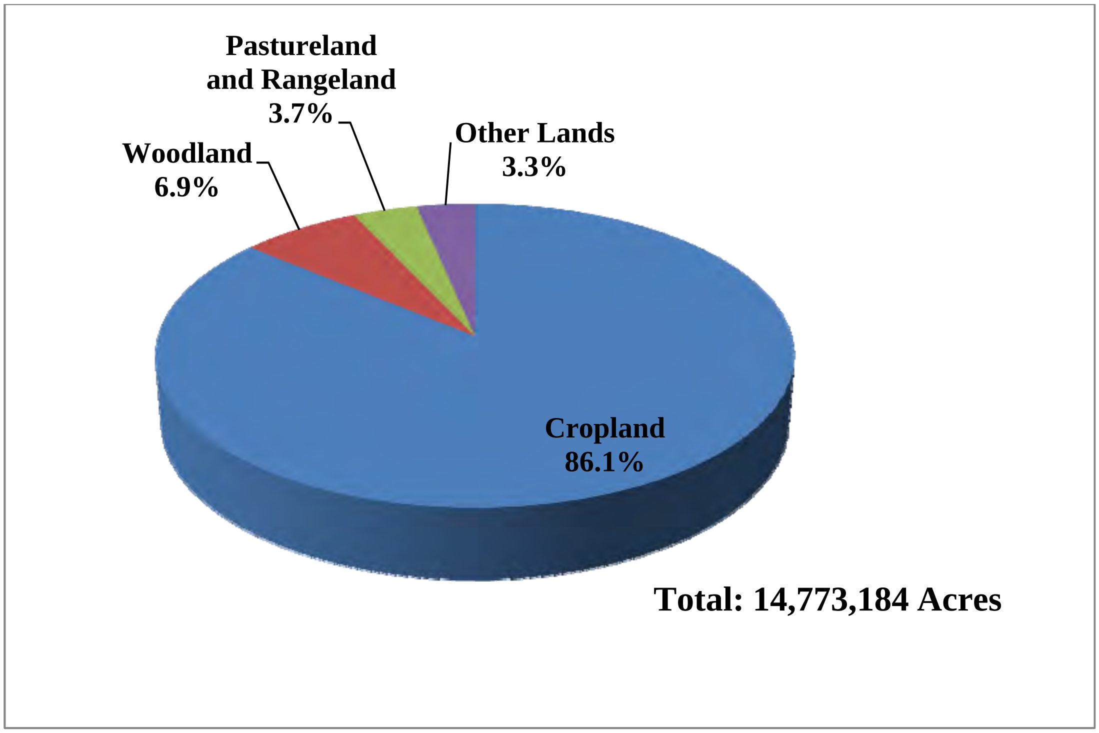


Figure 4-4: Indiana land use in 2007 (Data source: USDA [22])

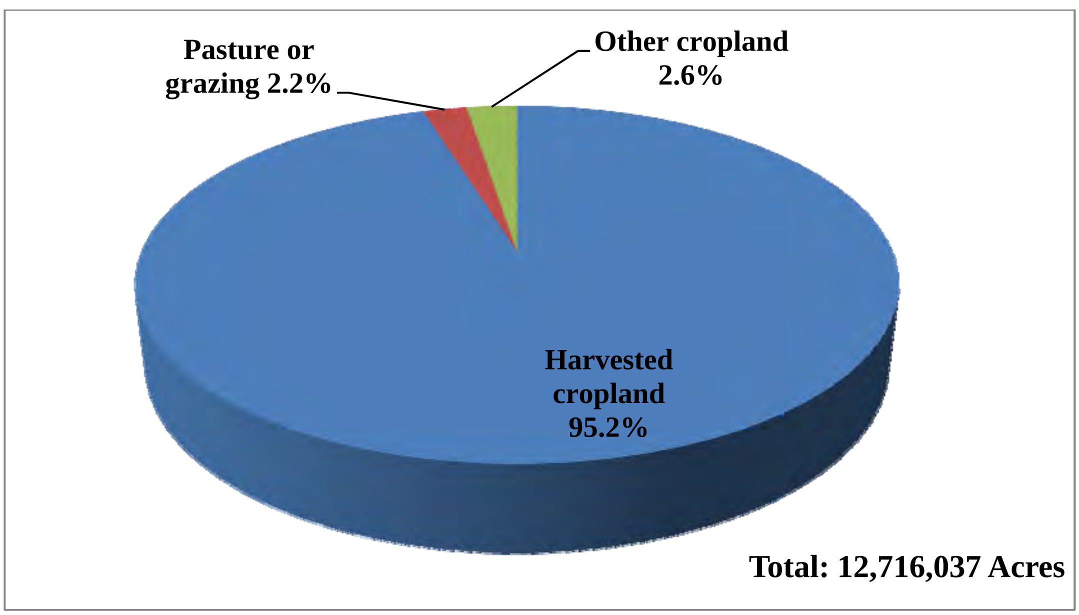


Figure 4-5: Indiana cropland use in 2007 (Data source: USDA [22])

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 biomass within the state. The northwest, north central and northeast regions also produce significant amounts of crop residues accounting for 18 percent, 14 percent and 13 percent, respectively [21].

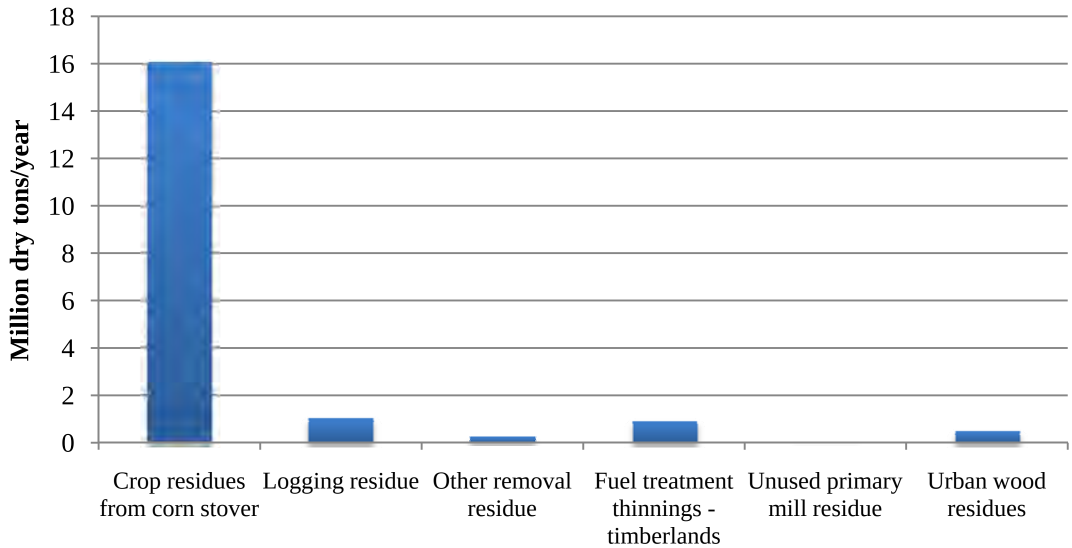


Figure 4-6: Estimated biomass production potential in Indiana (Source: ORNL [21])

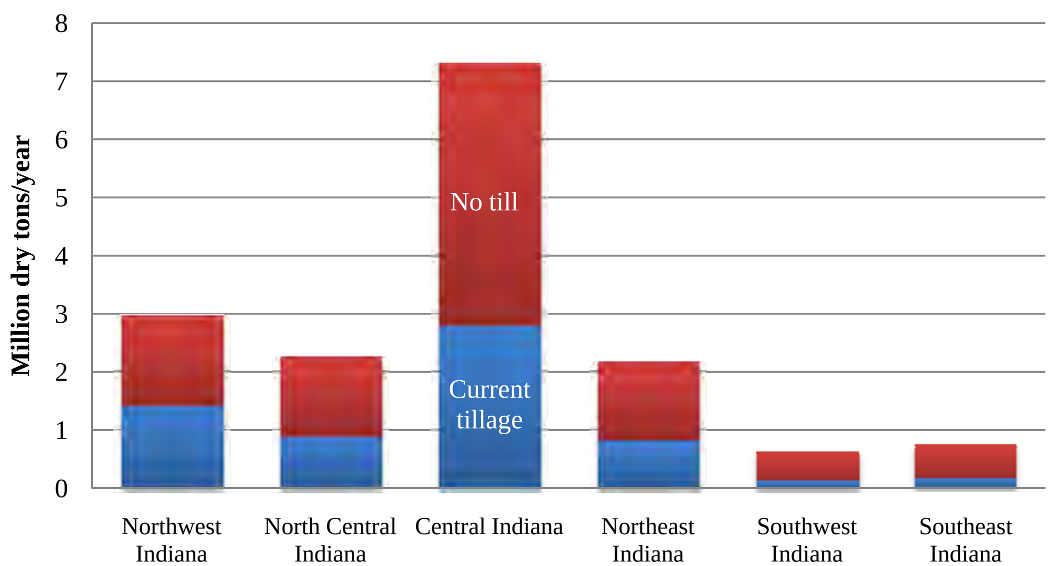


Figure 4-7: Estimated production potential of crop residues from corn stover in Indiana (Source: ORNL [21])

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 [23].

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.

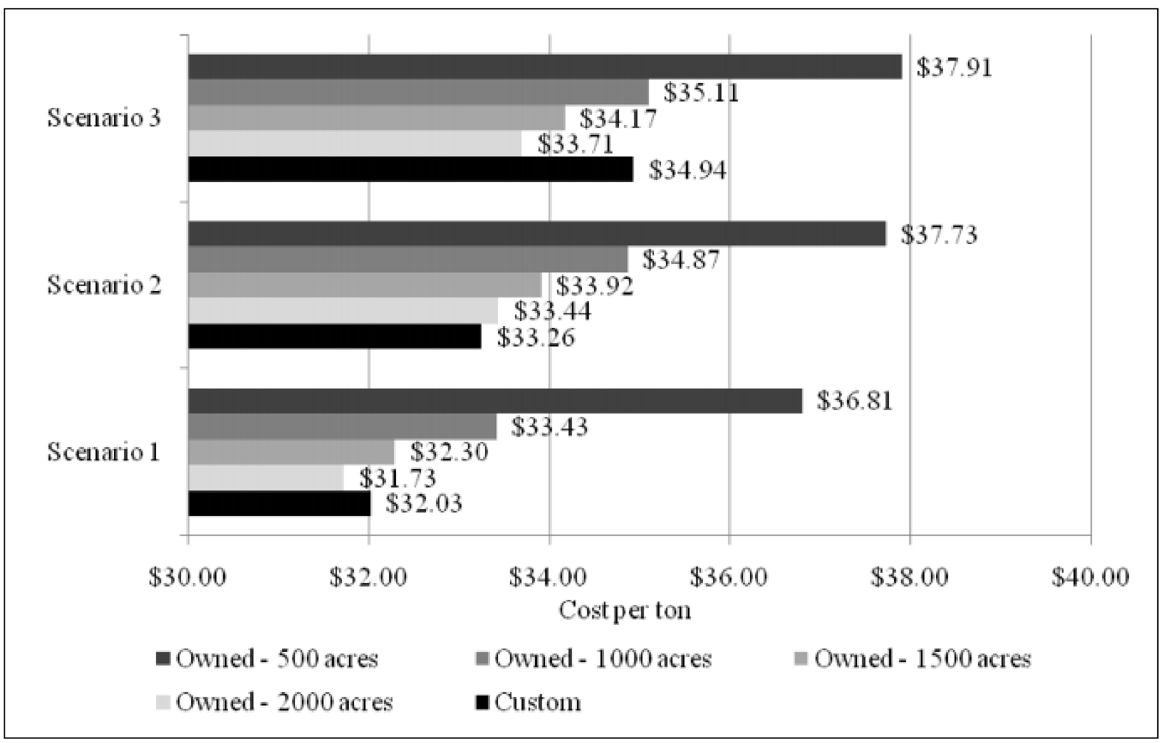


Figure 4-8: <u>Corn stover product only costs</u> (Source: Brechbill and Tyner [21])

According to the Electric Power Research Institute *Biomass Interest Group Technical Report for 2002* [24] Northern Indiana Public Service Company (NIPSCO) conducted biomass co-firing tests at two of its coal-fired power plants at its Michigan City Station (425 MW) in Michigan City and Bailly Station (480 MW) in Chesterton under a DOE Biomass Program. The tests were conducted with a biomass input fuel mix at 5 percent. At both plants, the 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 25.6 MW of landfill gas generation capacity [25]. The total generating capacity from Indiana's landfills is 45.9 MW [26].

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 600 kW of generating capacity [27].

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 [28].

4.5 Incentives for organic waste biomass

Federal Incentives

- Renewable Electricity Production Tax Credit (PTC) provides a 2.2 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 [29].
- Business Energy Investment Tax Credit (ITC) credits up to 30 percent of expenditures on 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 (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 [29].
- Qualified Energy Conservation Bonds (QECBs) are qualified tax credit bonds and 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". In February 2009, these funds were expanded to $3.2 billion [29].
- High Energy Cost Grant Program administered by the U.S. Department of Agriculture (USDA) is aimed at improving the electricity supply infrastructure in rural areas having home energy costs exceeding 275 percent of the national average. Eligible infrastructure includes renewable resources generation. The USDA has allocated a total of $15.5 million for the 2010 funding cycle. The individual grants range from $75,000 to $5 million [30]

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 [31]. These credits can be sold on the national market.

4.6 References

1. Energy Information Administration (EIA). Monthly Energy Review, May 2010. http://www.eia.doe.gov/mer/
2. EIA. Renewable energy annual 2007. April 2009. http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/rea_sum.html
3. EIA. Annual energy outlook 2010 with projections to 2035. http://www.eia.doe.gov/oiaf/aeo/
4. National Renewable Energy Laboratory (NREL). Biopower technical assessment: State of the industry and technology, March 2003. *www.chemicalvision2020.org/pdfs/*biopower_*tech*assessment_*entire_rpt.pdf*
5. Oregon State Website. Biomass Energy Technology. April 2010. http://www.oregon.gov/ENERGY/RENEW/Biomass/bioenergy.shtml
6. EERE. Large scale gasification. October 2005. http://www1.eere.energy.gov/biomass/printable_versions/large_scale_gasification.html

7. NREL. Biomass cofiring: a renewable alternative for utilities. June 2000. http://www.nrel.gov/docs/fy00osti/28009.pdf
8. Federal Energy Management Program. EERE. Biomass cofiring in coal-fired boilers. May 2004. *www1.eere.energy.gov/femp/pdfs/fta_biomass_cofiring.pdf*
9. NREL. Small modular biomass systems. December 2002. http://www.nrel.gov/docs/fy03osti/33257.pdf
10. U.S. Environmental Protection Agency. http://www.epa.gov/ttn/atw/boiler/boilerpg.html
11. EIA. Existing Net Summer Capacity of Other Renewables by Producer Type, Electric Power Industry 2008: Year in Review. January 21, 2010. http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html
12. Walsh, Marie, Oak Ridge National Laboratory (ORNL). Biomass resource estimates, 2000. http://bioenergy.ornl.gov/papers/misc/resource_estimates.html
13. U.S. Department of Energy and U.S. Department of Agriculture. Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply. April 2005. http://feedstockreview.ornl.gov/pdf/billion_ton_vision.pdf
14. NREL. Biomass maps. September 2009. http://www.nrel.gov/gis/biomass.html
15. NREL. Biochemical conversion technologies – projects. November 2007. http://www.nrel.gov/biomass/proj_biochemical_conversion.html
16. NREL. Thermochemical conversion technologies – projects. November 2009. http://www.nrel.gov/biomass/proj_thermochemical_conversion.html.

17. International Energy Agency (IEA). Cofiring database. http://www.ieabcc.nl/database/cofiring.php
18. Haq, Zia. EIA. Biomass for electricity generation. July 2002. http://www.eia.doe.gov/oiaf/analysispaper/biomass/pdf/biomass.pdf
19. Babu, Suresh P. IEA. Biomass gasification for hydrogen production - process description and research needs. 2002. http://www.ieahia.org/pdfs/Tech%20Report,%20Babu,%20IEA%20Bioenergy%20Thermal%20Gas%20Task.pdf
20. EIA. Renewable energy annual 2007. April 2009. http://www.eia.doe.gov/cneaf/solar.renewables/page/state_profiles/indiana.html
21. ORNL. Indiana’s counties energy crops estimates. Data provided by Dr. Wallace Tyner, 2006.
22. U.S. Department of Agriculture, National Agricultural Statistics Service. 2007 census of agriculture: Indiana state and county data. http://www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_1_State_Level/Indiana/index.asp
23. Brechbill, Sarah, and Tyner, Wallace. Department of Agricultural Economics, Purdue University. The economics of biomass collection, transportation, and supply to Indiana cellulosic and electric utility facilities. Working paper #08-03, April 2008

24. Electric Power Research Institute (EPRI), Biomass Interest Group: Technical Report for 2002.
25. Wabash Valley Power Association. http://www.wvpa.com
26. U.S. Environmental Protection Agency, Landfill Methane Outreach Program (LMOP). http://www.epa.gov/landfill/proj/index.htm
27. Kramer, Joseph M. Agricultural Biogas Casebook - 2004 update. http://www.rs-inc.com/downloads/Experiences_with_Agricultural_Biogas_Systems-2004_Update.pdf
28. Covanta Energy Corporation. http://www.covantaholding.com/site/locations/covanta-indianapolis.html
29. Database of State Incentives for Renewables and Efficiency (DSIRE). http://www.dsireusa.org/
30. U.S. Department of Agriculture, Rural Development, Electric Programs. http://www.usda.gov/rus/electric/hecgp/overview.htm
31. Indiana Department of Environmental Management. Indiana clean energy credit program. http://www.in.gov/idem/4134.htm

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 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 [3].

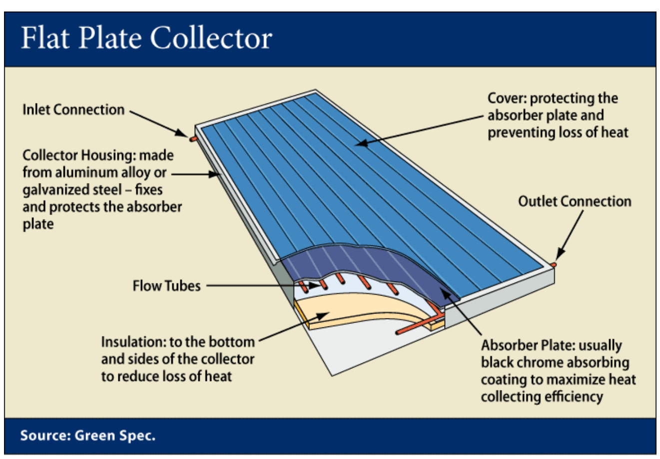


Figure 5-1: General layout of a flat-plate collector (Source: Texas Energy Report [2])

There are three main types of thermal concentrating solar power (CSP) systems in use or under development. These are the parabolic trough, solar power tower, and solar dish [4], and are illustrated in Figure 5-2.

- The trough system has trough shaped collectors with a parabolic cross section and 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 to a large-scale 354 MW system in California [5]. 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 where the solar resource is especially good [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 3-25 kW [6]. Many of these dish systems would have to 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].

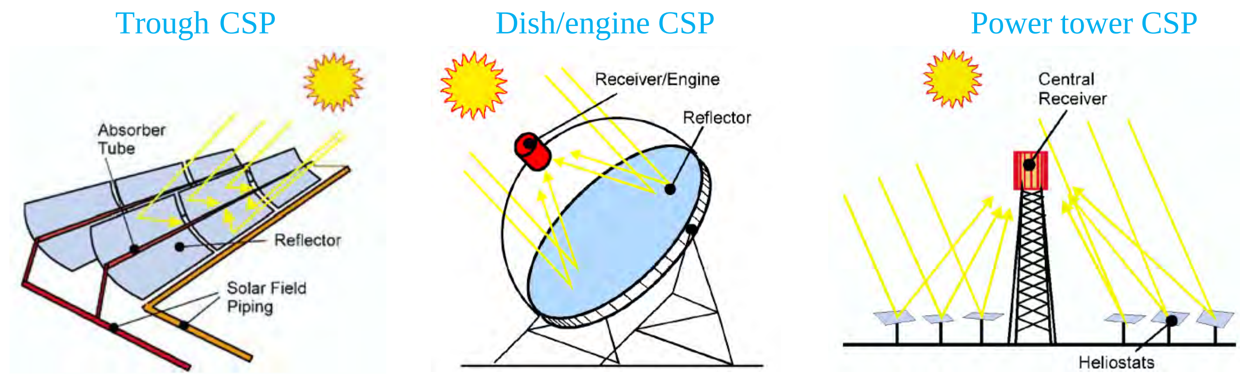


Figure 5-2: Types of concentrating solar power (CSP) collectors (Source: NREL [4])

Table 5-1 illustrates further differences between the three types of solar thermal technologies [7].

		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: EERE [7])

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,
- It has high equipment costs when compared to traditional technologies, and
- The collectors occupy a substantial amount of land area

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 [8]. Table 5-2 shows the forecast costs of energy from the solar thermal technologies in areas with high solar resources [9].

		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 [8])

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 2007, and 0.08 percent of all energy produced in the country [10]. 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 17.0 million square feet in 2008 [11]. This represents an increase from 15.1 million square feet in the previous year. The majority of shipments were low-temperature type collectors (83 percent) while medium and high-temperature collectors represented 17 percent of total shipments [12]. 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 [13]. Florida and California were the top destinations of solar thermal collectors, accounting for more than half of all domestic shipments [14]. Figure 5-4 illustrates the top states for domestic shipments of solar thermal collectors in 2007.

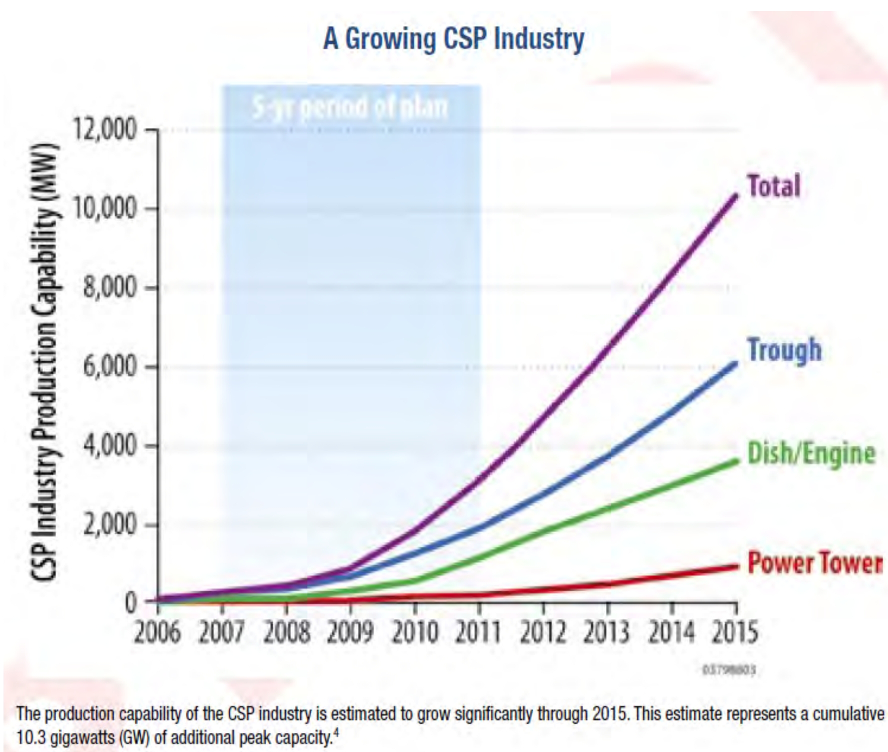


Figure 5-3: Expected growth in electricity generation capacity by concentrating solar power (Source: EERE [5])

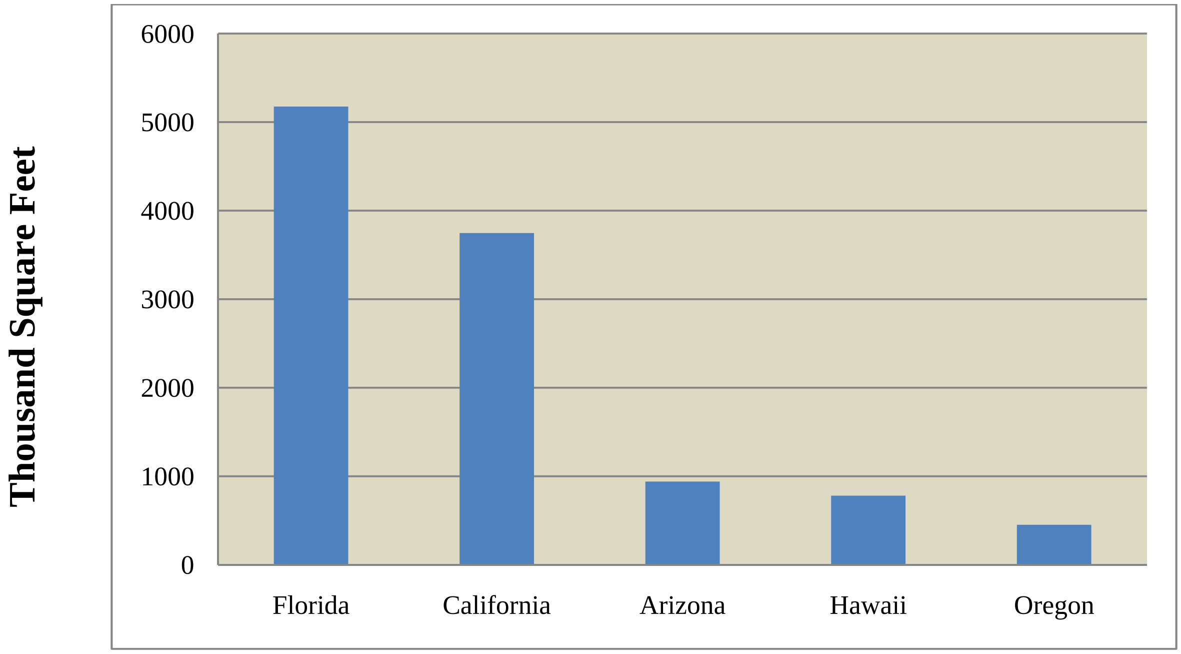


Figure 5-4: Top domestic destinations for solar thermal collectors in 2007 (Source: EIA [14])

Figure 5-5 shows annual average solar radiation with a fixed, flat-plate, collector orientation fixed at its latitude [15]. 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 [15].

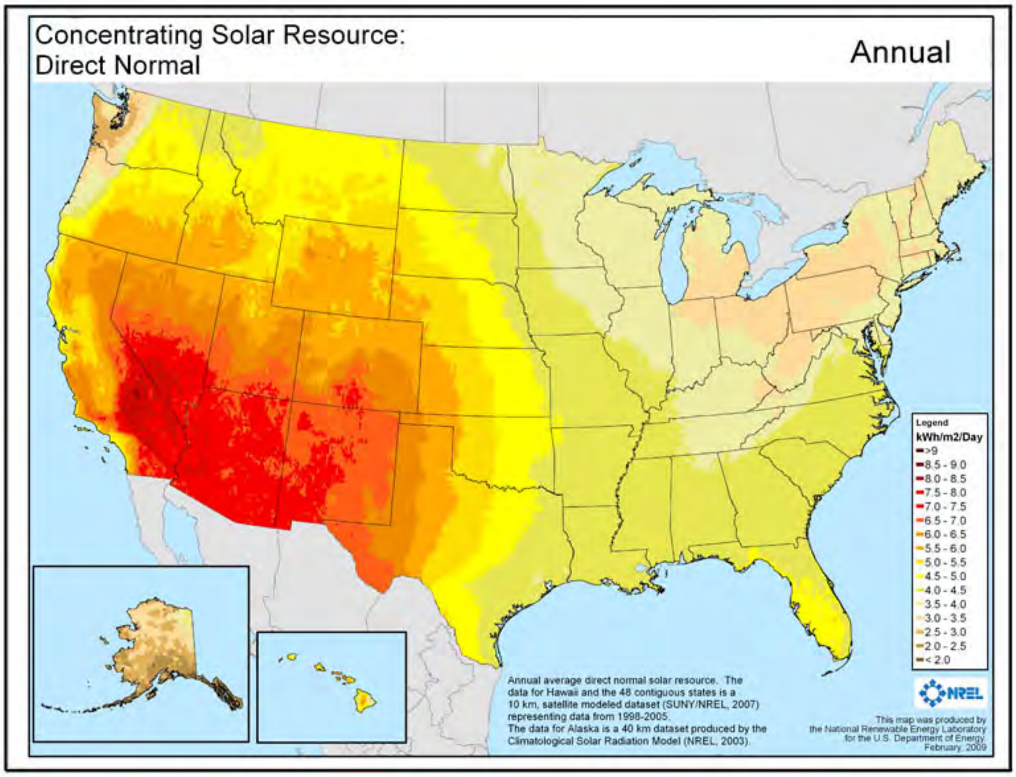


Figure 5-5: Annual average solar radiation for a flat-plate collector (Source: NREL [15])

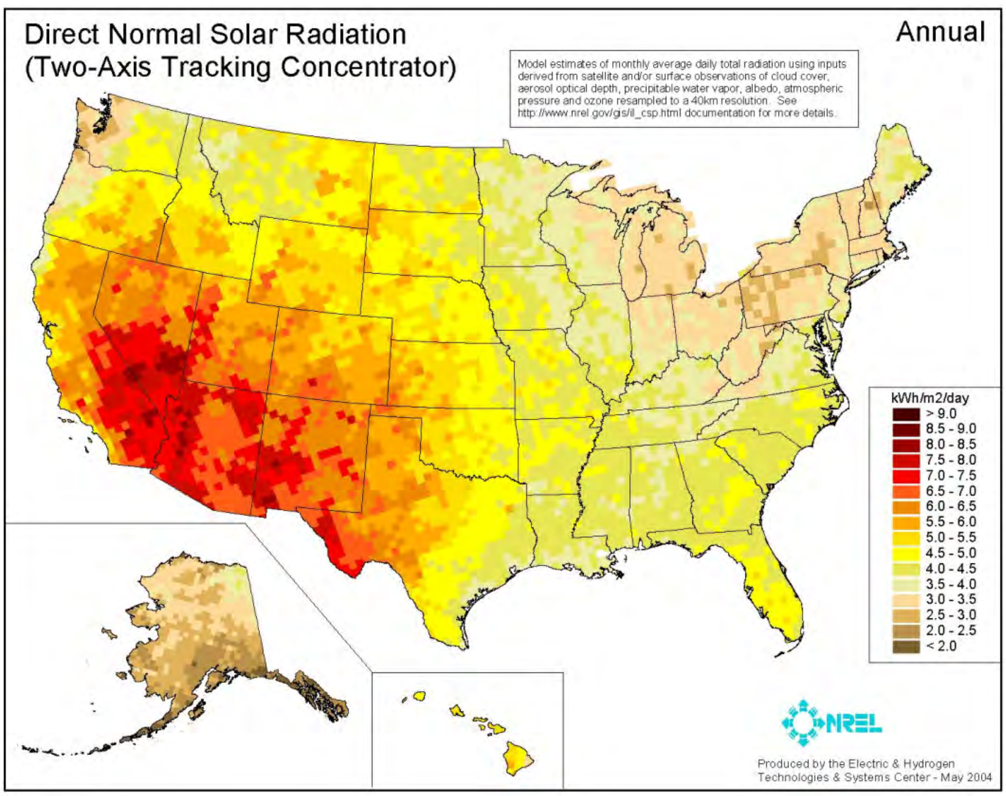


Figure 5-6: Direct normal solar radiation (two-axis solar concentrator) (Source: NREL [15])

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 [19].

Two power tower facilities, Solar One and Solar Two, were built in Barstow, California, in the 1980s and 1990s as demonstrations for the feasibility of the 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 [16]. The Solar Two project was discontinued in 1999. In 2009, Sierra SunTower was built in Lancaster, California. This is the only power tower plant in the United States. It has a capacity of 5 MW and can power 4,000 homes [17].

There are currently many projects in the Southwest investigating the long term use of dish/engine systems for power production [18]. 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 [19].

Current government initiatives in the solar industry include [20]:

- 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. 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 [21].

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 [22].

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 [23].

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 [15]. 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 [24].

5.5 Incentives for solar energy

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

Federal Incentives

- Business Energy Investment Tax Credit (ITC) credits up to 30 percent of expenditures on solar systems [25].
- 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 who would usually denied [25].

- 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 [25].
- Qualified Energy Conservation Bonds (QECBs) are qualified tax credit bonds and 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". In February 2009, these funds were expanded to $3.2 billion [25].
- 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 [25].
- 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" [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). 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 [25].
- 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 [26].
- High Energy Cost Grant Program administered by the U.S. Department of Agriculture (USDA) is aimed at improving the electricity supply infrastructure in rural areas having home energy costs exceeding 275 percent of the national average. Eligible infrastructure includes renewable resources generation. The USDA has allocated a total of $15.5 million for the 2010 funding cycle. The individual grants range from $75,000 to $5 million [27]

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 [28].
- 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 [29].
- 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 [29].
- 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 [29].
- Indiana Solar Thermal Grant Program: provides up to $150,000 for entities in Indiana's public, non-profit, and business sectors to offset the cost of purchasing solar water heating systems. Applicants must use more than 100,000 gallons of hot water annually and can receive up to $25,000. The deadline for the applications was September 1, 2010 [30, 31].

5.6 References

1. U.S. Department of Energy, Office of Science. Basic Research Needs for Solar Energy Utilization. Basic energy sciences workshop on solar energy utilization. April 2005. Updated September 2005. http://www.sc.doe.gov/bes/reports/files/SEU_rpt.pdf
2. Window on State Government. Solar Energy. http://www.window.state.tx.us/specialrpt/energy/renewable/solar.php
3. U.S. Department of Energy, Energy Efficiency and Renewable Energy (EERE). Solar collectors. August 2006. http://www1.eere.energy.gov/solar/sh_basics_collectors.html
4. Leitner, A. National Renewable Energy Laboratory. Fuel from the sky: solar energy's potential for Western energy supply. July 2002. www.nrel.gov/docs/fy02osti/32160.pdf
5. EERE. Solar Energy technologies program: Multi-year program plan 2007 – 2011. January 2006. http://www1.eere.energy.gov/solar/pdfs/set_myp_2007-2011_proof_1.pdf
6. Sandia National Laboratory, Concentrating Solar Power. http://www.sandia.gov/csp/cspoverview.html
7. EERE. Renewable Energy Technology Characterizations. December 1997. www.nrel.gov/docs/gen/fy98/24496.pdf

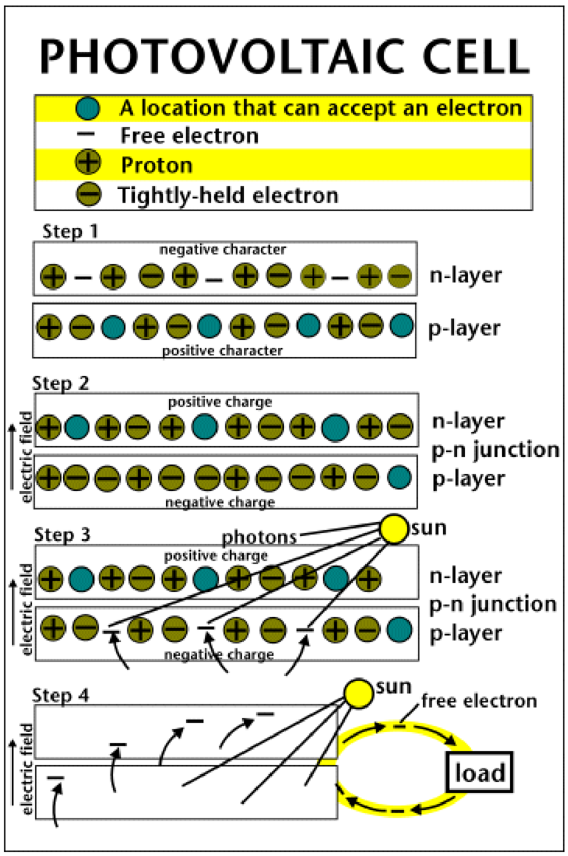
8. Sandia National Laboratory. CSP technologies overview. http://www.energylan.sandia.gov/sunlab/overview.htm
9. Sandia National Laboratory. Project financial evaluation. http://www.energylan.sandia.gov/sunlab/PDFs/financials.pdf
10. U.S. Department of Energy, Energy Information Administration (EIA). U.S. Energy Consumption by Energy Source. December 2008. http://www.eia.doe.gov/cneaf/solar.renewables/page/trends/table1.html
11. EIA. Annual shipment of solar thermal collectors. January 2010. http://www.eia.doe.gov/cneaf/solar.renewables/page/solarthermal/solarthermal.html
12. EIA. Anuual shipments of solar thermal collectors by type. January 2010. http://www.eia.doe.gov/cneaf/solar.renewables/page/solarreport/table2_3.html
13. EIA. Shipments of Solar thermal collectors by market sector, end use, and type, January 2010. http://www.eia.doe.gov/cneaf/solar.renewables/page/solarreport/table2_13.html
14. EIA, Shipments of solar thermal collectors ranked by origin and destination. January 2010. http://www.eia.doe.gov/cneaf/solar.renewables/page/solarreport/table2_4.html
15. National Renewable Energy Laboratory (NREL). Solar maps, May 2008. http://www.nrel.gov/gis/solar.html
16. Sandia National Laboratory. Solar two demonstrates clean power for the future. March 2000. http://www.energylan.sandia.gov/sunlab/files/stfuture.pdf
17. eSolar. Sierra SunTower fact sheet. 2009. http://esolar.com/sierra_fact_sheet.pdf
18. Sandia National Laboratory, Major CSP projects. http://www.energylan.sandia.gov/sunlab/projects.htm
19. SPG Media. Solar one concentrated solar power plant Nevada. 2008. http://www.power-technology.com/projects/solaronesolar/
20. NREL. Concentrating solar power research: Projects, April 2007. http://www.nrel.gov/csp/projects.html
21. EERE. Solar energy technologies program: deployment. October 2006. http://www1.eere.energy.gov/solar/deployment.html
22. EG2. EERE. Solar Energy Technologies Programs. Solar America Cities. http://www1.eere.energy.gov/solar/solar_america_cities.html
23. DOE. Press Releases April-June. President Obama Announces Over $467 Million in Recovery Act Funding for Geothermal and Solar Energy Projects. http://www.energy.gov/news2009/7427.htm
24. EERE. A consumer’s guide: heat your water with the sun. December 2003. http://www.nrel.gov/docs/fy04osti/34279.pdf
25. Database of State Incentives for Renewables and Efficiency (DSIRE). Federal Incentives. June 2008. http://www.dsireusa.org/
26. Center for Rural Affairs. Value added producer grants program fact sheet, 2007. http://www.cfra.org/resources/vapg/fact_sheet
27. U.S. Department of Agriculture, Rural Development, Electric Programs. http://www.usda.gov/rus/electric/hecgp/overview.htm

28. Indiana Department of Environmental Management. Indiana clean energy credit program. http://www.in.gov/idem/4134.htm
29. DSIRE. Indiana incentives. http://www.dsireusa.org/
30. Indiana Office of Energy and Defense Development. Current Programs. http://www.in.gov/oed/2588.htm
31. JCOnline. Ind. Offers grants for solar water heating systems. July 2010. http://www.jconline.com/article/20100713/NEWS09/100713001/Ind-offers-grants-for-solar-water-heating-systems

6. Photovoltaic Cells

6.1 Introduction

Unlike solar thermal systems, photovoltaic (PV) cells allow for the direct conversion of sunlight into electricity. The photovoltaic cell is a non-mechanical device constructed from semiconductor materials (see Figure 6-1). When the photons in sunlight strike the surface of a photovoltaic cell, some of them are absorbed. The absorbed photons cause free electrons to migrate in the cell, thus causing "holes." The resulting imbalance of charge between the cell's front and back surfaces creates a voltage potential like the negative and positive terminals of a battery. When these two surfaces are connected through an external load, electricity flows [1].



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

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

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].

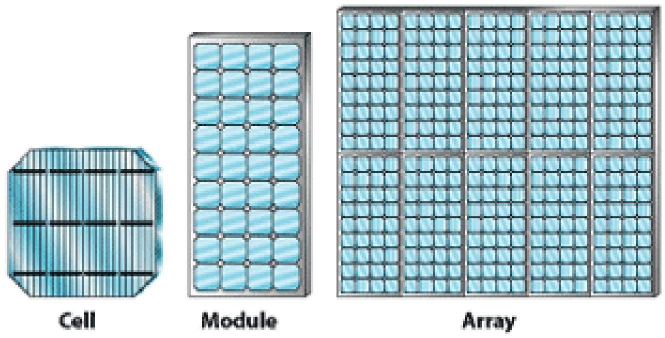


Figure 6-2: Illustration of a cell, module and array of a PV system (Source: EERE [3])

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 2009. As shown in the graph, experimental multi-junction concentrator-based PV cells reported the highest efficiency levels, approximately 40 percent [7].

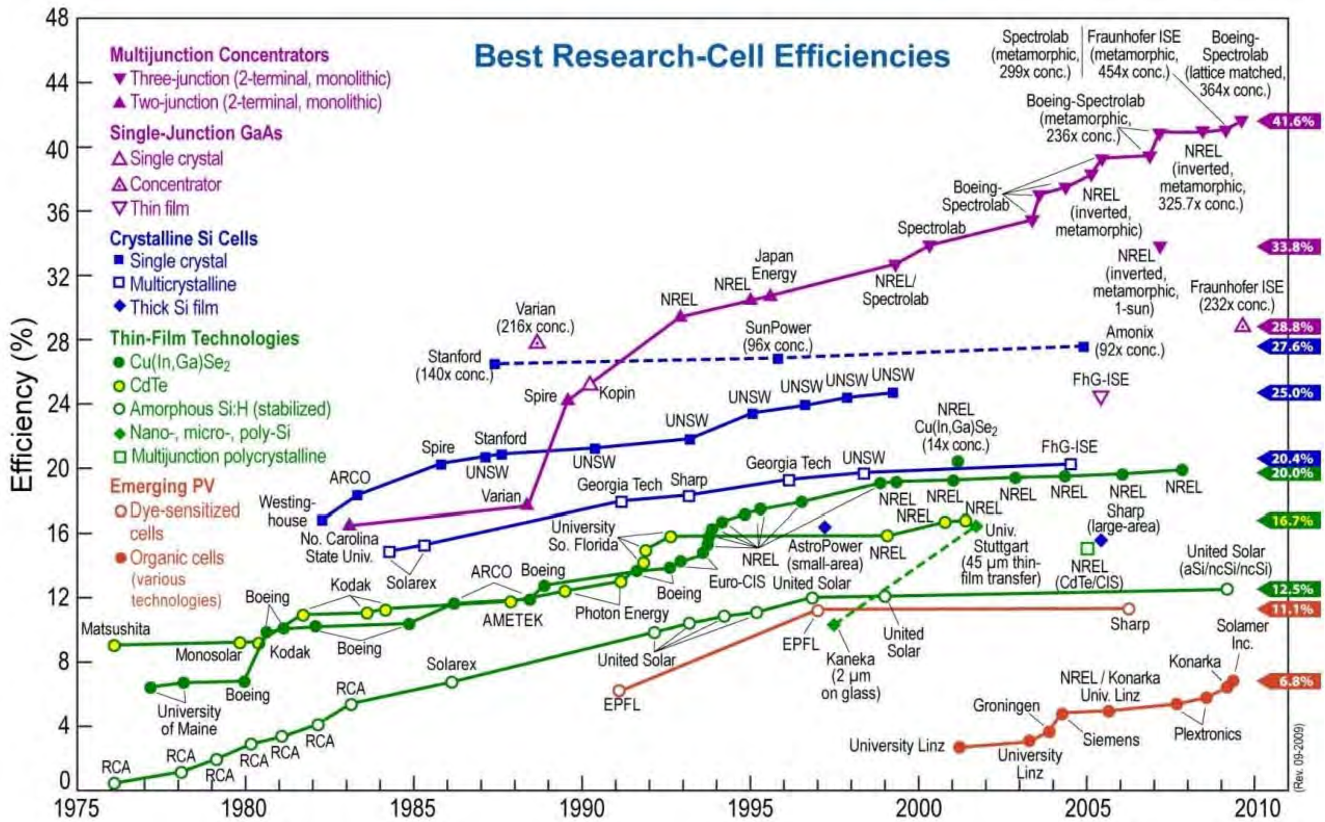


Figure 6-3: Improvements in solar cell efficiency, by system, from 1976 to 2009 (Source: NREL [8])

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 [9]:

- 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, 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), and water pumping power for irrigation systems. 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 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;
- A diversified power supply from thousands of solar units can increase the reliability of the grid and reduce the need for larger transmission capacity [10];
- The lack of moving parts[5] results in lower maintenance costs; and
- The modular nature of PV systems (PV arrays) allow for variable output power configurations.

The main disadvantages to using PV systems are:

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

- 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 [10].

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 [11]. 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, 11].

The recent trend in PV module prices is shown in Figure 6-4 [12]. Overall photovoltaic prices have declined on average 4 percent per year over the past 15 years [13].

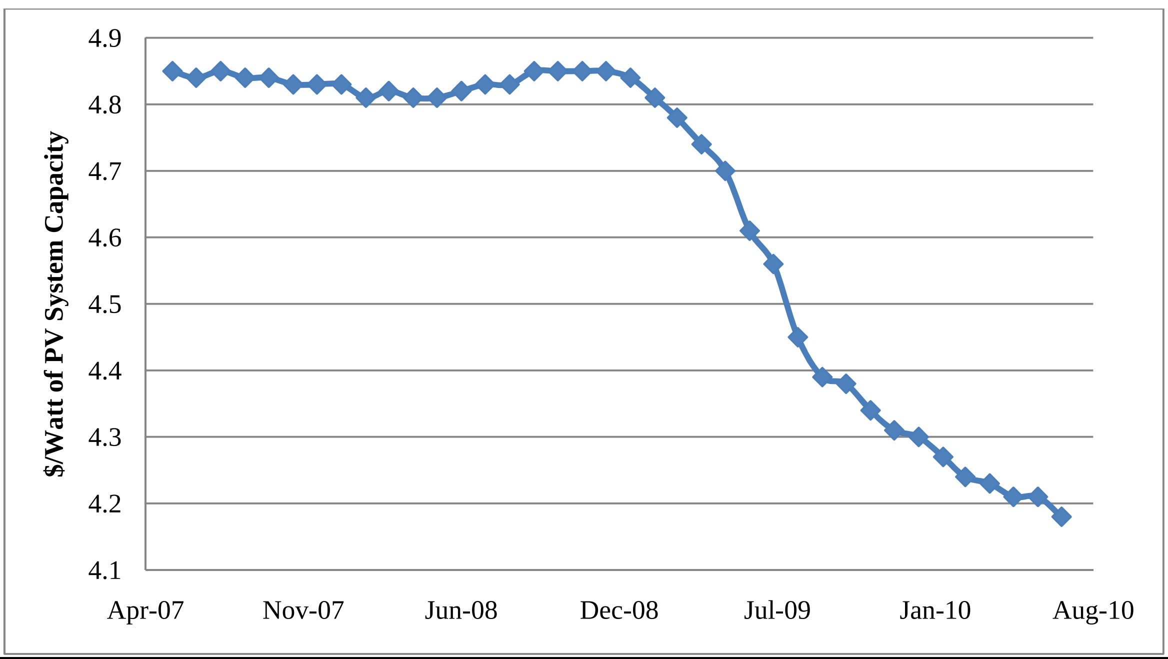


Figure 6-4: Historical PV module prices (Source: Solarbuzz [12])

Levelized PV energy costs of around 30 cents/kWh [11] are common, assuming a 25-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 [11].

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 currently without subsidies. 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 [14].

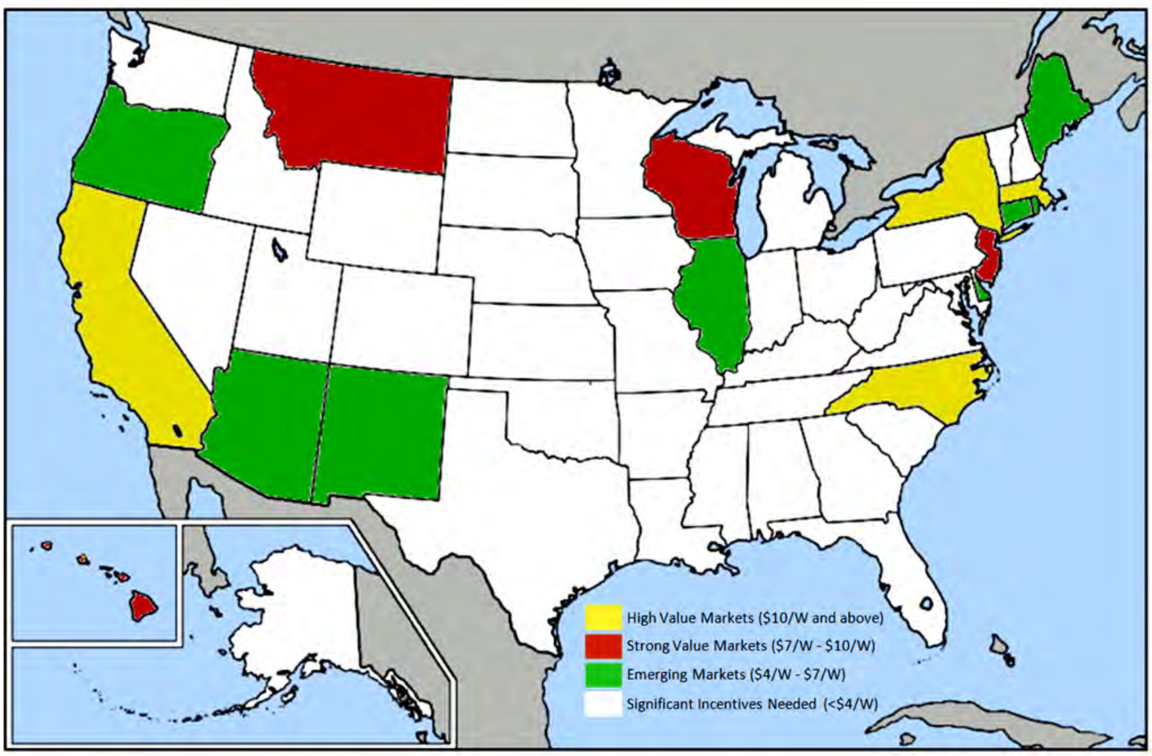


Figure 6-5: Breakeven turnkey costs by state (Source: DSIRE [14])

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.

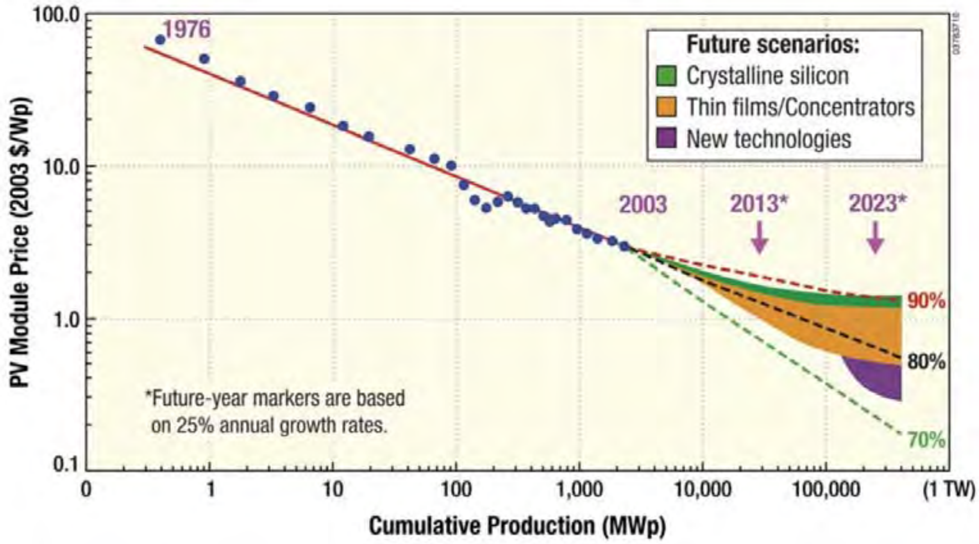


Figure 6-6: Learning curve for PV production (Source: DOE [7])

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].

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 2009, there were 90,000 solar electric systems installed in the United States [15].

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 [16]. 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.

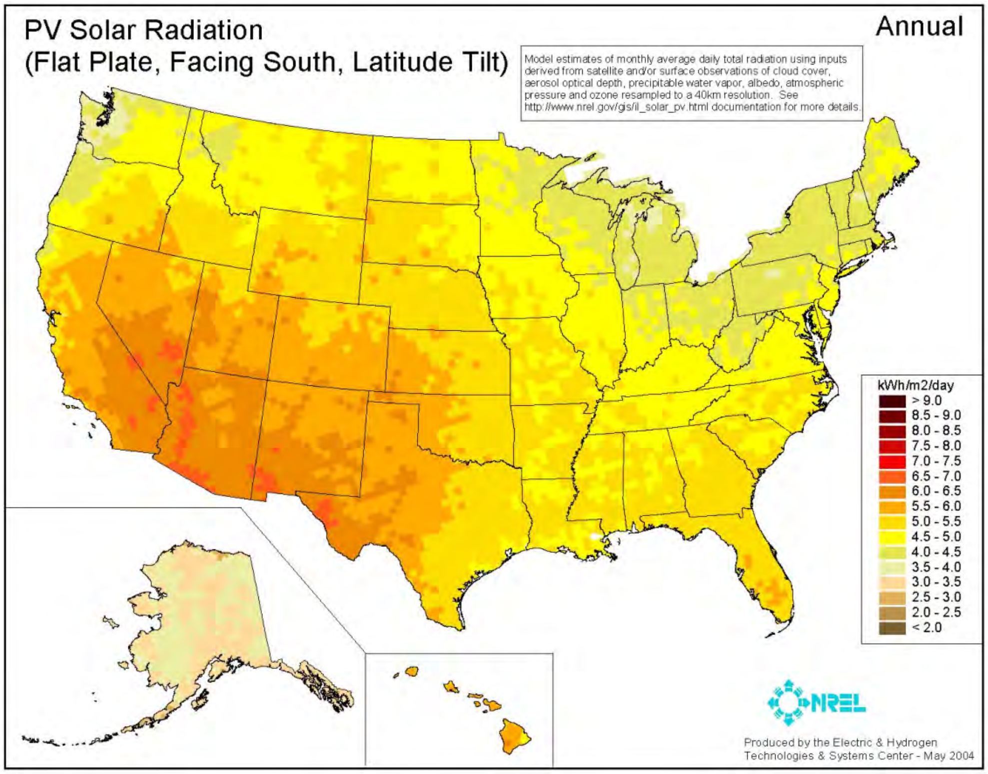


Figure 6-7: Annual average solar radiation for a flat-plate collector (Source: NREL [16])

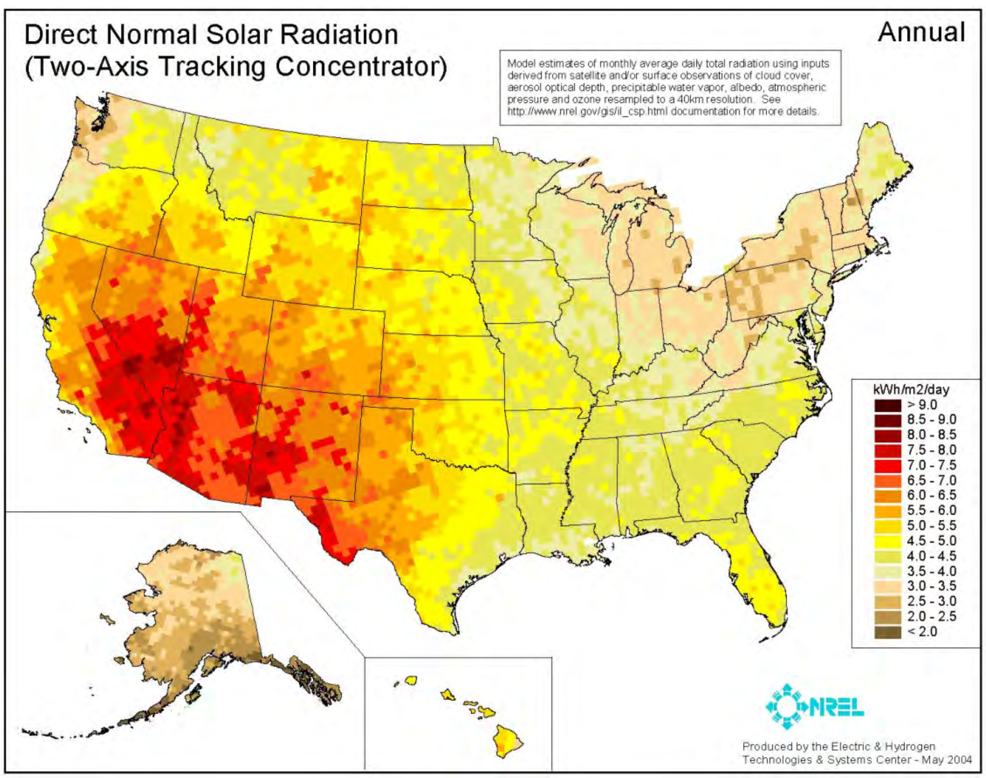


Figure 6-8: Direct normal solar radiation (two-axis solar concentrator) (Source: NREL [16])

The EIA currently tracks the shipments[6] of PV systems within the nation [17]. These domestic shipments provide an indication of the status of the PV market. Table 6-1 shows the total annual shipments, imports and exports of PV cells in the U.S.

Year	Total photovoltaic cells and modules shipment (kW)	Imported photovoltaic cells and modules (kW)	Exported photovoltaic cells and modules (kW)
1997	46,354	1,853	33,793
1998	50,562	1,931	35,493
1999	76,787	4,784	55,562
2000	88,221	8,821	68,382
2001	97,666	10,204	61,356
2002	112,090	7,297	66,778
2003	109,357	9,731	60,693
2004	181,116	47,703	102,770
2005	226,916	90,981	95,451
2006	337,268	173,977	130,757
2007	517,684	238,018	237,209
Total	1,844,021	595,300	945,244

Table 6-1: Total annual shipments, imports and exports of PV cells and modules in the U.S. (Source: EIA [17])

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 [17]. 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 International Energy Agency (IEA). The U.S. PV installations have increased an approximate 30 percent annual growth rate since 2003, increasing from 275 MW in 2003 to 624 MW in 2006. The fastest growing market sector was the grid-connected distributed sector. The grid connected distributed sector includes those PV systems installed to provide to a grid connected customer or directly to a number of customers at the distribution level [18].

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

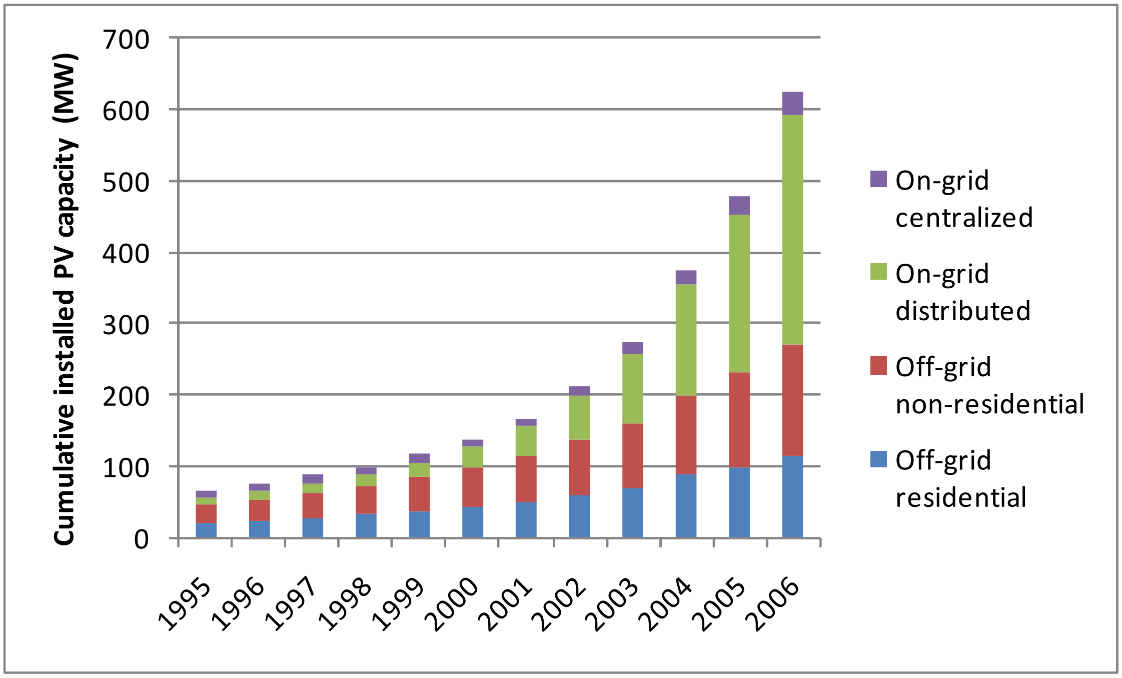


Figure 6-9: Cumulative installed PV capacity in the U.S. by sub-market (Data source: IEA [18])

In 2008, PV installations for residential, non-residential and utility uses were growing strongly, as shown in Figure 6-10 [19].

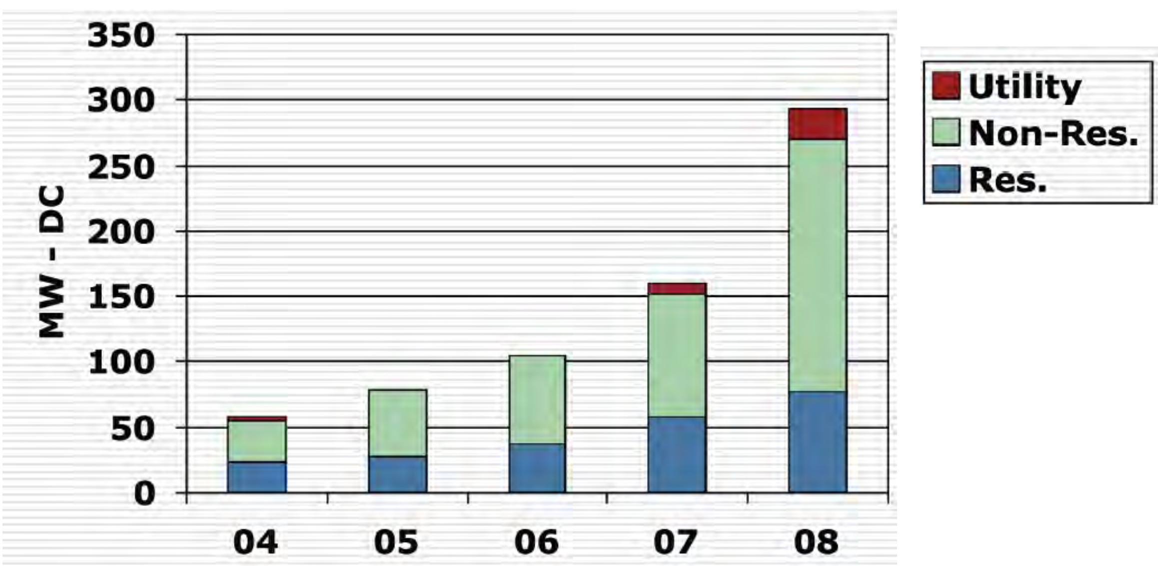


Figure 6-10: Residential, non-residential and utility PV installation in the U.S. (Source: IREC [19])

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. It was responsible for accelerating the development of advanced solar electric technologies, including PV and CPV systems. Its 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 [20].

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, the program had led to 377,000 new solar roof installations and 200 MW in PV capacity [21].

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 [22]:

- 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 ideal solar resources, there is some potential for fixed, flat-plate PV systems such as those shown in Table 6-2. 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. The ten schools currently participating in the program are [23]:

- 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	2 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	1	Union City Community High School

Table 6-2: 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 [24]. In addition, Duke Energy has installed an 8 kW system at its Bloomington office and a 2 kW system at its Kokomo office [25].

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[7] and there are no moving parts. Levelized energy costs from PV systems are around 30 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 or 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 [14]. Another NREL study done in 2009 observed that factors such as cost of electricity, rate structure and availability of financing have a greater influence on the breakeven cost in an electric service territory than resource availability [26].

The average cost of PV systems was $4.18 per watt in July 2010 [12], but this is still above the breakeven cost of entry of PV systems within Indiana which is less than $4 per watt. For small residential installments in Indiana the current price is $8.09 per watt [27].

A 3.5 MW PV system has been proposed the ERMCO Green Energy Corporation for installation at Fort Benjamin Harrison in Indianapolis. According to the developer, the project is financed using the 2009 Stimulus Act funds and when completed will be the largest roof-mounted PV system in the U.S. [28]. The financial viability of the project is also enhanced by the feed-in-tariff offered by Indianapolis and Light (IPL) as part of their Renewable Energy Production rate (REP). The REP rate buys electricity generated by PV systems of the size of this project at $0.2/kWh [29]. More details about IPL's incentive rates for electricity generated from renewable resources is given in Section 6.5 below.

6.5 Incentives for PV systems

Federal Incentives

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

[7] 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 [30].

- 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 [30].
- Qualified Energy Conservation Bonds (QECBs) are qualified tax credit bonds and 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". In February 2009, these funds were expanded to $3.2 billion [30].
- 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 [30].
- 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" [30].
- 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 [30].
- 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 [31].
- High Energy Cost Grant Program administered by the U.S. Department of Agriculture (USDA) is aimed at improving the electricity supply infrastructure in rural areas having home energy costs exceeding 275 percent of the national average. Eligible infrastructure includes renewable resources generation. The USDA has allocated a total of $15.5 million for the 2010 funding cycle. The individual grants range from $75,000 to $5 million [32]

Indiana Incentives

- Emissions Credits: Electricity generators that do not emit NO_x and that displace utility generation are eligible to receive NO_x emissions credits under the Indiana Clean Energy Credit Program. These credits can be sold on the national market [33].
- 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].
- 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].
- Indianapolis Power & Light Co. – Rate REP Renewable Energy Production: IPL is offering a "feed-in tariff" to facilities that produce renewable energy. IPL can purchase renewable energy and contract the production for up to 10 years. Solar compensation is $0.24/kWh for systems between 20 and 100 kW and $0.20/kWh for systems greater than 100kW up to 10MW [29, 30].
- Indianapolis Power & Light Co. – Small Scale Renewable Energy Incentives Program: IPL is offering compensation for new photovoltaic installments for its customers. The compensation is $2 per watt up to $4,000. Participants in the REP program are not eligible [30, 34].

6.6 References

1. U.S. Department of Energy, Energy Information Administration (EIA). Solar energy—energy from the sun. November 2007. http://www.eia.doe.gov/kids/energyfacts/sources/renewable/solar.html
2. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Department of Energy (EERE). Learning about PV: Quick Facts. January 2006. http://www1.eere.energy.gov/solar/pv_quick_facts.html
3. EERE. PV systems. December 2005. http://www1.eere.energy.gov/solar/pv_systems.html
4. European photovoltaic technology platform. Introduction to PV. http://www.eupvplatform.org/index.php?id=47
5. Gizmag. SANYO develops world's highest energy conversion efficiency solar cells. June 2007. http://www.gizmag.com/go/7480/
6. National Renewable Energy Laboratory (NREL). Concentrating photovoltaic technology. April 2007. http://www.nrel.gov/csp/concentrating_pv.html
7. U.S. Department of Energy, Office of Science. Basic research needs for solar energy utilization, September 2005. http://www.sc.doe.gov/bes/reports/files/SEU_rpt.pdf

8. NREL. Opportunities and challenges for development of a mature concentrating photovoltaic power industry. November 2009. http://www.nrel.gov/pv/pdfs/43208.pdf
9. EIA, Renewable Energy 2000: Issues and trends, February 2001. http://tonto.eia.doe.gov/ftproot/renewables/06282000.pdf
10. Solar Energy Industries Association. Our solar power future: The U.S. photovoltaics industry roadmap through 2030 and beyond. September 2004. http://www.gardenstatesolar.net/documents/roadmap_2030.pdf
11. Environmental Law & Policy Center. Repowering the Midwest: the clean energy development plan for the Midwest. 2001. http://www.elpc.org/documents/RepoweringtheMidwest.pdf
12. Solarbuzz LLC. Solar module retail price environment. June 2010. http://www.solarbuzz.com/ModulePrices.htm
13. Solarbuzz LLC. Fast Solar energy facts: global performance. March 2007. http://www.solarbuzz.com/FastFactsIndustry.htm
14. Herig, C., S. Gouchoe, R. Perez, T. Hoff. NREL. PV in Commercial buildings—mapping the breakeven turn-key value of commercial PV systems in the U.S. ASES Annual Conference, 2003. http://www.dsireusa.org/documents/PolicyPublications/Commercial%20PV%20ASES%202003%20paper.pdf
15. International Energy Agency (IEA). Photovoltaic power systems programme: 2008 annual report. http://www.iea-pvps.org/
16 . NREL. Solar maps. May 2008.http://www.nrel.gov/gis/solar.html
17. EIA. 2007 Renewable energy annual. April 2009. http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/rea.pdf
18. IEA. National survey report of PV power applications in the United States of America 2006. August 2007. http://www.iea-pvps.org/countries/download/nsr06/06usansr.pdf
19. Sherwood, Larry. Interstate Renewable Energy Council. U.S. solar market trends 2008. http://irecusa.org/fileadmin/user_upload/ASES_09/Sherwood-Market_Trends-ASES-May09.pdf
20. EERE. Solar energy technologies program. Solar america initiative. http://www1.eere.energy.gov/solar/solar_america/
21. EERE. Solar energy technologies program: deployment, January 2009. http://www1.eere.energy.gov/solar/deployment.html
22. EERE. Solar America initiative: Solar America cities. March 2008. http://www1.eere.energy.gov/solar/solar_america_cities.html
23. Duke Energy. Press release, May 22 2007. http://www.duke-energy.com/news/releases/2007052201.asp
24. British Petroleum Global. Service station comes of age at BP Connect. January 2001. http://www.bp.com/genericarticle.do?categoryId=2012968&contentId=2001318

25. Duke Energy. Solar. http://www.duke-energy.com/environment/additional-solar.asp
26. Denholm, P., Margolis, M., Ong S., Roberts, B. NREL. Break-even cost for residential photovoltaics in the United States: key drivers and sensitivities. Technical Report, December 2009. http://wwww.nrel.gov/docs/fy10osti/46909.pdf
27. Menards. Sunforce Products, Inc. August 3, 2010. http://shop.menards.com/shop/lighting-fans/alternative-energy/solar/130-watt-polycrystalline-solar-kit-with-sharpandreg-module/p-55422.htm?cid=3164
28. ERMCO Green Energy Group. http://www.ermcogreen.com/solar-projects
29. Indianapolis Power and Light Company. Renewable Energy Production. http://www.iplpower.com/ipl/index?page=IPLGeneral&Menu=01000000&DocID=020391af33d6012801538fc10057cb
30. Database of State Incentives for Renewables and Efficiency (DSIRE). Federal incentives. June 2008. http://www.dsireusa.org/
31. Center for Rural Affairs. Value added producer grants program fact sheet, 2007. http://www.cfra.org/resources/vapg/fact_sheet
32. U.S. Department of Agriculture, Rural Development, Electric Programs. http://www.usda.gov/rus/electric/hecgp/overview.htm
33. Indiana Department of Environmental Management. Indiana clean energy credit program. http://www.in.gov/idem/4134.htm.
34. Indianapolis Power and Light Company. Small Scale Renewable Energy Incentive Program. http://www.iplpower.com/ipl/index?page=IPLGeneral&Menu=01000000&DocID=020391af33d6012801538fc1004513

7. Fuel Cells

7.1 Introduction

A fuel cell is an electrochemical device that produces direct current electrical power without combustion. A fuel cell functions like a battery that does not run down but that keeps producing electricity as long as fuel is supplied. The basic fuel cell consists of two electrodes encompassing an electrolyte. Figure 7-1 shows the basic structure of a polymer electrolyte membrane (PEM) fuel cell.

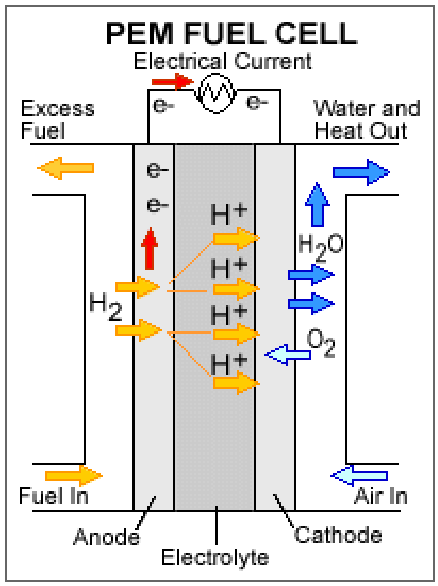


Figure 7-1: Schematic of basic fuel cell operation (Source: EERE [1])

Hydrogen (H_2) is fed into the anode, and oxygen (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. Several types of fuel cells currently under development, each with its own advantages, limitations, and potential applications are listed [1].

- Polymer Electrolyte Membrane Fuel Cells (PEM): 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 (DMFC): These fuels cells are a subset of PEM typically used for small portable power applications, with a size range of less than one watt to about 100W and operating at 60 - 90° C [3]. 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 (AFC): 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. AFC stacks have been proven to maintain stable operation for more than 8,000 operating hours.
- Phosphoric Acid Fuel Cells (PAFC): These fuel cells use liquid phosphoric acid as the electrolyte, porous carbon as electrodes, and a platinum catalyst. PAFCs are among the most mature cell types and were the first to be used commercially, with over 200 units currently in use. This type of fuel cell is typically used for stationary power generation, but some PAFCs have been used to power large vehicles such as city buses.
- Molten Carbonate Fuel Cells (MCFC): 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. 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 (SOFC): SOFCs use a hard ceramic compound as the electrolyte. 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 (RFC): 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 (electrolysis). This technology is still being developed by NASA and others.

The characteristics of the five basic fuel cell types that are currently being pursued by manufacturers are shown in Table 7-1.

	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 [3])

The attractive features of fuel cell technology include

- High energy conversion efficiencies exceeding 80 percent in combined heat and power applications;
- 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 [4].

Disadvantages and challenges facing the full deployment of fuel cell technology include

- Cost: Fuel cell systems are still more expensive than conventional energy conversion technologies. Section 7.2 discusses the economics of fuel cell systems;
- Durability and reliability: The durability of fuel cell systems has not yet been established. For example fuel cells intended for automotive use will need to reach the same levels equivalent to the current automotive engine's 5,000 hour lifespan and be able to function over the vehicle operating conditions of 40 °C to 80 °C similar to current automobile engines.
- Size: The fuel cell system (fuel cell, fuel processor, compressor/expander and sensors) are still larger than ideal, especially for the transportation industry.
- Air, Thermal, and Water Management: According to the DOE fuel cell technologies program none of the compression technology available today is appropriate for use in a fuel cell intended for automobiles. Also because the sensitivity of fuel cells to operating and ambient temperatures, large heat exchangers are needed to manage the heat and water in a fuel cell.
- Hydrogen Storage: The necessary infrastructure to produce, store and transport hydrogen is not yet in place.

Although fuel cells run on hydrogen, the most plentiful gas in the universe, hydrogen is never found alone in nature. Therefore, efficient methods of extracting hydrogen in large quantities are required. There are several methods being currently pursued by DOE to produce hydrogen at an economically competitive price [5].

- <u>Natural Gas Reforming</u>: Hydrogen can be produced from methane (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.
- <u>Electrolysis</u>: Electrolysis uses an electric current to split water into hydrogen and oxygen. The electricity required can be generated using renewable sources.
- <u>Gasification</u>: 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.
- <u>Renewable Liquid Reforming</u>: 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 using solar or wind energy is seen as the ideal hydrogen production method to achieve the full environmental potential of the hydrogen economy.

Applications for the fuel cell technology fall into two broad categories: stationary uses and fuel cell systems for the transportation industry. Stationary fuel cell uses includes such applications as grid-connected units for electricity generation and other grid support services; combined heat and power units for buildings; emergency back-up units, off-grid units powering such installations as communication towers, and electricity generation units gas from landfills and wastewater treatment plants. The fuelcell.org database lists 460 stationary fuel cell installations in the U.S., including four in Indiana. Uses in the transportation industry include fuel cell engines for cars and buses and material handling units (forklifts) and auxiliary power units for heavy duty trucks [6].

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 is roughly 12 cents/kWh. 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 [7]. 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 [8].

Unlike stationary fuel cells, which are economically viable in certain situations, the cost of fuel cells for transportation purposes remains prohibitively high. The cost of today’s hand-built prototypes is still well above the level necessary for commercialization. Prototype fuel cell engines for automotive transportation in operation today are on the order of $3,000/kW, considerably higher than the approximately $30/kW cost of conventional internal combustion engines in use today. DOE estimates that the mass-production cost of a fuel cell engine is approximately $225/kW. Figure 7-2 shows the technology progression since 1990 and into the future [9]. The cost of the Clarity, Honda Motor Corporation's fuel cell powered automobile, is estimated at $300,000. Six of these automobiles have been leased to drivers in Southern California at a Honda subsidized price of $600 per month [10].

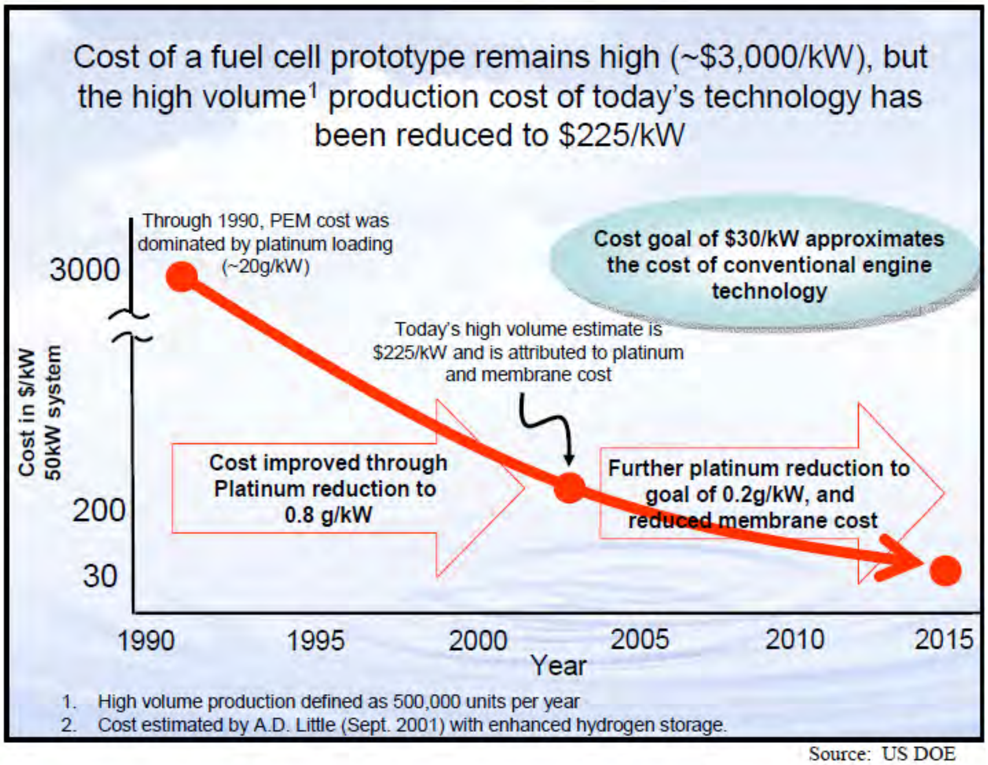


Figure 7-2: Cost of fuel cell vehicle engine (Source: *FuelCells2000* [9])

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 [11]:

- 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.

Stationary fuel cell systems deployed in the U.S. include [12]:

- 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 [13]:

- 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.
- 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.

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 [4]. 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.

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 to have 2 million vehicles (out of 280 million vehicles) 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 [14].

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 [15].

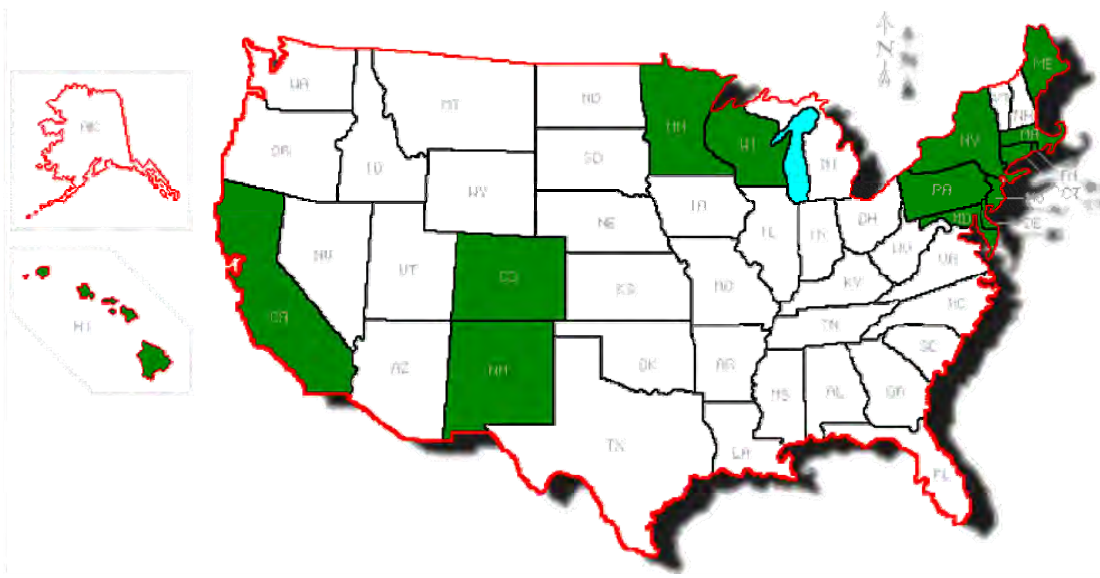


Figure 7-3: Renewable portfolio standards that include fuel cells (Source: *FuelCells2000* [2])

7.4 Fuel cells in Indiana

Table 7-2 shows the four fuel cell installations listed for Indiana in the *FuelCells2000* database [12]. According to this database the first fuel cell to be installed in Indiana was the Ballard Power 250 kW stationary generator at the Crane Naval Surface Warfare Center in the 1990s. 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. The second system to be installed in 2000 was a 3 KW unit in a residence in Chesterton in a project developed in a partnership involving NiSource, Gas Technology Institute and Ishikawajima-Harima Heavy Industries.

Site	Year	Manufacturer	City	Capacity
Crane Naval Surface Warfare Center	1990s	Ballard Power Systems	Crane	250 kW
Wabash River Energy facility	2003	FuelCell Energy	Terre Haute	2 MW
U.S. Navy Naval Surface Warfare Center-Crane Division	2004	Hydrogenics Corp.	Crane	Not listed
Residential unit in a new housing development	2000	MOSAIC Energy	Chesterton	3 kW

Table 7-2: Fuel cell installations in Indiana (Source: *FuelCells2000* [12])

The third and largest plant, installed in 2003, is the 2 MW fuel cell set at the Wabash River coal gasification site near Terre Haute. This installation was designed to run on gasified coal, or syngas, from the nearby gasification facility. Partial funding was provided by the DOE as part of the federal Clean Coal Technology Program. According to fuelcell.org this was the first fuel cell plant to use a combination natural gas and coal-derived synthetic 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 [16].
- 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 [17].
- 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 [16].
- 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 certified at the 75 percent level in the *Leadership in Energy and Environmental Design* (LEED) certification 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 [18].

- 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 [16].
- High Energy Cost Grant Program administered by the U.S. Department of Agriculture (USDA) is aimed at improving the electricity supply infrastructure in rural areas having home energy costs exceeding 275 percent of the national average. Eligible infrastructure includes renewable resources generation. The USDA has allocated a total of $15.5 million for the 2010 funding cycle. The individual grants range from $75,000 to $5 million [19]

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 [20].

7.6 References

1. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE). http://www.eere.energy.gov/hydrogenandfuelcells/fuelcells/fc_types.html
2. FuelCells2000. Fuel cell basics: How they work. http://www.fuelcells.org/basics/how.html
3. EERE. Comparison of fuel cell technologies. http://www1.eere.energy.gov/hydrogenandfuelcells/fuelcells/pdfs/fc_comparison_chart.pdf
4. Environmental Law & Policy Center. Repowering the Midwest: The clean energy development plan for the heartland. 2001.
5. EERE. Hydrogen production basics. http://www1.eere.energy.gov/hydrogenandfuelcells/production/basics.html
6. FuelCells2000. Fuel cell basics: applications. http://www.fuelcells.org/basics/apps.html
7. Murray, James. Business green. UTC Power to launch fuel cell that is "cheaper than the grid." Mar 2008. http://www.businessgreen.com/business-green/news/2211404/utc-power-launch-fuel-cell
8. EERE. Fuel cell technology challenges. http://www1.eere.energy.gov/hydrogenandfuelcells/fuelcells/fc_challenges.html

9. FuelCells2000. Questions and answers about hydrogen and fuel cells. www.fuelcells.org/info/library/QuestionsandAnswers062404.pdf
10. CNNMoney.com, October 14, 2009. The hydrogen car fights back. http://money.cnn.com/2009/10/13/technology/hydrogen_car.fortune/index.htm
11. FuelCells2000. Fuel cell basics: FAQs. http://www.fuelcells.org/basics/faqs.html
12. FuelCells2000. Fuel cell installation database. http://www.fuelcells.org/db/
13. FuelCells2000. Fuel cell technology update: August 2008. http://www.fuelcells.org/news/updates.html
14. National Research Council. Transitions to alternative transportation technologies: A focus on hydrogen. July 2008. http://www.nap.edu/catalog.php?record_id=12222#toc
15. Rose, Bob. Ohio Fuel Cell Symposium. Fuel Cells in the States. May 2006. http://www.fuelcells.org/info/Ohio.pdf
16. Database of State Incentives for Renewables and Efficiency (DSIRE). June 2008. http://www.dsireusa.org/
17. Montana Grain Growers Association. Food, conservation, and energy act of 2008. http://www.mgga.org/FarmPolicy/thenewCSP.pdf
18. Council of Development Finance Agencies. Green building finance, http://www.cdfa.net/cdfa/cdfaweb.nsf/pages/greenbuildingfactsheet.html
19. U.S. Department of Agriculture, Rural Development, Electric Programs. http://www.usda.gov/rus/electric/hecgp/overview.htm
20. Indiana Department of Environmental Management. Indiana clean energy credit Program. http://www.in.gov/idem/4134.htm

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[8] 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 [3]:

- 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.

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

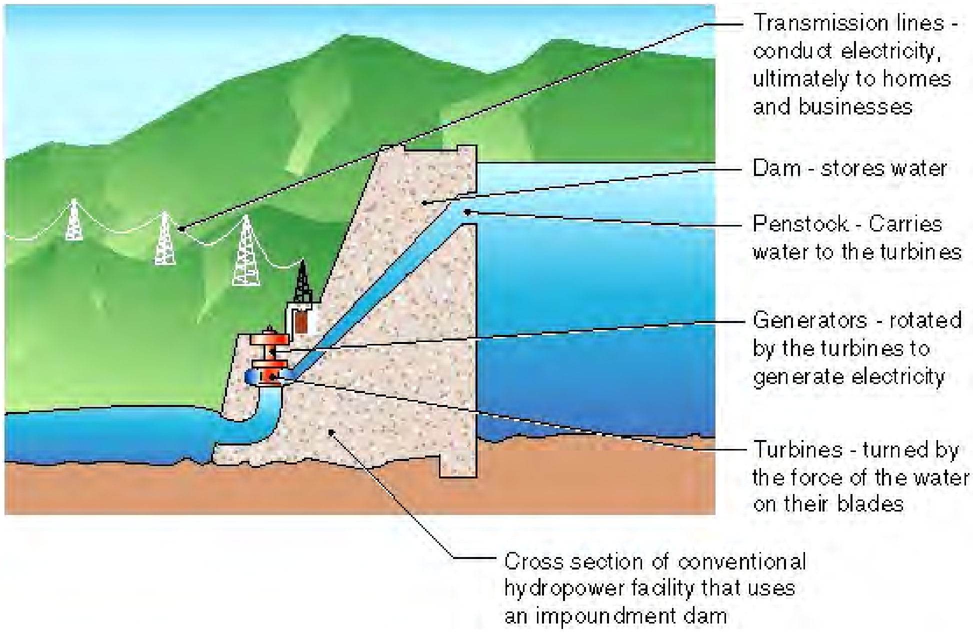


Figure 8-1: Schematic of impoundment hydropower facility (Source: INEL [2])

Hydropower is a renewable resource that has many benefits, including [4]:

- 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;
- Hydropower produces negligible air emissions; and
- 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 [5]. Electricity production is the primary function of only two percent of all U.S. dams, as shown in Figure 8-2 [6].

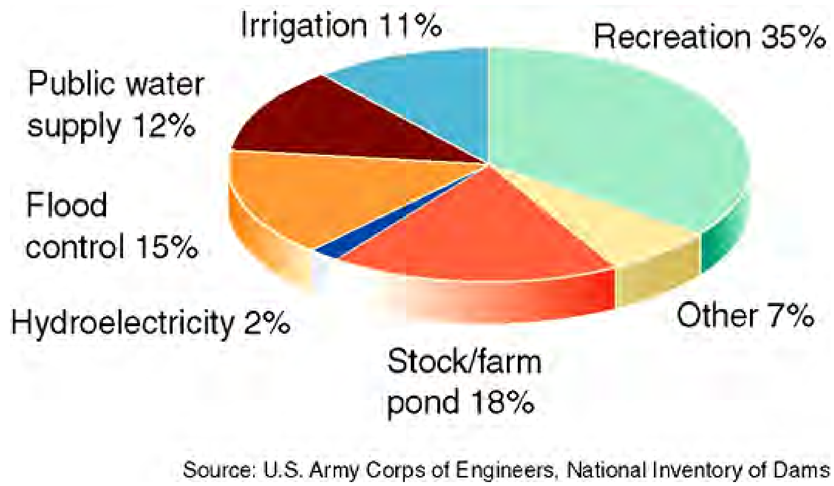


Figure 8-2: Primary function of U.S. dams (Source: NREL [6])

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 [5]. Potential environmental impacts of hydroelectric facilities include [5, 7]:

- 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 [8]. Though the Energy Policy Act of 2005 helped reform the licensing procedure, many still consider the process to be burdensome and complicated [9]. Obtaining a license for a new facility, or renewing the license of an older facility, can take 8-10 years or longer [8].

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 [10]. Figures 8-3 and 8-4 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.

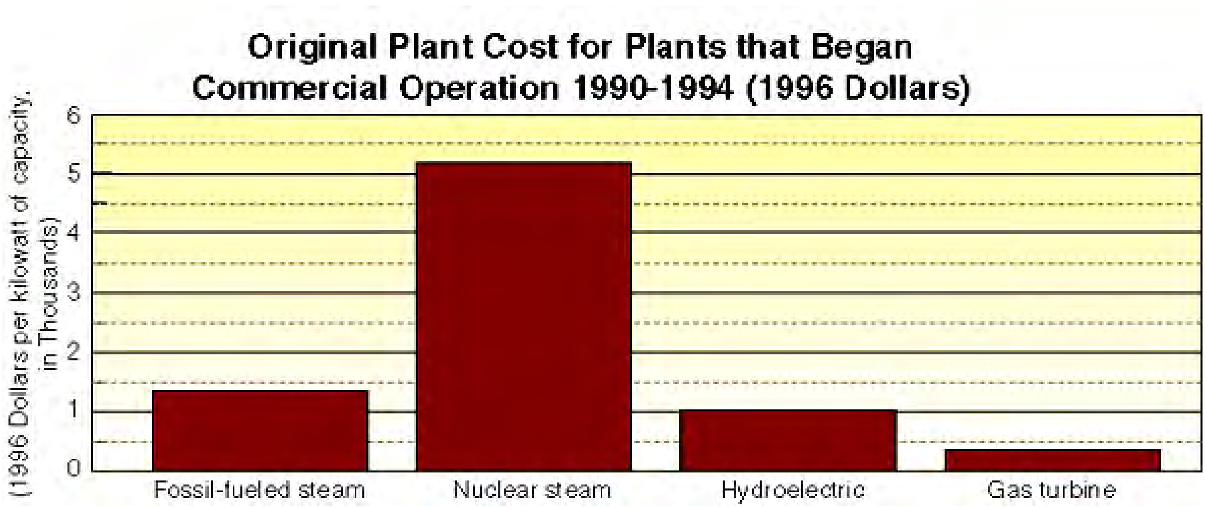


Figure 8-3: Plant costs per unit installed capacity (Source: INEL [10])

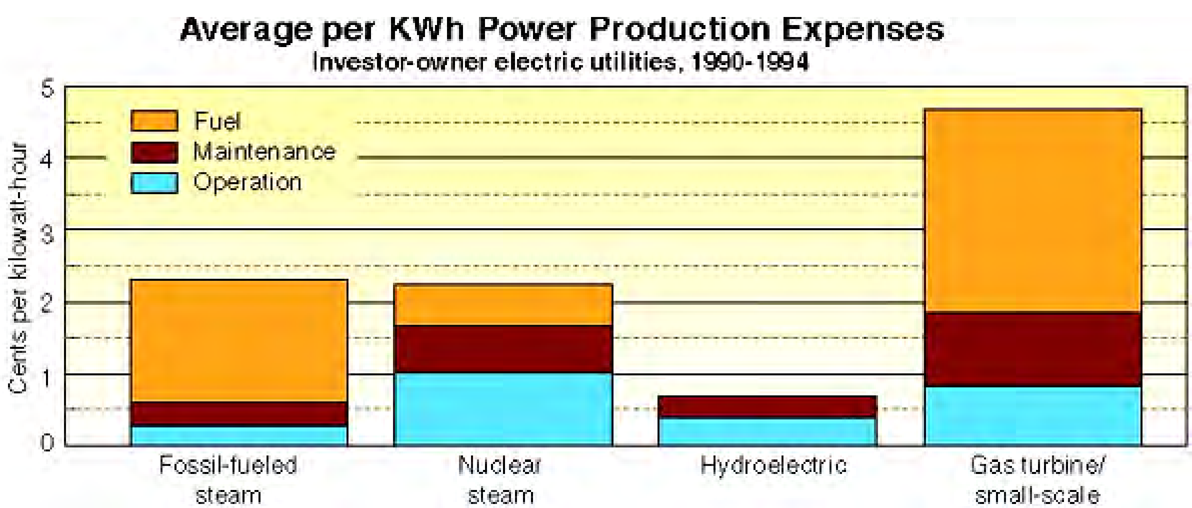


Figure 8-4: Average production costs of various types of generating plants (Source: INEL [10])

8.3 State of hydropower nationally

In 2008, the U.S. consumed 7.7 quads of renewable energy. Of this, 2.7 quads (35 percent) were from hydroelectric energy [11] and in 2009, 7 percent of electricity in the U.S. was produced from hydropower [12, 13]. In 2008 there were 3,996 hydropower facilities catalogued by the Energy Information Administration in the U.S., with a total net summer capacity of 78 GW. The states of Washington, California and Oregon account for 40 percent of total hydropower nameplate capacity in the country [14].

1.Washington	21,203		6.Arizona	2,720
2.California	10,122		7.Tennessee	2,639
3.Oregon	8,364		8.Montana	2,660
4.New York	4,299		9.Idaho	2,346
5.Alabama	3,272		10.Georgia	2,041

Table 8-1: Top ten U.S. states in hydropower capacity in 2008 (MW) (Data source: EIA [15])

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].

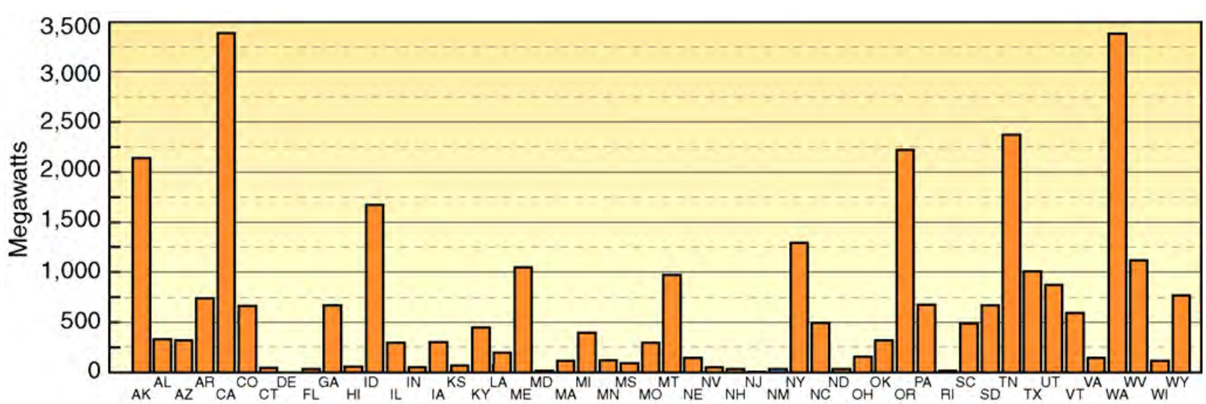


Figure 8-5: State breakdown of potential hydropower capacity (Source: INEL [16])

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 [6].

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 [7]. 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. The 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 should reduce the cost of implementation and help smooth the hydropower integration process [18].

8.4 Hydropower from existing dams in Indiana

Until the commissioning of the first wind farm in Indiana in 2008, hydroelectricity has been the main source of renewable electricity in Indiana as shown in Figure 8-6.

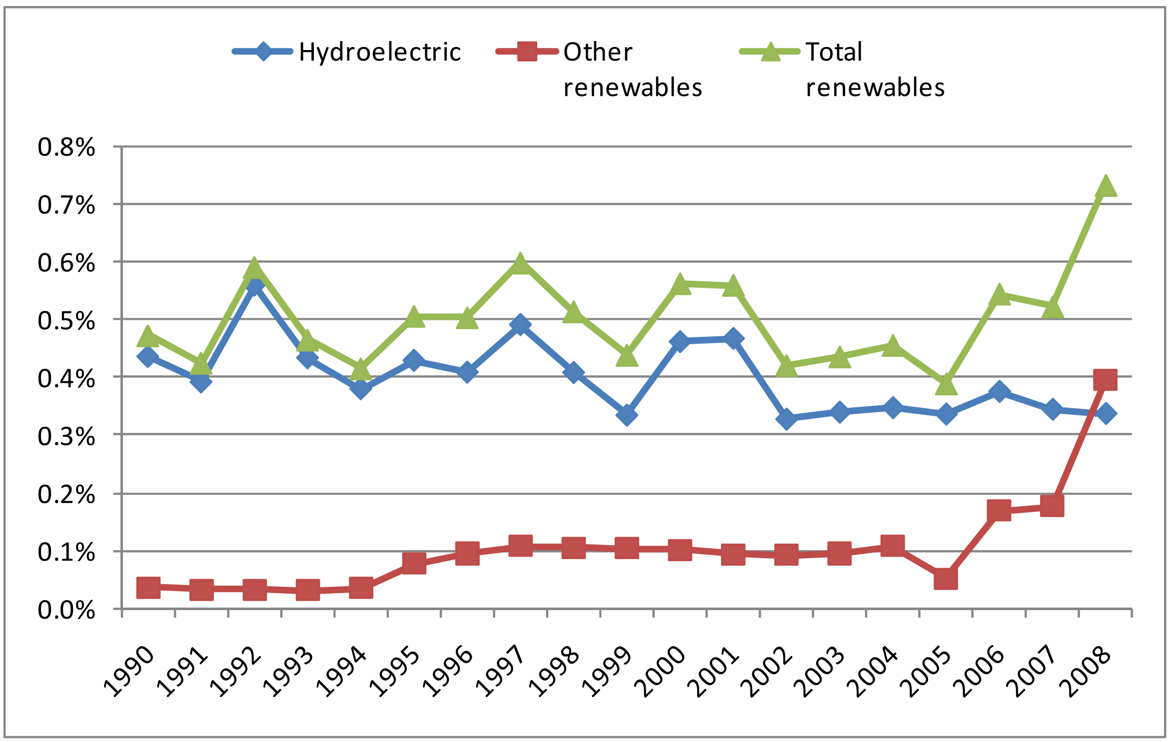


Figure 8-6: Renewables share of Indiana net electricity generation (1990-2008) (Data source: EIA [19])

However, when one considers total Indiana energy consumption, wood and more recently ethanol take the more dominant role as sources of renewable energy consumed in Indiana as shown in Figure 8-7. Hydroelectricity comes in third contributing less 0.2 percent of the total energy consumed in Indiana.

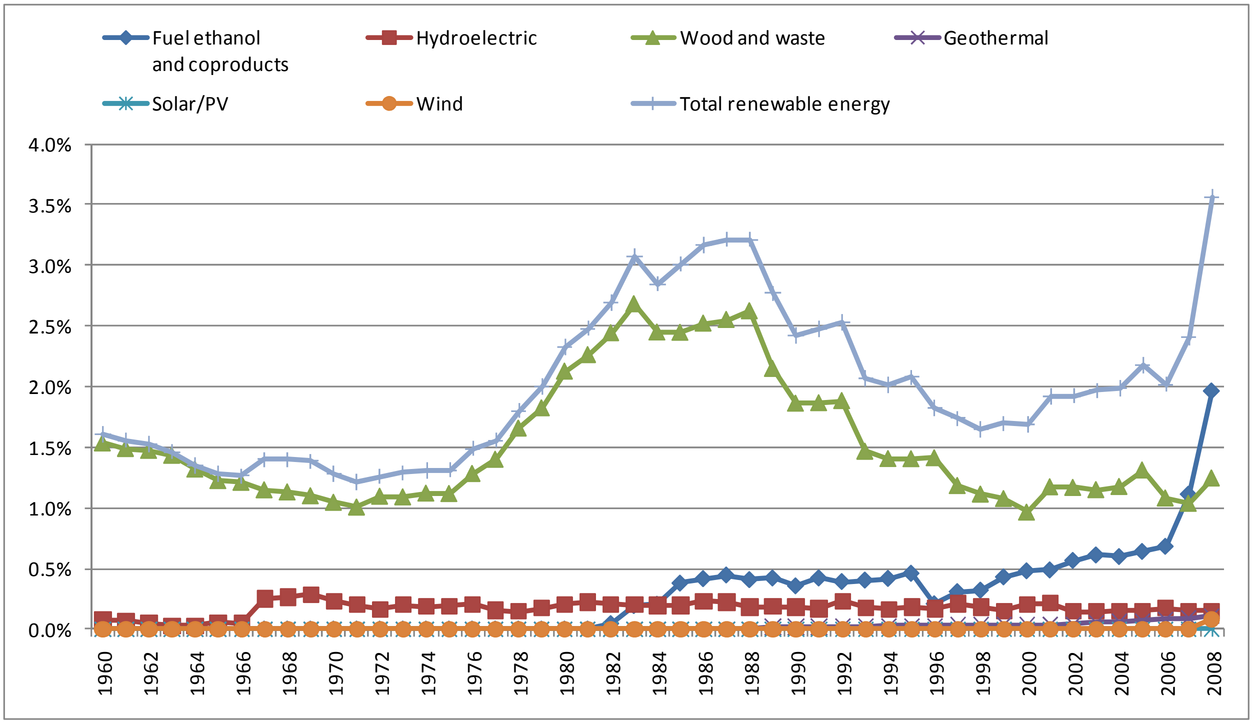


Figure 8-7: Renewables share of Indiana total energy consumption (1960 – 2008) (Data source: EIA [20])

A 1995 national hydro-potential study conducted by DOE estimated Indiana to have the potential for approximately 43 MW of exploitable capacity on 5 of Indiana's river basins as shown in Table 8-2 [21].

	Exploitable hydro potential (MW)	Number of sites	Number of sites with existing power generation	Number of sites without existing power generation	Number of un-developed sites
Wabash river basin	22.73	12	0	11	1
St. Joseph river basin	10.32	12	3	9	0
Ohio main stream	9.23	3	0	2	0
Maumee river basin	1.08	2	0	2	0
Cumberland River basin	0.0045	1	0	0	1
Total	**43.4**	**30**	**3**	**24**	**2**

Table 8-2: Hydropower potential in Indiana (Source: INEL [21])

The 43 MW shown in Table 8-2 is the net capacity that can exploited after screening out capacity deemed unsuitable for development due to environmental factors. The gross total capacity before the screening was assessed at 84 MW.

American Municipal Power is in the process of developing five new run-of-the-river hydroelectric projects on existing dams along the Ohio River whose combined capacity will be more than 350 MW. Four of these projects, including the one near Cannelton, Indiana, are at an advanced stage with the contract for the manufacture of the turbines having been signed. The other three are located at the Smithland, Meldahl and Willow Island Locks and Dams in the Illinois, Ohio and Pennsylvania sections of the Ohio River [22].

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 [23].
- 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. [23].
- Conservation Security Program: 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].
- 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 [23].
- High Energy Cost Grant Program administered by the U.S. Department of Agriculture (USDA) is aimed at improving the electricity supply infrastructure in rural areas having home energy costs exceeding 275 percent of the national average. Eligible infrastructure includes renewable resources generation. The USDA has allocated a total of $15.5

million for the 2010 funding cycle. The individual grants range from $75,000 to $5 million [27]

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 [28].
- 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 [29].
- 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].

8.6 References

1. Wisconsin Valley Improvement Company. How hydropower works. http://www.wvic.com/hydro-works.htm
2. Idaho National Laboratory (INEL). Hydropower: Types of hydropower facilities. http://hydropower.inel.gov/hydrofacts/hydropower_facilities.shtml
3. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE). Types of hydropower turbines. http://www1.eere.energy.gov/windandhydro/hydro_turbine_types.html
4. National Hydropower Association. Hydropower: The power of moving water. http://www.hydro.org/hydrofacts/docs/general_hydro.pdf
5. EERE. Advantages and disadvantages of hydropower. http://www1.eere.energy.gov/windandhydro/hydro_ad.html
6. EERE. Hydropower: Setting a course for our energy future. July 2004. http://www.nrel.gov/docs/fy04osti/34916.pdf
7. EERE. DOE hydropower program annual report for FY 2002. July 2003. http://hydropower.inl.gov/techtransfer/pdfs/hydro_final_fy_02.pdf
8. Church Ciocci, Linda. Power Engineering International. Hydropower licensing reform: What's all the fuss? July 2003. http://pepei.pennnet.com/articles/article_display.cfm?article_id=181517
9. National Hydropower Association. Backgrounders: Energy Policy Act of 2005. http://www.hydro.org/hydrofacts/backgrounders.php
10. INEL. Hydropower: Plant costs and production expenses. http://hydropower.inel.gov/hydrofacts/plant_costs.shtml
11. July 2010 Monthly Energy Review Table 1.3. http://www.eia.doe.gov/emeu/mer/overview.html

12. EIA. Renewable Energy Consumption and Electricity Preliminary Statistics 2008. http://www.eia.doe.gov/cneaf/alternate/page/renew_energy_consump/rea_prereport.html
13 EIA. July 2010 Electric Power Monthly. http://www.eia.doe.gov/cneaf/electricity/epm/table1_1.html
14. EIA. Existing Generating Units in the United States by State, Company and Plant, 2008. http://www.eia.doe.gov/cneaf/electricity/page/capacity/capacity.html
15. EIA. State Renewable Electricity Profiles. http://www.eia.doe.gov/cneaf/solar.renewables/page/state_profiles/r_profiles_sum.html
16. Conner, A.M., J.E. Francfort, and B.N. Rinehart. U.S. hydropower assessment final report. December 1998. http://hydro2.inel.gov/resourceassessment/pdfs/doeid-10430.pdf
17. INEL. Undeveloped hydropower potential by state. http://hydropower.inel.gov/hydrofacts/undeveloped_potential.shtml
18. EERE. Advanced hydropower technology. http://www.eere.energy.gov/windandhydro/hydro_advtech.html
19. EIA. Indiana Electricity Profile Table 5, Release date: April 2009. http://www.eia.doe.gov/cneaf/electricity/st_profiles/indiana.html
20. EIA. State Energy Data System (SEDS), Released June 2010, next release June 2011. http://www.eia.doe.gov/emeu/states/hf.jsp?incfile=sep_use/total/use_tot_inc.html&mstate=INDIANA
21. J.E. Francfort, B.N. Rinehart. INEL. U.S. hydropower resource assessment for Indiana. December 1995. http://hydropower.inl.gov/resourceassessment/pdfs/states/in.pdf
22. American Municipal Power. http://amppartners.org/generation-assets/hydroelectric/, http://amppartners.org/images/Ohio_River_Hydro_map.jpg
23. Database of State Incentives for Renewables and Efficiency (DSIRE). http://www.dsireusa.org/library/
24. Department of Agriculture, National Resources Conservation Service (NRCS). Conservation security program 2008 national payment schedule. June 2008. http://www.nrcs.usda.gov/programs/csp/CSP_2008/2008_pdfs/2008_CSP_Natl_Payment_Schedule.pdf
25. NRCS. Renewable energy generation activity sheet. January 2008. http://www.nrcs.usda.gov/programs/csp/CSP_2008/2008_pdfs/activity_sheets/Renewable_Energy_Generation_Activity_Sheet.pdf
26. Montana Grain Growers Association. Food, Conservation, and Energy Act of 2008. http://www.mgga.org/FarmPolicy/thenewCSP.pdf
27. U.S. Department of Agriculture, Rural Development, Electric Programs. http://www.usda.gov/rus/electric/hecgp/overview.htm
28. Indiana Department of Environmental Management. Indiana clean energy credit program. http://www.in.gov/idem/4134.htm
29. Indiana Office of Energy and Defense Development. http://www.in.gov/oed/2588.htm
30. DSIRE http://www.dsireusa.org/

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

- Diatoms are found mainly in oceans, but also inland in fresh and saltwater environments. These store carbon mainly as oils or as a carbohydrate.
- Green algae are the most commonly seen occurring in such places as swimming pools. They store carbon mainly as starch.
- Blue-green algae are closer to bacteria in structure and play an important role in fixing nitrogen in the atmosphere. Blue-green algae store carbon mainly as lipids.
- 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 a source of renewable energy started in the U.S. as early as the 1950s. At that time the focus of the research was on growing 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]. The algae research at NREL was revived in 2009 [3].

Algae have several advantages over other biomass as a source of 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.

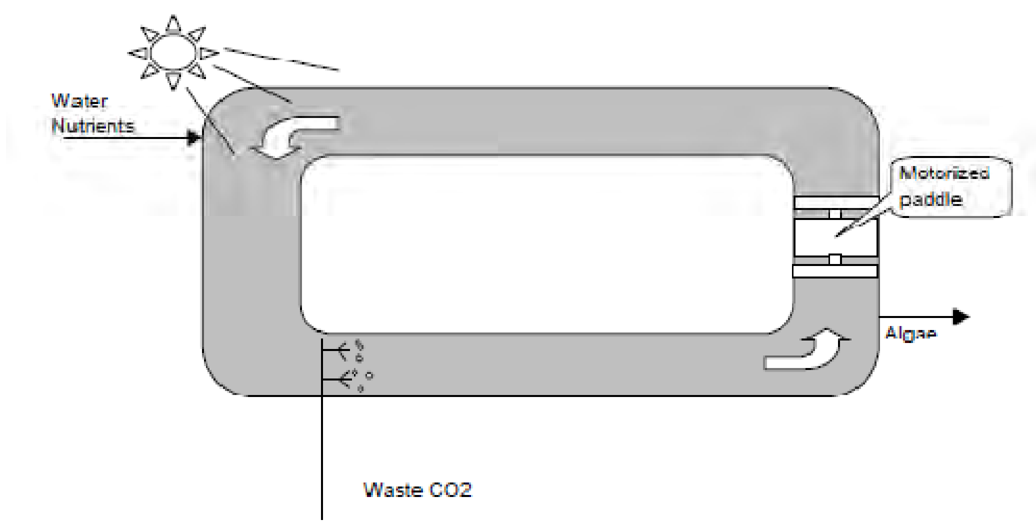


Figure 9-1: Algae pond (Source: NREL [1])

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].

One particularly elegant application for the use of algae is to couple bioreactors with coal power plants and allow the flue gas to pass through the reactors. This decreases the amount of CO_2 emissions from the plant and increases the uptake of CO_2 by the algae [1]. This is a popular concept in attempts at commercialization of the technology. 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 [4, 6]. GreenFuel was the company that the Arizona Public Service used to develop the project. However, during Phase II of the project, in 2009, GreenFuel was forced to sell its assets due to financial reasons [5]. Arizona Public Service has continued the Red Hawk project. There are other successful algae ventures, such as PetroAlgae, that are attempting to commercialize the technology.

Figure 9-2: Algae bioreactors at an Arizona Public Service power plant (Source: APS: [4])

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*. These costs are preliminary costs and better projections will not be available until a commercial scale algae oil production system is in place [7]. As stated in Figure 9-3 the average production cost from projects included is $109/gallon with very wide variability as represented by a standard deviation of $301/gallon.

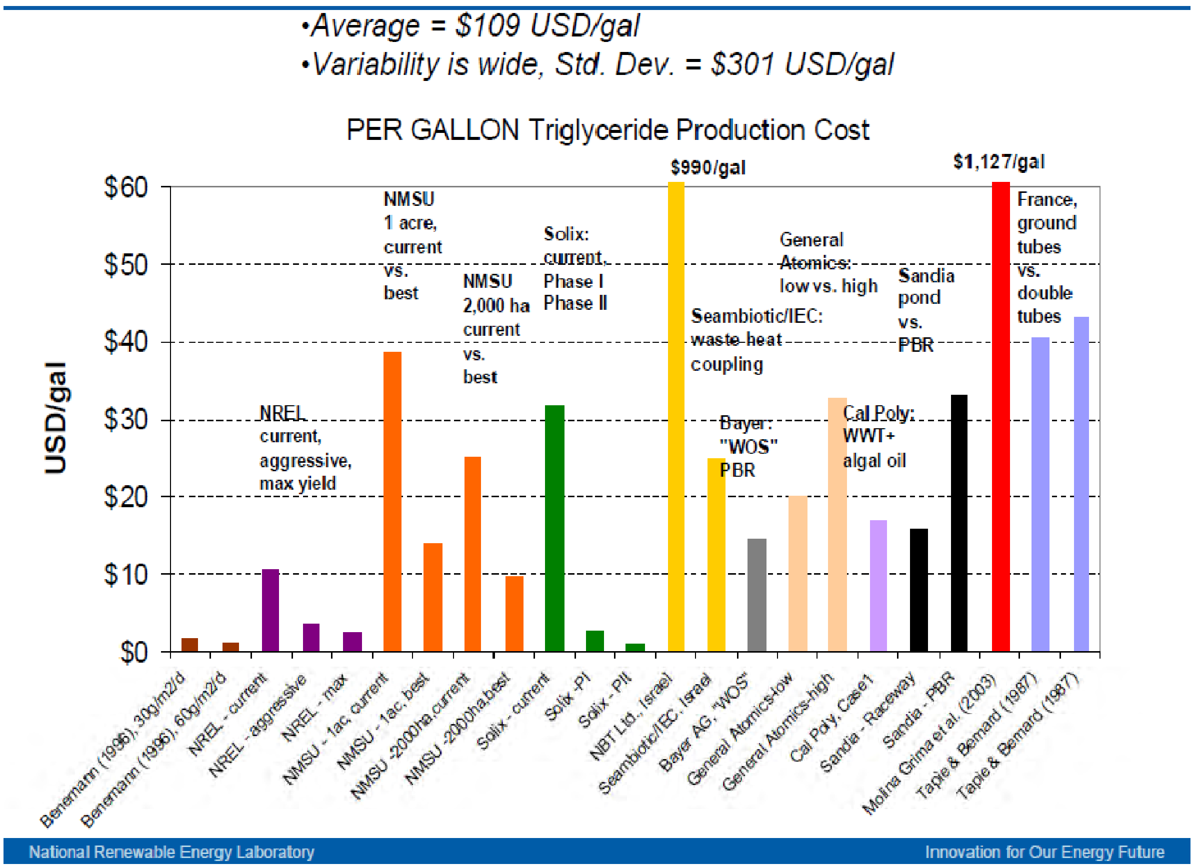


Figure 9-3: Cost comparison of various algae research projects (Source: NREL: [7])

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 Israel 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 is to "*identify the critical barriers currently preventing the development of a domestic, commercial-scale algal biofuels industry*" [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 begun 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 the increased concern about the effect of carbon dioxide on global climate change [8]. Some 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*" [8].

- 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 [8].

- U.S. Air Force funded project carried out in 2006 by a partnership of 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 [8].

- Starting in 2004 the DOE Small Business Innovative Research Grants program has provided awards to various algae production, harvesting and processing applied research projects [8].

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 was issued after this workshop [2].

9.4 Algae-based energy in Indiana

The following algae developers are operating in Indiana

- <u>Algaewheel Corporation of Indianapolis.</u> Algaewheel has carried out pilot projects in Seymour, Whitestown and at Purdue University's swine research facility. The primary application of Algaewheel technology is in wastewater treatment facilities [9, 10]. A demonstration project using Algaewheel technology to manage nitrogen content in water is taking place in Hopewell, Virginia [11].

- <u>Biotown USA.</u> Nicknamed Biotown USA in 2005, Reynolds, Indiana has become a prominent figure for biomass renewable energy resources. At the start of 2010, a $2.7 million wastewater treatment plant became operational, using a 6,500 square-foot greenhouse installed by Algaewheel Technologies. After passing through filters, the wastewater flows through wheels containing algae. The algae feed on nutrients in the water while using energy from the sun. After passing through more filters and a disinfection system, the treated wastewater exits the plant. The plant is able to process 90,000 gallons of wastewater per day [12, 13].

- <u>Stellarwind Bio Energy LLC.</u> Stellarwind opened a small scale production facility and corporate headquarters in Indianapolis in March 2009 [14 - 16].

9.5 Incentives for algae-based energy

Recent federal government actions have re-energized 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. It is mandated that 21 billion gallons out of the 36 billion gallon total required biofuel be from biomass other than corn ethanol in 2022. It is expected that this 21 billion gallon mandate gallon creates an opportuity for algae and other new generation biofuels [2].

- Biomass research funds made available in the 2009 American Recovery and Renewal Act, also known as the 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

- Renewable Electricity Production Tax Credit (PTC) provides a 2.2 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 [17].
- Business Energy Investment Tax Credit (ITC) credits up to 30 percent of expenditures on qualifying renewable energy systems [17].
- 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 [17].
- Qualified Energy Conservation Bonds (QECBs) are qualified tax credit bonds and 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". In February 2009, these funds were expanded to $3.2 billion [17].
- 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 [18].
- High Energy Cost Grant Program administered by the U.S. Department of Agriculture (USDA) is aimed at improving the electricity supply infrastructure in rural areas having home energy costs exceeding 275 percent of the national average. Eligible infrastructure includes renewable resources generation. The USDA has allocated a total of $15.5 million for the 2010 funding cycle. The individual grants range from $75,000 to $5 million [19]

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 [20].
- Indianapolis Power & Light Co. – Rate REP Renewable Energy Production: IPL is offering a "feed-in tariff" to facilities that produce renewable energy. IPL can purchase

renewable energy and contract the production for up to 10 years. Biomass compensation is $6.18/kW per month plus $0.085/kWh [17, 21].

9.6 References

1. National Renewable Energy Laboratory (NREL). A look back at the U.S. Department of Energy's aquatic species program: Biodiesel from algae. 1998. http://www.nrel.gov/biomass/pdfs/24190.pdf.
2. Department of Energy Office of Energy Efficiency and Renewable Energy (EERE). Draft national algal biofuels technology roadmap. June 2009. https://e-center.doe.gov/iips/faopor.nsf/UNID/79E3ABCACC9AC14A852575CA00799D99/$file/AlgalBiofuels_Roadmap_7.pdf
3. NREL. Algae-to-fuel research enjoys resurgence at NREL. April 2009. http://www.nrel.gov/features/20090403_algae.html
4. Arizona Public Service news release, Technology development project fact sheet, FF010: emissions to fuel project, http://www.aps.com/_files/renewable/FF010EmissionstoFuelProject.pdf
5. LaMonica, Martin. CNET News. PetroAlgae still sees green in pond scum. May 2009. http://news.cnet.com/8301-11128_3-10241645-54.html?tag=mncol;title
6. Oilgae. APS to bury CO2, run experimental algae-biofuel plants. April 2009. http://www.oilgae.com/blog/2009/04/aps-to-bury-c02-run-experimental-algae.html
7. Philip Pienkos, NREL. Historical overview of algal biofuel technoeconomic analyses. DOE algal biofuels workshop, December 2008. http://www.orau.gov/algae2008pro/plenary.htm
8. Al Darzins. NREL. Recent and current research and roadmapping activities: overview. DOE algal biofuels workshop, December 2008. www.nrel.gov/docs/fy09osti/45609.pdf.
9. The Lugar Energy Initiative. Profiles of a patriot. http://lugar.senate.gov/energy/links/patriot/18_limcaco.cfm
10. Algaewheel Technologies, LLC. http://www.algaewheel.com/
11. NBC. Algae demonstration project underway in Hopewell. January 2010. http://www.nbc12.com/Global/story.asp?S=11817700
12. WIBC. Heralded BioTown project a shadow of its goal. March 2010. http://www.wibc.com/news/Story.aspx?ID=1211929
13. Algaewheel. Wastewater treatment. 2010. http://www.algaewheel.com/usage/wastewater-treatment/
14. Green.Indy June 8, 2009. http://green.indy.com/posts/indiana-algae-the-next-green-fuel
15. Biodiesel Now March 17, 2009. http://www.biodieselnow.com/forums/t/24281.aspx
16. http://www.stellarwindbioenergy.com/index.htm
17. Database of State Incentives for Renewables and Efficiency (DSIRE). http://www.dsireusa.org/

18. U.S. Department of Agriculture. Value-added producer grants, 2008. http://www.rurdev.usda.gov/rbs/coops/vadg.htm
19. U.S. Department of Agriculture, Rural Development, Electric Programs. http://www.usda.gov/rus/electric/hecgp/overview.htm
20. Indiana Department of Environmental Management. http://www.in.gov/idem/4134.htm
21. Indianapolis Power and Light Company. Renewable Energy Production. http://www.iplpower.com/ipl/index?page=IPLGeneral&Menu=01000000&DocID=020391af33d6012801538fc10057cb

Appendix:
Energy from Woody Biomass

A.1 Introduction

Woody biomass has historically been one of the main sources of renewable energy in the U.S. and in Indiana. In 2008, biomass, mostly woody biomass, supplied over 3 percent of total energy consumed in the U.S. and 1.2 percent of Indiana's total energy consumption. At its peak in the 1980s wood and wood waste supplied as much as 2.5 percent of Indiana's total energy. In more recent years (starting in 2007) corn-based fuel ethanol has overtaken wood as the main source of renewable energy in Indiana. The drivers behind this rapid rise in corn-based ethanol production are discussed in Section 1 of this report. Figure A-1 shows the historical contribution of renewable resources in Indiana's total energy consumption.

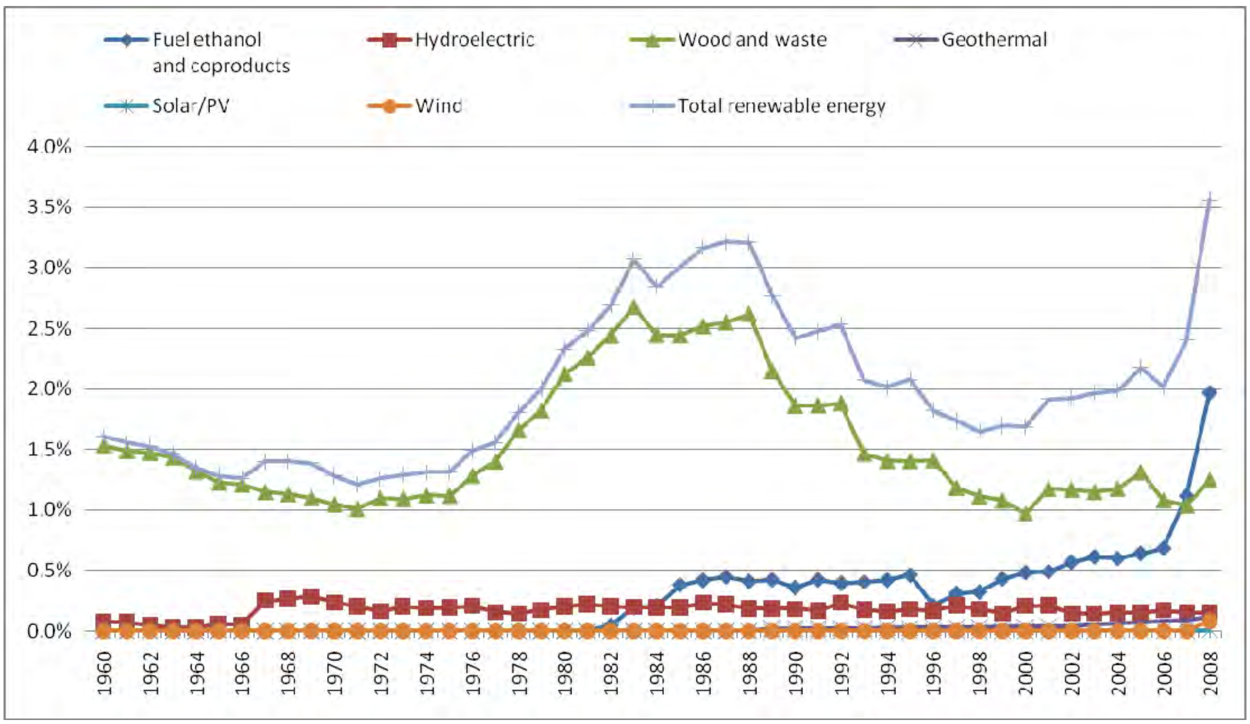


Figure A-1: Renewables share of Indiana total energy consumption (1960 – 2008) (Data source: EIA [1])

A.2 Energy from woody biomass nationally

In 2005 the U.S. Department of Agriculture (USDA) and the U.S. Department of Energy (DOE) issued a joint report from a study done to investigate the viability of using energy from biomass to replace 30 percent of U.S. petroleum consumption by the year 2030. According to this report, *Biomass Feedstock for a Bioenergy and Bioproducts Industry: the Technical Feasibility of a*

Billion-Ton Annual Supply [2], approximately 1.3 billion tons of biomass could be sustainability produced in the U.S. by the mid-21st century. That amount is more than sufficient to meet the 30 percent petroleum replacement target. Of this 1.3 billion tons of biomass available annually, 368 million tons would be from the forest (wood) industry. The sources of forest biomass would include residues generated from traditional logging and other forest and timberland management activities; residues recoverable from forest fire management activities, the current use of wood as heating fuel and for electric generation; wood products industry residues, and a projected growth resulting from increasing demand of wood industry products; and an improvement in the forest biomass equipment enabling recovery of material that is currently inaccessible. Figure A-2 shows the quantities of forest biomass potentially available as feedstock for the bioenergy industry according to the billion-ton biomass vision.

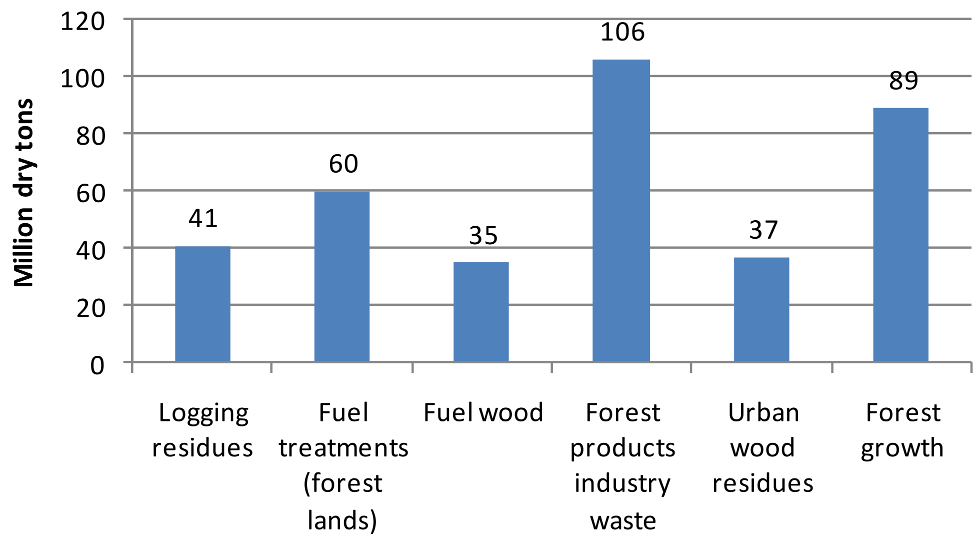


Figure A-2: Estimate of annual sustainably recoverable forest biomass in the U.S. (Data source: USDA, DOE [2])

A.3 Availability of woody biomass in Indiana

According to the Indiana Department of Natural Resources (DNR) [3] there are three main sources of residue woody biomass in Indiana: harvesting residues, standing dead trees and residues from the wood products industry. Further, the wood industry can be divided into primary and secondary wood manufacturing industries. The primary manufacturing industry includes industries such as saw milling, building materials, and paper/pulp industries. This primary wood industry is currently the main source of the woody biomass residue. DNR estimates that 1.3 million green tons of residues are produced annually from the primary wood industry. However, most of this residue is already being used for other purposes, and only about one percent (17,700 tons in 2005) is unused and therefore potentially available for production of more woody biomass-based energy. The current usage includes the 20 percent that is currently being used for energy as shown in Figure A-3. No data on the amount of residue available from secondary mills or from municipal solid waste could be found.

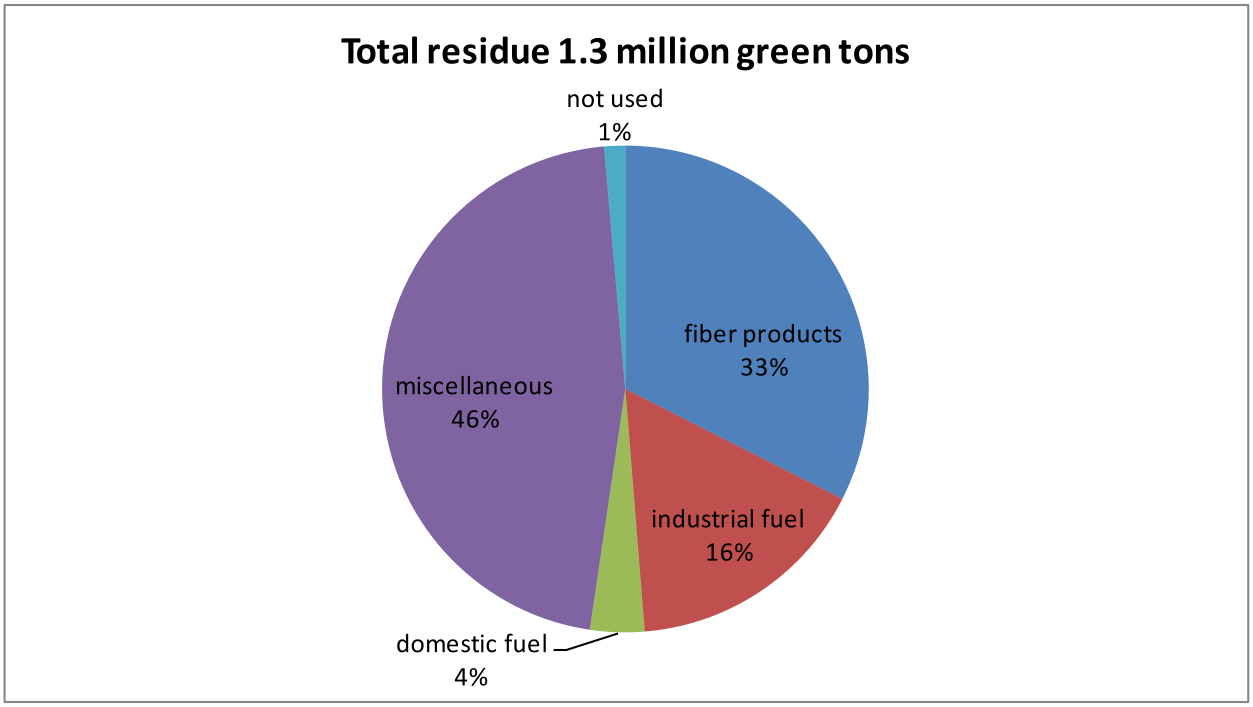


Figure A-3: Uses of primary mill residue in Indiana in 2005 (Data source: DNR [3])

Table A-1 shows the approximate amount of additional energy over and above the amount currently being produced that can be extracted from wood industry residue. The heat values are estimated from the USDA Forest Service fuel value calculator [4], assuming a 20 per cent moisture content for primary mill residue and 0 percent moisture content for construction/demolition residue. If all of Indiana's residue from Table A-1 is burned in a combined heat and power plant operating at 70 percent efficiency, the 132 billion Btu extracted would amount to approximately 0.005 percent of Indiana's 2,900 trillion Btu of total energy consumed in Indiana in 2008. If, on the other hand, the residue was used to generate electricity in an electricity generating plant operating at a heat rate of 16,000 Btu/kWh, the resulting 12 GWh of electricity would amount to 0.011 percent of Indiana's 110,000 GWh annual electricity consumption.

	Unused residue (tons)	Net heating value (Btu/ton)	Net heat available (mmBtu)	Energy from CHP plant* (mmBtu)	Energy from thermal plant* (mmBtu)	Electricity* (MWh)
Primary mill residue	17,700	10,560,000	186,912	130,838	112,147	11,504
Secondary mill residue	NA	NA	NA	NA	NA	NA
Municipal solid waste	NA	NA	NA	NA	NA	NA
Construction & demolition residue	162	13,800,000	2,236	1,565	1,341	138
Total			103,048	72,134	61,829	6,342

*Assumed efficiencies: combined heat and power plant (CHP) 70%; thermal plant 60%; electricity-only generating plant 16,000 Btu/kWh

Table A-1: Energy available from wood industry residue (Data source: DNR [3], USDA [4])

Table A-2 shows the energy potential if logging residues and standing dead trees were used. Logging residues and standing dead trees are currently not harvested for the most part. Therefore they present a potential source of biomass for substantially increasing the current levels of bioenergy production. The 4.8 trillion Btu obtained if all logging residues were passed through a combined heat and power plant (CHP) operating at 70 percent efficiency is approximately 0.2 percent of Indiana's total energy consumption in 2008. The 400 GWh obtained if the logging residue was passed through an electricity generating plant operating at a 16,000 Btu/kWh heat rate would be enough to meet 0.4 percent of Indiana's annual electricity consumption. The standing dead trees have the potential to supply 0.8 percent of Indiana's total annual energy demand or 1.9 percent, or approximately one week's worth, of Indiana's annual electricity consumption.

	Harvesting/logging residue	Standing dead trees
Available residue (cubic feet)		398,000,000
Available (tons)	1,200,000	3,719,626
Net heating value* (Btu/ton)	5,740,000	8,950,000
Total energy available (mmBtu)	6,888,000	33,290,654
Energy from CHP plant (mmBtu)	4,821,600	23,303,458
Energy from thermal plant (mmBtu)	4,132,800	19,974,393
Electricity (Mwh) (~16000 Btu/kWh)	423,939	2,048,956

*Assumed moisture content: Harvesting residue 50%; standing dead trees 30%.

Table A-2: Energy available from forest residue (Data sources DNR: [3], USDA [4])

A.4 Limitations to the access and utilization of woody biomass

As can be seen in Table A-2 if woody biomass is to play a much greater role in the energy mix in Indiana than its current 1 percent, use will have to be made of material that is currently left in forests such as logging residue and standing dead trees. Due to the low value of wood residue currently, there has been no financial incentive to invest in the infrastructure needed to collect and deliver these materials. According to the DNR report on the use of woody biomass for bioenergy, this infrastructure will require substantial capital investments which are currently not economical [3]. This observation is corroborated by other studies, including the USDA/DOE billion-ton vision report referred to in Section A.2 [2]. The USDA/DOE report observed that challenges related to access and transport of the forest biomass would greatly limit the amount of the total forest biomass identified in the billion-ton study that could be economically put to use. Further, a proposed boiler emissions rule revision by the Environmental Protection Agency (EPA) will likely further negatively impact the competitiveness of biomass energy. The proposed rule would reclassify biomass fired boilers in such a manner that they would now be subject to the *Maximum Achievable Control Technology* (MACT) to restrict the emission of mercury, carbon monoxide and other non-mercury metals. The proposal was issued in April 2010 with a public comment period that ended in August [5].

A.5 Carbon neutrality of energy from woody biomass

The discussion about the desirability of harvesting forest biomass as a feedstock for energy production has been brought into focus by the June 2010 publication of the *Biomass Sustainability and Carbon Policy Study* conducted for the Massachusetts Department of Energy Resources by the Manomet Center for Conservation Sciences [6]. The study came to the conclusion that using forest biomass as a substitute for fossil fuels would result in more emissions in the short run than would have been emitted using traditional fossil fuels. This is due to the fact that biomass generally emits more green house gases (GHG) than fossil fuels per unit of energy produced. Table A-3 shows Manomet's estimate of the total GHG emissions per unit of energy produced by biomass and fossil fuels in the three scenarios considered in the study.

Scenario	**Forest Biomass**	**Coal**	**Fuel oil (#6)**	**Fuel oil (#2)**	**Natural gas**
Utility-Scale Electric	**Kilograms/MWh**				
Fuel Production & Transport	7	9			34
Fuel Combustion	399	270			102
Total	406	279			136
Thermal	**Kilograms/mmBtu**				
Fuel Production & Transport	1		6	6	6
Fuel Combustion	35		27	25	17
Total	36		33	31	23
Combined Heat and Power	**Kilograms/mmBtu**				
Fuel Production & Transport	1		6	6	6
Fuel Combustion	35		29	27	18
Total	36		35	33	24

Table A-3: Green house gas emissions in carbon-equivalent kilograms per unit of energy (Source: Manomet [6])

The estimates in Table A-3 include the direct and indirect emissions of carbon and other green house gases in the production, processing and transportation of the feedstock in equivalent kilograms of carbon per unit of energy. For example, burning forest biomass in an electricity-only generating plant releases a total 406 kilograms of carbon-equivalent GHG per Megawatthour (MWh) of electricity produced while coal releases 279 kg/MWh.

Table A-4 shows the excess GHG emissions when biomass is used to replace fossil fuels to produce electricity, heat or in a combined heat and power plant. The excess GHG emissions is expressed as percentage of the emissions from a biomass power plant. For example, forest biomass burned to produce electricity releases 31 percent more GHG than coal when expressed as a percent of total biomass emissions, that is (406-279)÷406).

	Coal	Fuel oil (#6)	Fuel oil (#2)	Natural gas
Electric	31%			66%
Thermal		8%	15%	37%
Combined heat & power		2%	9%	33%

Table A-4: Initial excess green house gas emissions when forest biomass is used to replace fossil fuel (Source: Manomet [6])

As the forest grows to replace the harvested material the excess carbon shown in Tables A-3 and A-4, referred to in the Manomet study as the 'carbon debt', is absorbed and in the long term the re-growth results in a continuing 'carbon dividend'. However the time it takes to pay off the initial carbon debt and hence achieve carbon neutrality relative to burning fossil fuels can be long – as long as 20 years when biomass replaces coal for electricity-only generation and greater than 90 years when forest biomass is used to replace natural gas in electricity-only generating plants. Table A-5 shows the carbon debt payback periods for various energy settings in Massachusetts.

Fossil Fuel Technology	Carbon Debt Payback (years)
Oil (#6), Thermal/CHP	5
Coal, Electric	21
Gas, Thermal	24
Gas, Electric	>90

Table A-5: Length of time to pay back the initial carbon debt (Data source: Manomet [6])

In applying the results from their study, Manomet cautions readers to take into account that the results are very site specific, being affected by such factors as: the characteristics of the fuel system being replaced, the efficiency of converting biomass to energy, the volume of material harvested from the site, the forest ecosystem productivity and such dynamics as forest fires, dead wood production and deadwood decay rates. In addition, the study compares the harvesting of live forest biomass and not the use of residues that are already being removed from forests for current wood industry and forest management purposes. They also point out that the use of woody biomass planted as a dedicated energy crop as discussed in Section 3 of this report would not incur the carbon debt as the harvesting of forest biomass does as long as no plants were cleared to make way for the plantation. The carbon neutrality of the dedicated energy crop forest is enhanced by the fact that the standing trees in the plantation represent stored carbon that would not have been there otherwise.

As can be seen in Table A-3 the excess carbon emissions in biomass relative to fossil fuels occurs in the combustion phase rather the production and transportation phases. The emissions from combustion in the electricity-only generating plants in the Manomet study are 339 kg/MWh for biomass, 270 kg/MWh for coal, and 102 kg/MWh for natural gas. This higher carbon emission level is a reflection of the fact that biomass power plants operate at a much lower efficiency that fossil fuel fired power plants. The efficiencies of the power plants used in the Manomet study were as follows: 48 percent for natural gas fired; 32 percent for coal fired; and 20-25 percent for biomass fired power plants. Inefficiencies in the combustion of biomass are due to such factors as the low energy density per unit mass, higher moisture content and high alkali levels that cause slag and corrosion in the boiler [7].

A.6 Incentives for woody biomass

Federal Incentives

- Renewable Electricity Production Tax Credit (PTC) provides a 2.2 cents/kWh tax credit for wind, geothermal and for trees planted for energy use (closed-loop biomass) and 1.1 cents/kWh for open-loop biomass. Wood waste falls under the open-loop biomass 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 [8, 9].
- Grants for Forest Biomass Utilization: Sections 209, 210, and 944 of the 2005 Energy Policy Act enable grant programs for rural or remote communities. One program is for communities that improve the commercial value of woody biomass for increased efficiency or use, and the other is for small business bioproduct marketing and certification. USDA is authorized to issue grants to improve the commercial value of forest biomass for such uses as electric power and heat. Eligible communities can get up to $500,000 total or up to $20 per ton of green forest biomass for utilization in generating electricity and heat. DOE may issue grants for rural and remote community electrification, with grants up to $20 million per year available for increased efficiency or use of renewable energy sources including woody biomass [8].
- 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 [8, 9].
- High Energy Cost Grant Program administered by the U.S. Department of Agriculture (USDA) is aimed at improving the electricity supply infrastructure in rural areas having home energy costs exceeding 275 percent of the national average. Eligible infrastructure includes renewable resources generation. The USDA has allocated a total of $15.5 million for the 2010 funding cycle. The individual grants range from $75,000 to $5 million [10]

A.7 References

1. U. S. Energy Information Administration (EIA). State Energy Data System (SEDS). http://www.eia.doe.gov/emeu/states/state.html?q_state_a=in&q_state=INDIANA
2. U.S. Department of Energy and U.S. Department of Agriculture (USDA). Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply. http://feedstockreview.ornl.gov/pdf/billion_ton_vision.pdf.
3. Indiana Department of Natural Resources. Woody biomass feedstock: for the bioenergy and bioproducts industries. http://www.in.gov/dnr/forestry/files/fo-WoodyBiomass_final.pdf
4. USDA. TechLine, Updated July 2004. www.fpl.fs.fed.us/documnts/techline/fuel-value-calculator.pdf
5. U.S. Environmental Protection Agency. http://www.epa.gov/ttn/atw/boiler/boilerpg.html
6. Manomet Center for Conservation Sciences. Biomass sustainability and carbon policy study. June 2010. http://www.manomet.org/sites/manomet.org/files/Manomet_Biomass_Report_Full_LoRez.pdf
7. Ileleji, Klein., Purdue Agricultural and Biological Engineering Department. Technologies for generating power from biomass. Presentation at the Indiana Biomass Working Group, March 2010.
8. Rahman, M., Hodges, A. W., Monroe, M., Purdue University, Purdue Extension. https://www.extension.org/pages/Federal_Policies_and_Incentives_Promoting_Woody_Biomass_Production_and_Utilization
9. Database of State Incentives for Renewables and Efficiency (DSIRE). http://www.dsireusa.org/
10. U.S. Department of Agriculture, Rural Development, Electric Programs. http://www.usda.gov/rus/electric/hecgp/overview.htm