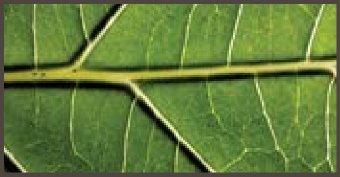
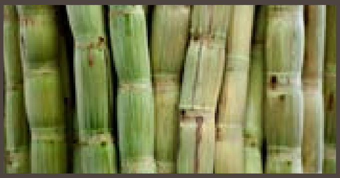
PURDUE UNIVERSITY
Discovery Park
ENERGY CENTER

September 2016

2016 INDIANA RENEWABLE ENERGY RESOURCES STUDY





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

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Acronyms and Abbreviations

AC	Alternating current
ARRA	American recovery and reinvestment act
AMP	American Municipal Power
AWEA	American Wind Energy Association
Btu	British thermal unit
CAFO	concentrated animal feeding operations
CHP	combined heat and power plant
CO_2	Carbon dioxide
CPV	Concentrating photovoltaic
CREB	Clean renewable energy bonds
CSP	Concentrating solar power
DC	Direct current
DOE	U.S. Department of Energy
DSIRE	Database of state incentives for renewables and efficiency
EERE	Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy
EIA	Energy Information Administration, U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ft	Feet
ft^3	Cubic feet
GIS	Geographical information system
GW	Gigawatt
GWh	Gigawatthour
IEA	International Energy Agency
IMPA	Indiana Municipal Power Agency
INL	Idaho National Laboratory, U.S. Department of Energy
IPL	Indianapolis Power and Light Company

IREC	Interstate Renewable Energy Council
ITC	Business energy investment tax credit
IURC	Indiana Utility Regulatory Commission
I&M	Indiana Michigan Power
KDF	Bioenergy Knowledge Discovery Framework, U.S. Department of Energy
kW	Kilowatt
kWh	Kilowatthour
LLC	Limited liability company
LMOP	Landfill Methane Outreach Program, Energy Information Administration, U.S. Department of Energy
m	Meters
m/s	Meters per second
MACRS	Modified accelerated cost-recovery system
MGD	Million gallons per day
MGY	Million gallons per year
mmBtu	Million British thermal unit
mmscfd	Million standard cubic feet per day
MMTCO2e/yr	million metric ton of carbon dioxide-equivalent per
mph	Miles per hour
MSW	Municipal solid waste
MTBE	Methyl tertiary butyl ether – a gasoline oxygenating additive
MW	Megawatt
MWh	Megawatthour
NAABB	National Alliance for Advanced Biofuels and Bioproducts
NIPSCO	Northern Indiana Public Service Company
NO_x	Nitrogen oxide
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
POLYSYS	Policy analysis system
PPA	Power purchase agreements
PTC	Production tax credit
PV	Photovoltaic
QECB	Qualified energy conservation bonds
REAP	Rural Energy for America Program, U.S. Department of Agriculture
RPS	Renewable portfolio standard
SEDS	State Energy Data System, Energy Information Administration, U.S. Department of Energy
SEGS	Solar Electric Generation System
SEIA	Solar Energy Industries Association
SOx	Sulfur oxides
SUFG	State Utility Forecasting Group
USDA	U.S. Department of Agriculture
VEETC	Volumetric ethanol tax credit
W	Watts
W_{DC}	Direct Current Watts
W/m^2	Watts per square meter
WPCP	Water pollution control plant
WVPA	Wabash Valley Power Association
WWTP	wastewater treatment plant

Foreword

This report represents the fourteenth 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 2011, clarifying the topics to be covered in the report.

The report consists of seven 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 six 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, and hydropower. 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 renewable resource.
- References: This section contains references that can be used for a more detailed examination of the particular renewable resource.

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 2016 Indiana Renewable Energy Resources Report presents an overview of the trends in renewable energy penetration in the U.S. and in Indiana.

1.1 Trends in renewable energy consumption in the United States

Figure 1-1 shows the amounts of renewable energy in quadrillion British thermal units (Btu) consumed in the U.S. from 1949 to 2015. Until the early 2000s hydroelectricity and woody biomass were the dominant sources of renewable energy consumed in the U.S. The last fifteen years have seen a rapid increase in biofuels (mainly corn-based ethanol), wind and solar as sources of renewable energy. In 2015 biofuels, wind and solar combined contributed 47 percent of the 9.7 quadrillion Btu of renewable energy consumed in the U.S. The rapid increase in corn-ethanol has been driven by two factors: it serves as a replacement of the oxygenating additive MTBE in gasoline which started being phased out in 2000, and the Federal Renewable Fuel Standard, first authorized in the 2005 Energy Policy Act and then expanded in 2007, which created mandates for the production of biofuels. This rapid increase in corn-ethanol has since slowed and even turned into a decline in 2012 in line with declining U.S. gasoline demand. The rapid increase in wind energy started with the introduction of the Federal Production Tax Credit (PTC) in 1992, and continued with the proliferation of renewable portfolio standards (RPS) in a number of states. The rapid expansion in solar capacity installations is attributed to a combination of state RPSs, financial incentives offered by the federal government as part of the 2008/2009 economic recovery packages and the declining cost of installing photovoltaic systems. These federal incentives include the modification of the 30 percent Investment Tax Credit (ITC) to remove the $2,000 cap and to allow utilities access to the ITC, the provision for investors to take a 30 percent cash grant in lieu of the ITC and PTC, and the provision of extra funds for the U.S. Department of Energy (DOE) loan guarantee program. This cash grant provision and the special DOE loan guarantee program provided under Section 1705 of the Energy Policy Act were retired in 2011. However, the production tax credit and the investment tax credit are still in place having been extended most recently to 2019 by the Consolidated Appropriations Act of 2016.

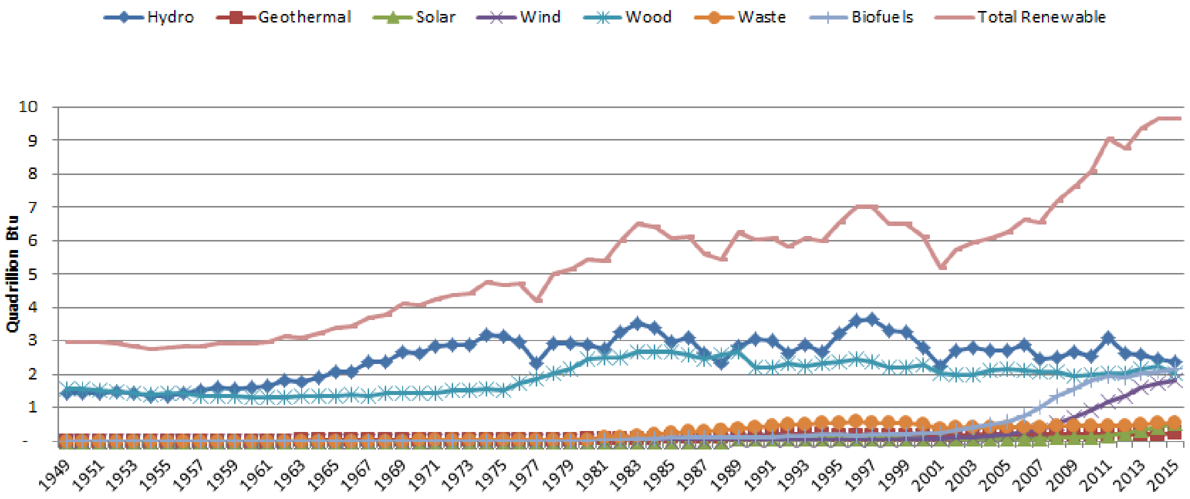

Figure 1-1: Renewable energy consumption in the U.S. (1949-2015) (Data source: EIA [1])

Despite the growth shown in Figure 1-1, renewable energy's share of the total energy consumed in the U.S. remains modest at approximately 10 percent. Fossil fuels supply 81 percent of the energy consumed, while nuclear energy supplies the remainder. Figure 1-2 shows the sources of total energy consumed in the U.S. from 1949 to 2015.

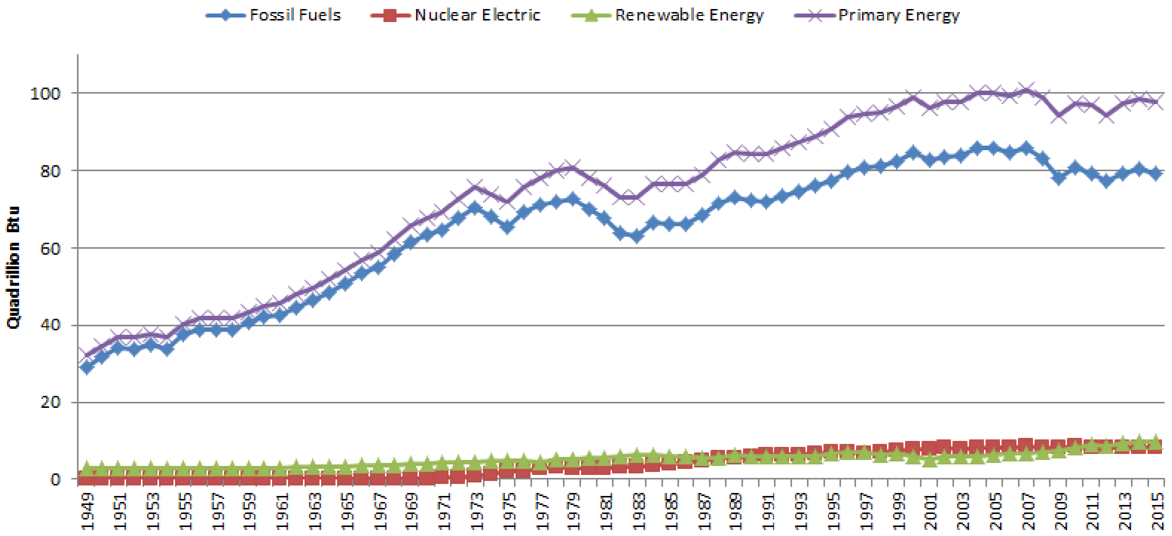

Figure 1-2: U.S. energy consumption by source (1949-2015) (Data source: EIA [2])

Figure 1-3 shows the contribution of the various energy sources to total energy consumed in the U.S. in 2015. Petroleum continued to be the dominant energy source supplying 36 percent, followed by natural gas at 29 percent and coal at 16 percent. Among the renewable resources, biomass (including wood, biofuels, municipal solid waste, landfill gas and others) comprised 49 percent of the total renewable energy, followed by hydroelectricity at 25 percent. Wind power's contribution rose to 19 percent from 18 percent in 2014, solar rose from 4 to 6 percent and geothermal remained at 2 percent.

When one considers renewable resources in electricity generation (Figure 1-4), hydroelectricity and wind played dominant roles in 2015 together contributing 81 percent of the total renewable electricity generated (46 percent from hydro and 35 percent from wind). Woody biomass contributed 8 percent, waste biomass 4 percent, solar 5 percent and geothermal 3 percent. As expected, pumped hydroelectricity's net energy contribution was negative.[1]

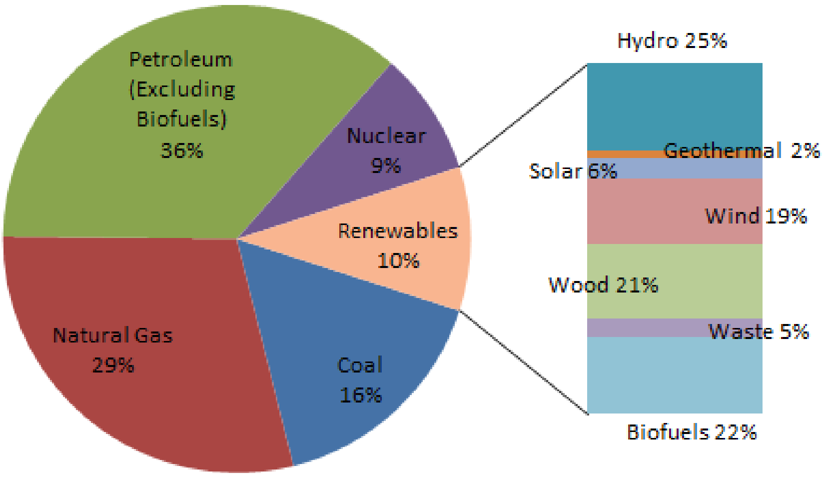

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Figure 1-3: U.S. total energy consumption by energy source in 2015 (Data source: EIA [1, 3])

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[1] Pumped hydroelectric facilities use electricity from the grid during periods of low demand and price to pump water from a lower reservoir to a higher one. That water is then available to generate electricity during high demand and price periods. Due to evaporation and inefficiencies in the pumping and generating processes, less energy is generated than is used. However, the value of the lost energy is more than compensated because low cost, off-peak electricity is converted to high cost, on-peak electricity.

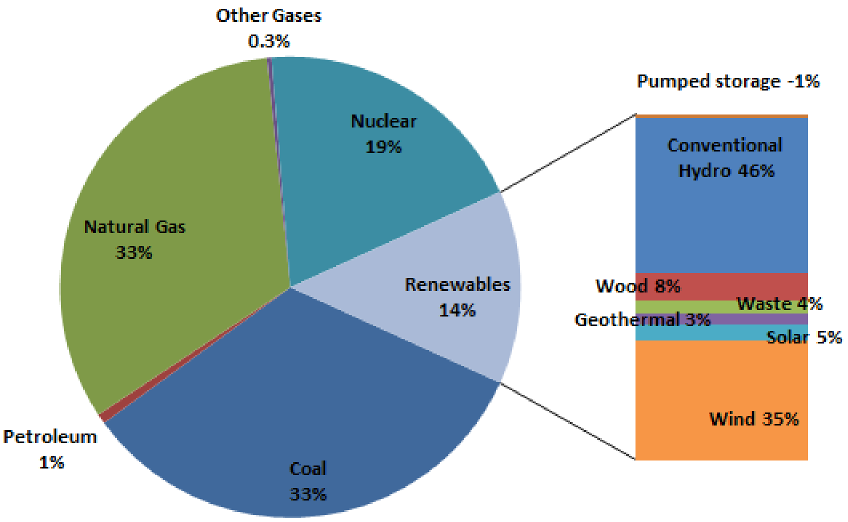

Figure 1-4: Net U.S. electricity generation by energy source in 2015 (Data source: EIA [4])

1.2 Trends in renewable energy consumption in Indiana

Figure 1-5 shows renewable energy consumption in Indiana from 1960 to 2013. 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, until the recent expansions in ethanol and wind increased renewable resources to over 5 percent. Before the entry of ethanol and wind in the 2000s, woody biomass had been the main source of renewable energy in Indiana, comprising over 80 percent of the total renewable energy. This has since changed with biofuels becoming the dominant source of renewable energy, supplying half of the renewable energy consumed in Indiana in 2013. Wind and woody biomass each supplied approximately 22 percent.

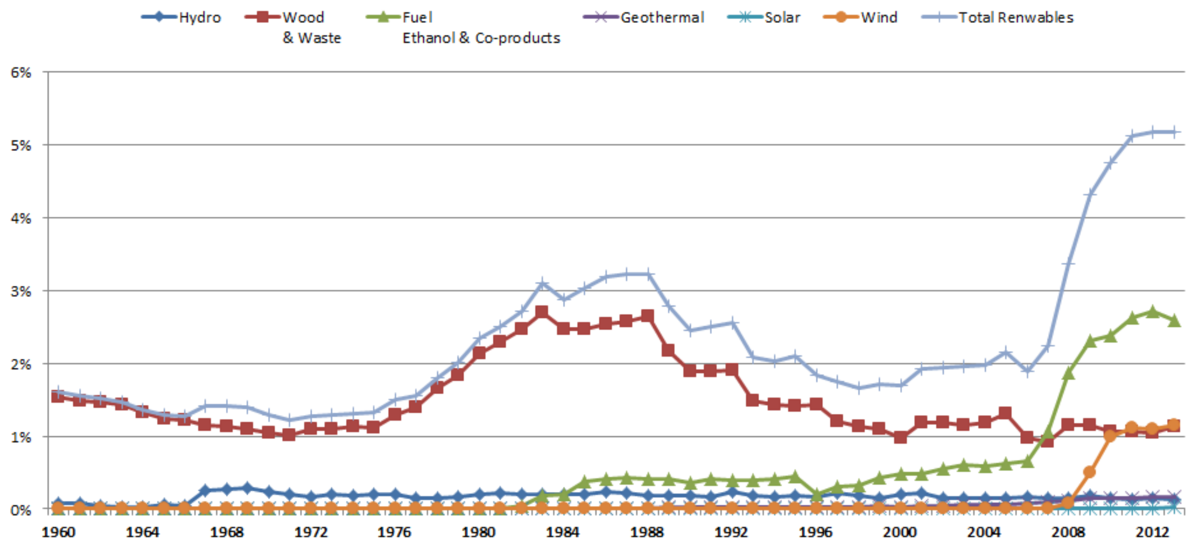

Figure 1-5: Renewables share of Indiana total energy consumption (1960-2013) (Data source: EIA [5])

Figure 1-6 shows the contribution of renewable energy to Indiana's electricity generation from 1990 to 2014. The arrival of utility-scale wind energy projects in 2008 caused a rapid increase in renewable energy's share of Indiana's electricity generation. The renewables share of annual electricity generation rose from 0.5 percent in 2007 to 3.8 percent in 2014 most of which (80 percent) was from wind. The share of hydroelectricity, which until 2007 was the primary source of renewable electricity, dropped to 0.3 percent of Indiana's 2014 generation. Solar photovoltaic generation has grown from virtually none in 2011 to 102 GWh in 2014 which was approximately 0.1 percent of Indiana's total generation.

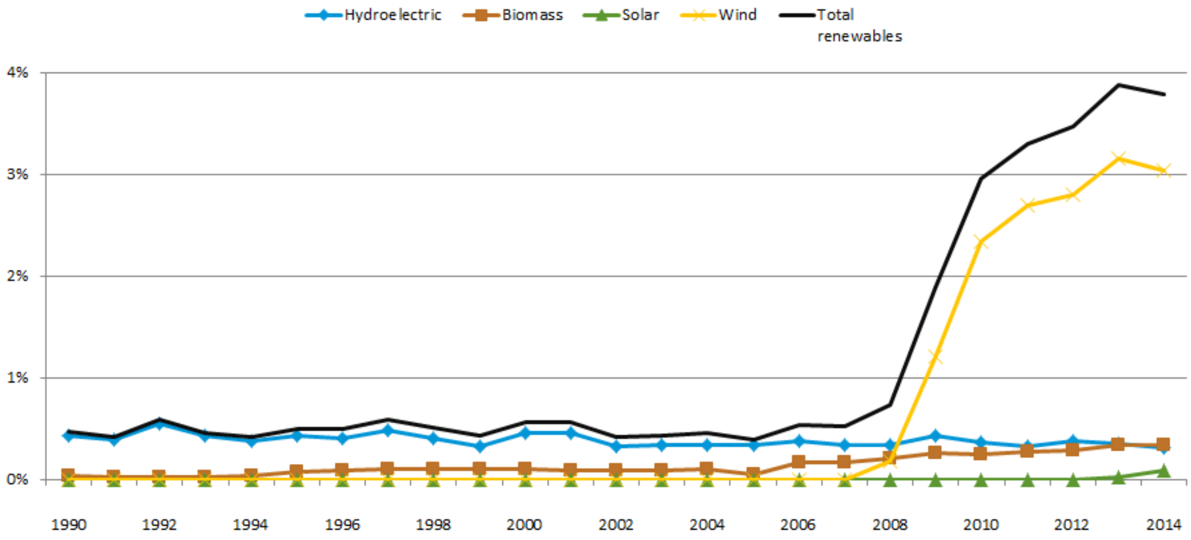

Figure 1-6: Renewables share of Indiana electricity generation (1990-2014) (Data source: EIA [6])

As can be seen in Figure 1-7 there was a rapid growth in installed wind capacity in Indiana in the three years 2008 to 2010 when nine utility scale wind farms and three community wind projects[2] with a combined capacity of 1,347 MW were commissioned. Although that rapid pace of expansion has slowed down considerably, wind energy capacity in Indiana has continued to grow with three wind farms with a combined capacity of 550 MW and community projects with a combined capacity of 7.8 MW having been installed in the last 5 years. The latest wind farm in Indiana is the 150 MW Amazon wind farm in Benton County commissioned in December 2015. Indiana utilities have a total 1,112 MW contracted through power purchase agreements, with 697 MW from wind farms in Indiana and 415 MW from out of state wind farms.

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[2] Community wind projects are single wind turbine projects installed as a community effort to supplement a community's electricity supply. They are typically installed in school s or other such community facilities.

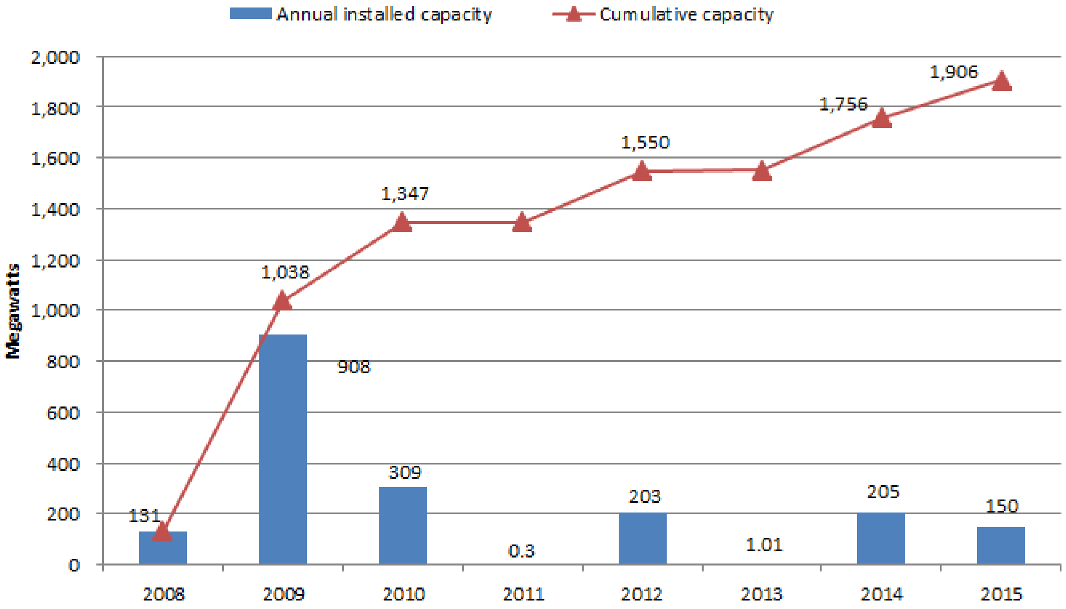

Figure 1-7: Wind energy installed capacity in Indiana (Data sources: IURC, DOE [7-10]).

Another renewable resource, solar photovoltaic, has been experiencing very rapid growth with the installed capacity increasing from virtually none in 2008 to over 135 MW at the time this report was written. Eighty-four percent of that capacity (113 MW) was commissioned in 2013 and 2014. Figure 1-8 shows the annual and cumulative PV capacity installations in Indiana as reported to the National Renewable Energy Laboratory's (NREL) *Open PV Project* database and the Indiana Utility Regulatory Commission (IURC) as of July 2016. Five large projects installed in Marion County account for nearly half of Indiana's installed capacity. They are the 20 MW Indianapolis International Airport solar farm, the 20 MW Indy Solar I and II solar farm located in Franklin township, the 9 MW project at the Indianapolis Motor Speedway, the 8.6 MW Solar Indy III project in Decatur township, and the 8 MW Maywood Solar farm in Indianapolis. Table 1-1 lists PV installations in Indiana with a capacity greater than 1 MW.

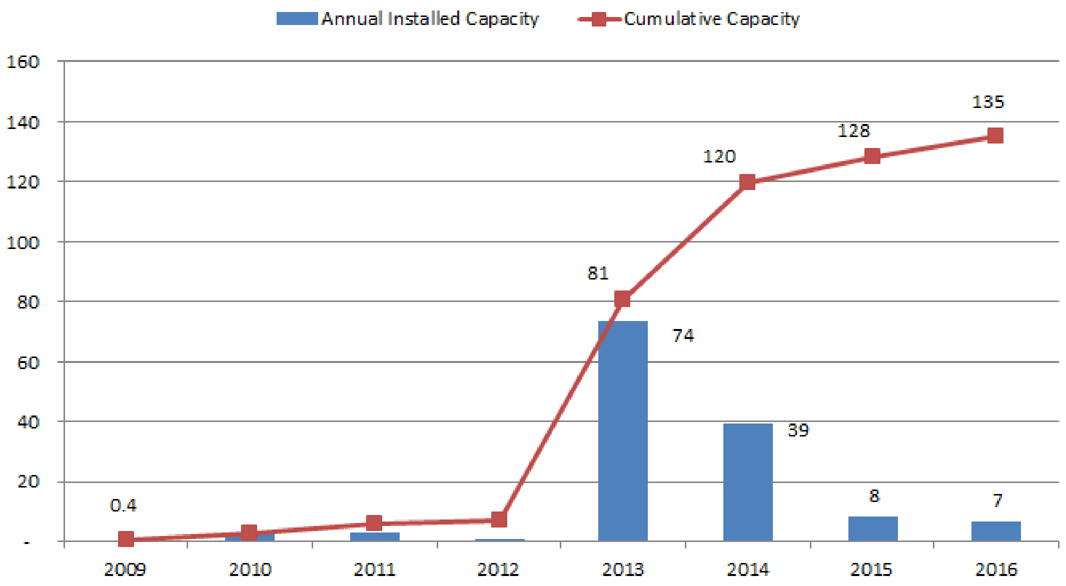

Figure 1-8: Indiana installed PV capacity (Data source IURC [7], NREL [11])

Project	**Location (County)**	**Capacity (MW_{AC})**
Indianapolis Airport (I, IIA, IIB)	Marion	20.02
Indy Solar 1&II (Franklin Township)	Marion	20.00
Indianapolis Motor Speedway	Marion	9.00
Indy Solar No. 3 (Decatur Township)	Marion	8.64
Maywood / Vertellus	Marion	8.00
Lifeline Data Centers	Marion	4.00
CWA Authority	Marion	3.83
Duke Realty #129	Marion	3.40
Duke Realty #98	Marion	3.40
Crawfordsville Solar Park	Montgomery	3.00
Frankton Solar Park	Madison	3.00
Peru Solar Park	Miami	3.00
Rexnord Industries	Marion	2.80
Equity Industrial	Marion	2.73
Grocers Supply Company	Marion	2.73
Duke Realty #87	Marion	2.72
Lake County Solar, LLC - East Chicago	Lake	2.00
Lake County Solar, LLC - Griffith	Lake	2.00
Pendleton Solar Park	Madison	2.00
GSA Bean Finance Center	Marion	1.80
Citizens Energy (LNG North)	Marion	1.50
Lincoln Solar, LLC	Cass	1.50
Middlebury Solar, LLC	Elkhart	1.50
Portage Solar, LLC	Porter	1.50
Lanesville Solar	Harrison	1.10
Hobart Solar, LLC	Lake	1.00
New Castle Solar	Henry	1.00
Omnisource	Marion	1.00
Rensselaer Solar Farm	Jasper	1.00
Richmond Solar Farm	Wayne	1.00
Scotland Solar	Greene	1.00
Tell City Solar Park	Perry	1.00
Valparaiso Solar, LLC	Porter	1.00
Waterloo Solar, LLC	Dekalb	1.00

Table 1-1: PV systems in Indiana of capacity 1 MW and above (Data source: IURC [7])

In addition, Indiana utilities have several PV projects under development. The largest of these is a 17 MW project by Duke Energy at the Crane Naval Support Activity Center. Duke has also signed power purchase agreements totaling 20 MW with four PV projects under construction in Clay, Howard, Sullivan and Vigo Counties [12, 13]. Indiana Michigan Power (I&M) has approval from the IURC to build five PV projects with a combined capacity of 15.7 MW in its service territory. The status of the projects is as shown in Table 1-2.

Project	Location	Capacity (MW)	Status
Deer Creek	Marion	2.5	Commissioned Dec 2015
Twin Branch	Mishawaka	2.6	Commissioned Aug 2016
Olive	New Carlisle	5	Under construction
Watervliet	Watervliet (Michigan)	4.6	Under construction
To be determined	To be determined	1	Approved by IURC

Table 1-2 Indiana Michigan Power solar PV projects (Data source: I&M [14-18])

Indiana Municipal Power Agency (IMPA) has plans to add five 10 MW projects in the next five years [19]. Hoosier Energy is in the process of adding ten 1 MW solar arrays across its member service territories. At least three of these projects had been completed at the writing of this report [20, 21].

The factors credited for rapid growth in photovoltaic generation capacity in Indiana include federal, state and utility incentives. Federal incentives include the extension and modification of the 30 percent investment tax credit (ITC) to remove the $2,000 cap for solar and small wind, the provision by the 2009 American Recovery and Reinvestment Act (ARRA) for a 30 percent cash grant in lieu of the ITC and the production tax credit, and the provision in the ARRA for funds for a U.S. Department of Energy loan guarantee program targeted towards renewable energy resources. The favorable conditions at the state level include the expansion of the net metering rule to include all customer classes, renewable generating systems up to 1 MW, and the increase of the cap at which a utility may limit system-wide net metering[3] capacity to one percent of its most recent summer peak [22]. Another major factor has been the feed-in tariffs [4] offered by two of Indiana's utilities Indianapolis Power and Light (IPL) and Northern Indiana Public Service Company (NIPSCO). The IPL feet-in-tariff ended in 2013.

Table 1-3 shows the 12.7 MW of net metering generation in the respective territories of Indiana utilities, while Table 1-4 shows the 124.3 MW contracted to two Indiana utilities under their feed-in tariffs.

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[3] The net metering rule allows customers with eligible renewable resource generating facilities to receive credit for the self-generated electricity at the retail rate. At the end of each billing cycle the customer pays for the net electricity received from the utility. In the Indiana rule excess generation by the customer is credited to the next billing cycle.

[4] A feed-in tariff by a utility offers a long-term contract to buy electricity from a customer-owned renewable resource generating facility at incentive rates that reflect the cost of generating electricity from the renewable technology.

	Wind (kW)	Solar (kW)	Total (kW)
Duke	2,212	3,904	6,116
Indiana Michigan	254	820	1,074
IPL	50	1,402	1,452
NIPSCO	2,100	811	2,911
Vectren	4	1,186	1,190
Total	**4,620**	**8,123**	**12,743**

Table 1-3: Renewable generation contracted under net metering (Data source: IURC [7])

	Wind (kW)	Photovoltaic (kW)	Biomass (kW)	Total (kW)
IPL	0	94,365	0	94,365
NIPSCO	180	15,440	14,348	29,968
Total kW	**180**	**109,805**	**14,348**	**124,333**

Table 1-4: Renewable generation contracted under feed-in tariffs (Data source: IURC [7])

1.3 Cost of renewable resources

One of the main barriers to widespread use of renewable resources for electricity generation is the cost. Figure 1-9 shows the estimated capital costs of utility scale electricity generating technologies provided in the 2016 EIA update of generating plant costs. As can be seen in the figure, only wind energy has a capital cost that is competitive with natural gas fueled generation [23].

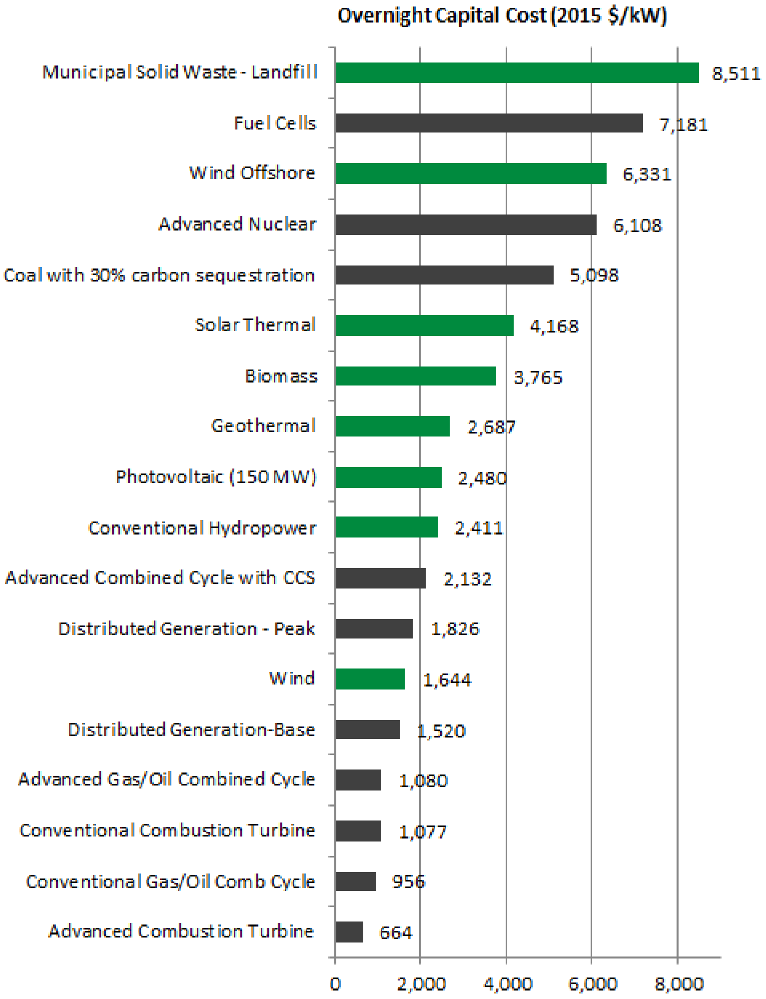
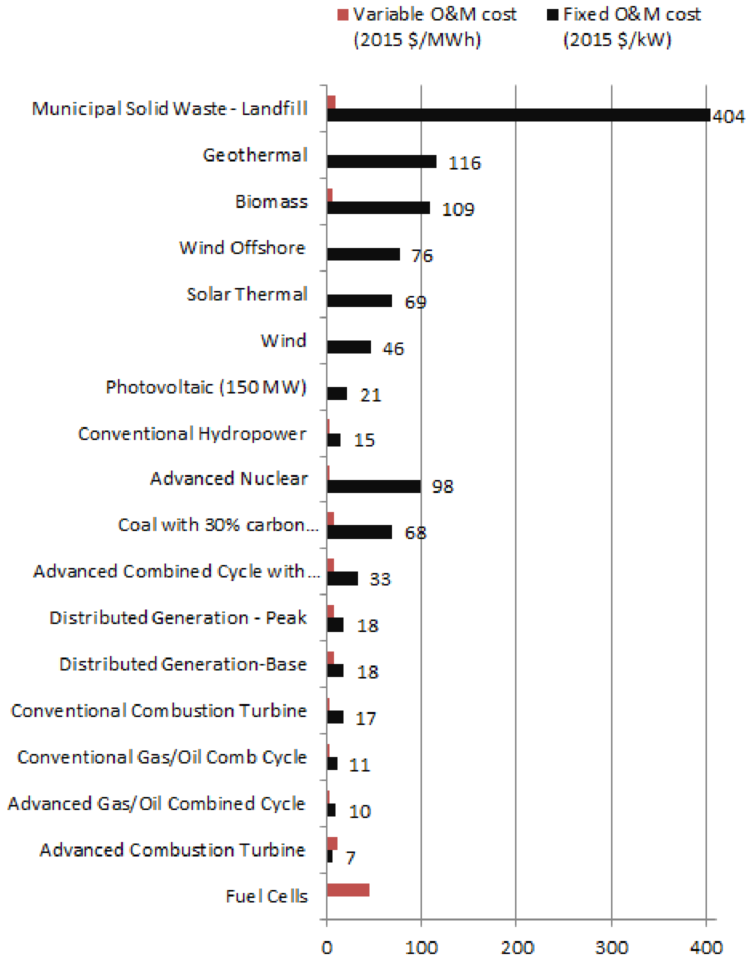


Figure 1-9: Estimated generating technologies capital cost (Data source EIA [23])

Figure 1-10 shows the EIA estimated fixed and variable operating and maintenance (O&M) costs. As can be seen from the figure, renewable resources do not have a clear advantage over conventional generating technologies in terms of fixed O&M costs. But renewables such as solar, wind, hydro and geothermal have the obvious advantage of virtually free fuel (variable O&M).



<u>**Figure 1-10:** Estimated generating technologies fixed and variable O&M cost</u> (Data source EIA [23])

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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.

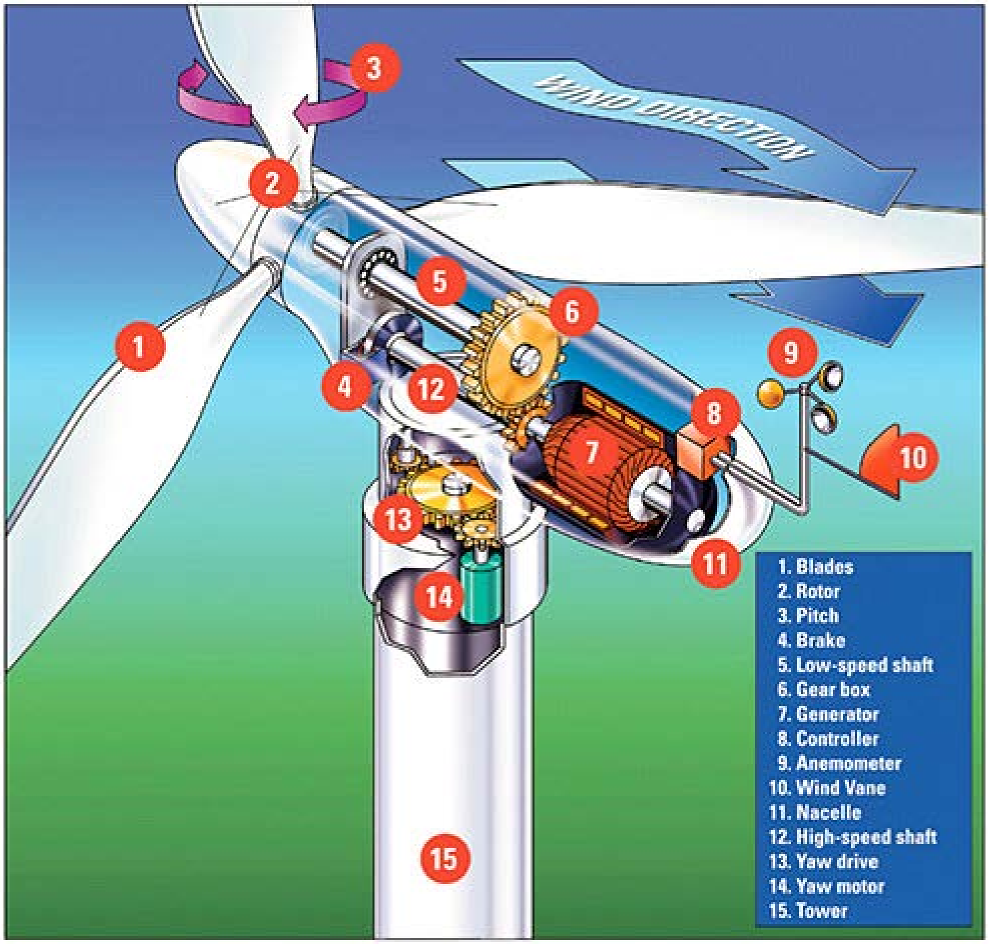

Figure 2-1: Horizontal wind turbine configuration (Source: Alternative Energy News [1])

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. Turbine capacity and wind farm sizes have grown steadily to the point where the 2 megawatt (MW) turbine and wind farms with hundreds of MW of capacity are common [2, 3].

Although wind farms' capacities have grown to be comparable to fossil fueled generators, the total electricity that can be produced from a wind farm annually is typically much less than the electricity that is available from a fossil-fueled power plant with the same maximum capacity. A baseload coal or nuclear power plant in the U.S. may have an annual capacity factor[5] of over 80 percent while typically the capacity factors of wind farms are estimated to range between 20 and 40 percent, depending on the average annual wind speed at their location [4].

Wind speeds are important in determining a turbine's performance. Generally, annual average wind speeds of greater than 7 miles per hour (mph), or 3 meters per second (m/s), are required for small electric wind turbines not connected to the grid, whereas utility-scale wind plants require a minimum wind speed of 11 mph (5 m/s). 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 is used to classify sites into "wind power classes" [5]. Wind power density is measured in watts per square meter (W/m^2) and is calculated from annual observed wind speeds and the density of air. Table 2-1 lists the wind class categories 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	0–100	0- 4.4 (9.8)	0-200	0-5.6 (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 - 1000	7.0 – 9.4 (15.7 – 21.1)	> 800	8.8-11.9 (19.7-26.6)

Table 2-1: Wind resource classification (Data source: NREL [6])

In addition to 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. A major disadvantage of wind is that the amount of energy available from the generator

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

at any given time is dependent on the intensity of the wind resource at the time, which is difficult to predict. This intermittency of intensity reduces the wind generator's value both at the operational level and also at the system capacity planning level where the system planner needs information about how much energy they can depend on from a generator at a future planning date, i.e., when the wind intensity cannot be perfectly predicted. Another disadvantage of wind energy is that good wind sites tend to be located far from main load centers and transmission lines. Concerns have also been raised about the death of birds and bats flying into wind turbines, the possibility of turbines causing radar interference, and potential adverse effects of the shadow flicker[6] on people living in close proximity.

2.2 Economics of wind energy

Figure 2-2 shows capital cost estimates for electricity generating plant modeled by the EIA in the 2016 Annual Energy Outlook. According to these estimates, onshore utility scale wind power plants have the lowest capital cost among the renewable options at $1,644/kW. In addition, onshore wind has a lower capital cost than two of the baseload plants modeled, i.e. nuclear and coal with 30 percent carbon capture and storage. Offshore wind power plants, on the other hand, have an estimated capital cost that is higher than all other generating technologies modeled except municipal solid waste power plants and fuel cells.

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[6] Shadow flicker is the pulse of shadows and reflections that is sometimes cast by the moving turbine blades.

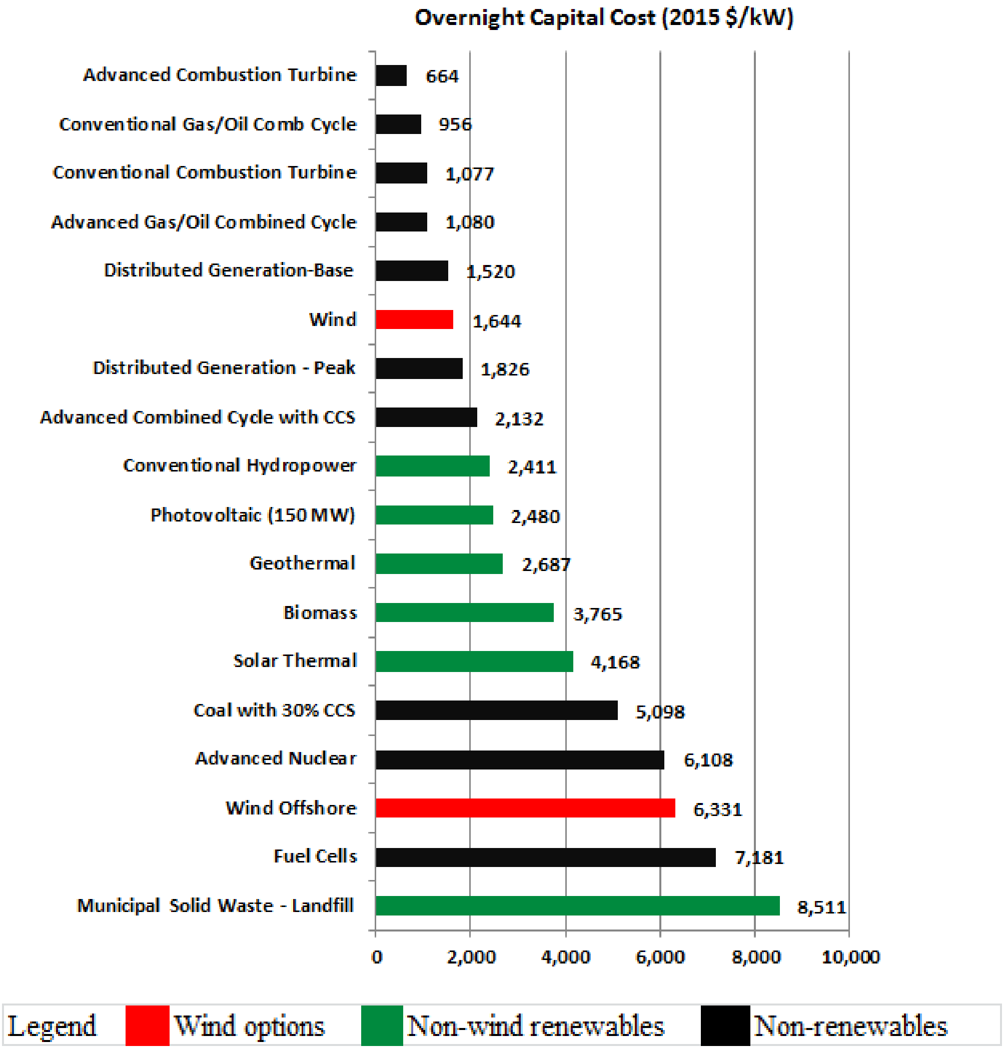


Figure 2-2: Estimated capital costs of various electric generation options (Source: EIA [7])

Figure 2-3 shows the trend in installed wind power plant costs for the projects installed from 1982 to 2015 contained in the 2015 *Wind Technologies Market Report* [8] from Lawrence Berkeley National Laboratory (LBNL). As can be seen in the figure, after a period of increasing project cost between 2005 and 2009, the costs have been declining. The 2015 capacity-weighted average installed project cost of $1,690/kW was 27 percent lower than the peak $2,329/kW reported in 2009. The decline in installed costs of wind energy projects reflects the reduction in turbine prices that has been occurring since 2008.

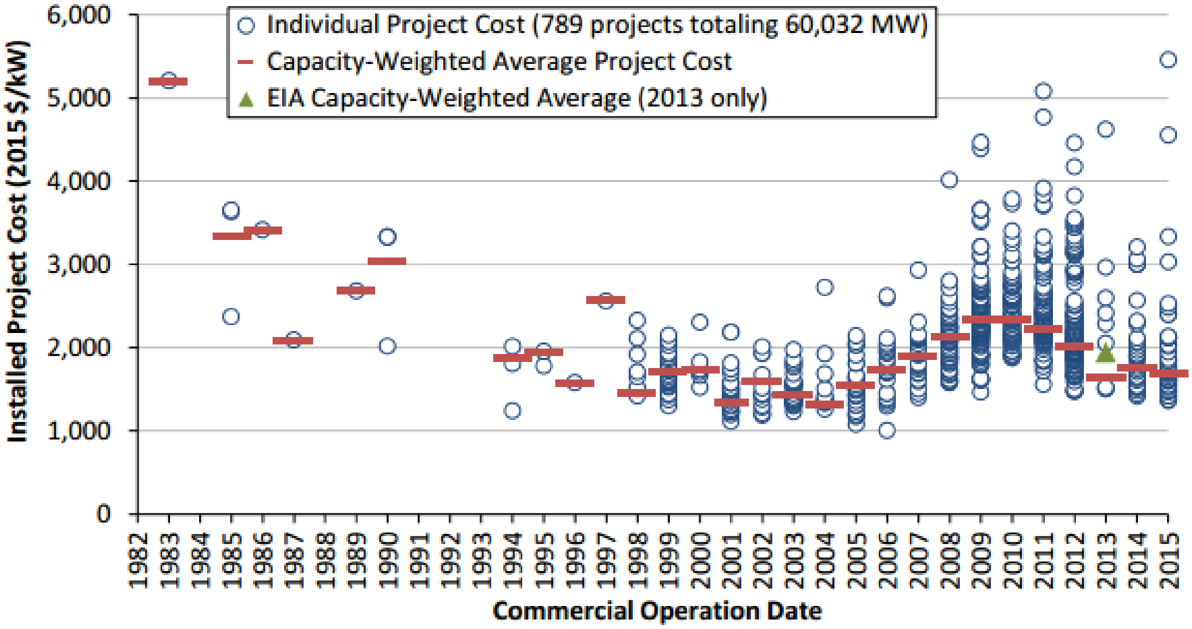


Figure 2-3: Installed wind power project costs over time (Source: LBNL [8])

According to the *2015 Wind Technologies Market Report*, operation and maintenance (O&M) costs are a significant part of the overall cost of wind power plants. Figure 2-4 shows the O&M costs of electricity generating plants according to the EIA June 2016 estimates. EIA estimates the variable O&M to be zero for both onshore and offshore wind farms while the fixed O&M cost is $76/kW for offshore wind and $46/kW for onshore wind farms.

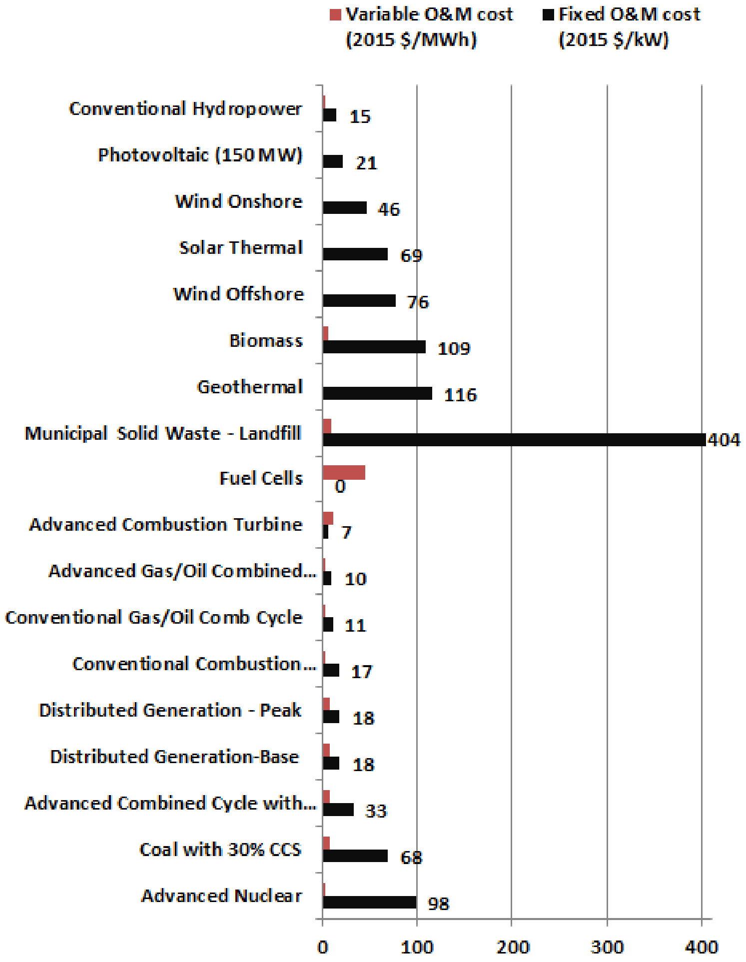


Figure 2-4: Generating technologies O&M cost (Data Source: EIA [7])

Figure 2-5 shows the project-level O&M costs by commercial operation date in the *2015 Wind Technologies Market Report*. It represents the O&M costs in $/MWh for the 154 installed wind power projects totaling 12,080 MW with commercial operation dates between 1982 and 2014 in the LBNL database. Due to data availability issues, each project's O&M costs are shown in terms of its average annual O&M costs between 2000 and 2015, using however many years of available data for that period. The figure suggests that projects installed within the past decade have incurred lower O&M costs on average. Specifically, capacity-weighted average O&M costs for the 24 sampled projects constructed in the 1980s were $35/MWh, which dropped to $24/MWh for the 37 projects installed in the 1990s, to $10/MWh for the 65 projects installed in the 2000s, and to $9/MWh for the 28 projects installed since 2010.

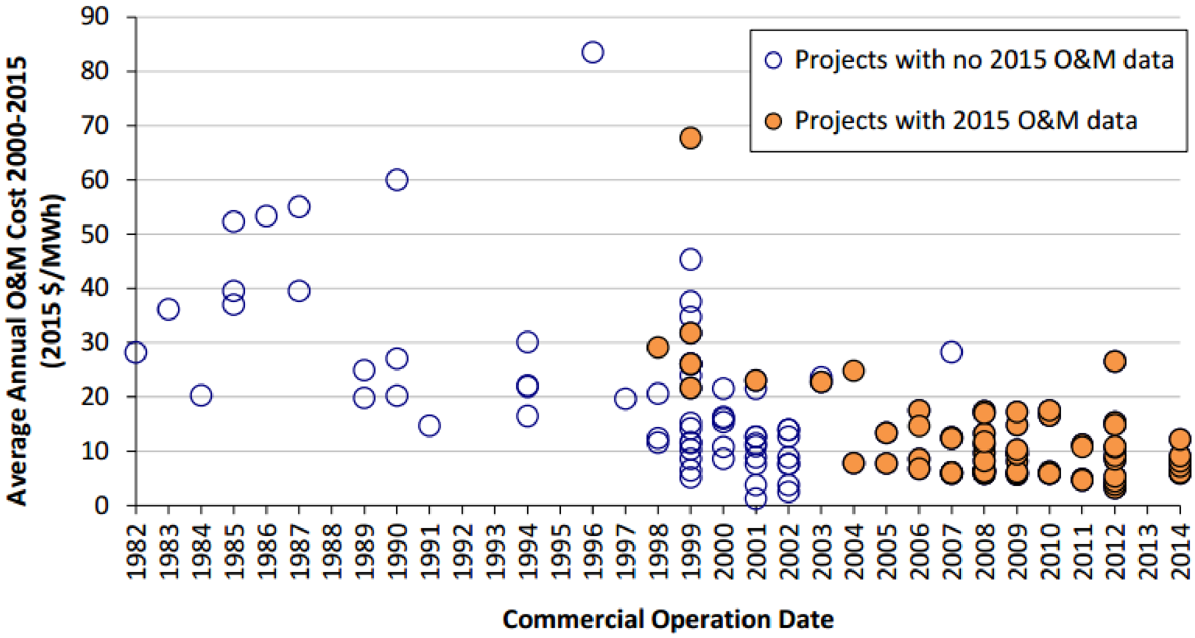


Figure 2-5: Average O&M costs for available data years (Source: LBNL [8])

Figure 2-6 shows the range of average annual wholesale electricity prices for a flat block of power at 23 different pricing nodes located throughout the country and the average generation-weighted price in power purchase agreements (PPA) executed in each year from 2003 to 2015. As can be seen from the figure, average long-term wind PPA prices compared favorably to yearly wholesale power prices until the sharp drop in wholesale prices in 2009 due to lower natural gas prices. In 2009 and 2010, wind power prices were higher than the wholesale electricity prices on a nationwide basis. This condition changed in 2011 and 2012 when the wind power prices fell below the higher end of the wholesale power price range. In 2013 and 2014, declining wind PPA prices, combined with a rise in wholesale power prices, put wind back at the bottom of the range. In 2015 a drop in the wholesale power prices combined with a sharp rise in wind PPA prices have reduced wind's competiveness. Wind project owners are able to take a price lower than the wholesale market price because they have access to the $23/MWh federal production tax credit (PTC).

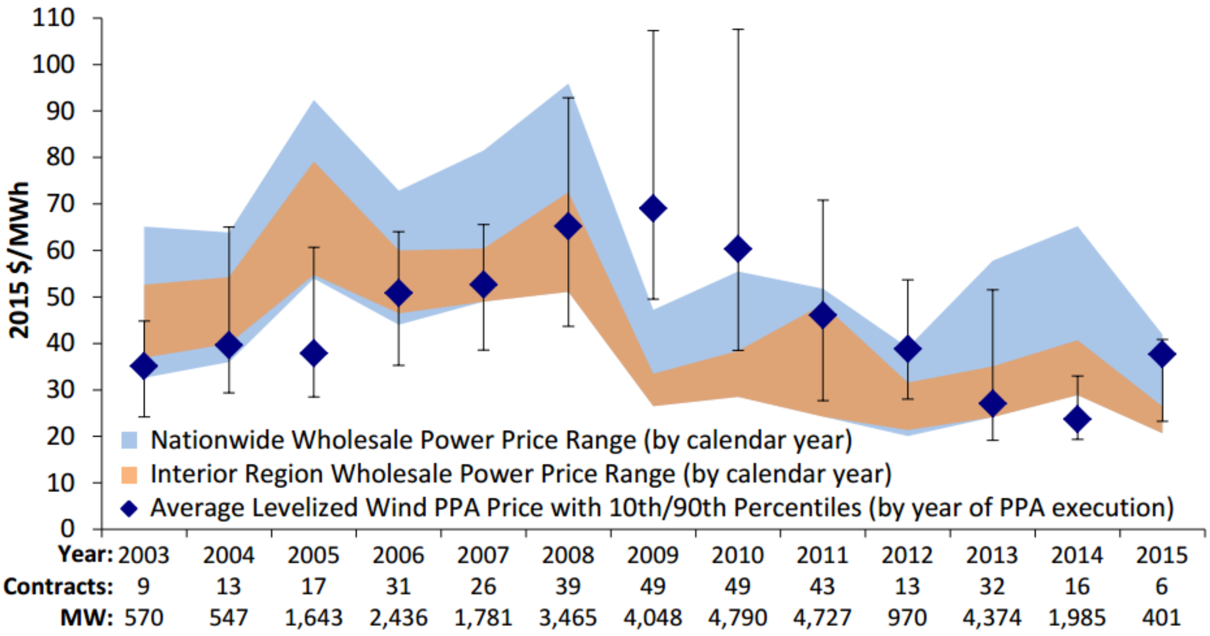


Figure 2-6: Average wind and wholesale electricity prices (Source: LBNL [8])

2.3 State of wind energy nationally

In the wake of the 2008 financial crisis which drastically reduced access to capital, the annual wind capacity additions dropped from 10,000 MW in 2009 to 5,215 MW in 2010. This rate recovered to an annual addition of 6,647 MW in 2011 and a record high of 13,082 MW in 2012. This recovery did not last, with capacity additions of only 1,098 MW in 2013 and 4,767 in 2014. The capacity addition in 2015 rose to 8,115 MW driven mainly by the expected expiry of the federal production tax credit at the end of 2015. The credit has since been extended to 2019 by the Consolidated Appropriations Act of 2016. Figure 2-7 shows the capacity installation from 2001 through the first quarter of 2016. According to the American Wind Energy Association the cumulative installed wind capacity in the U.S. at the end of the first quarter of 2016 was 74,512 MW [9].

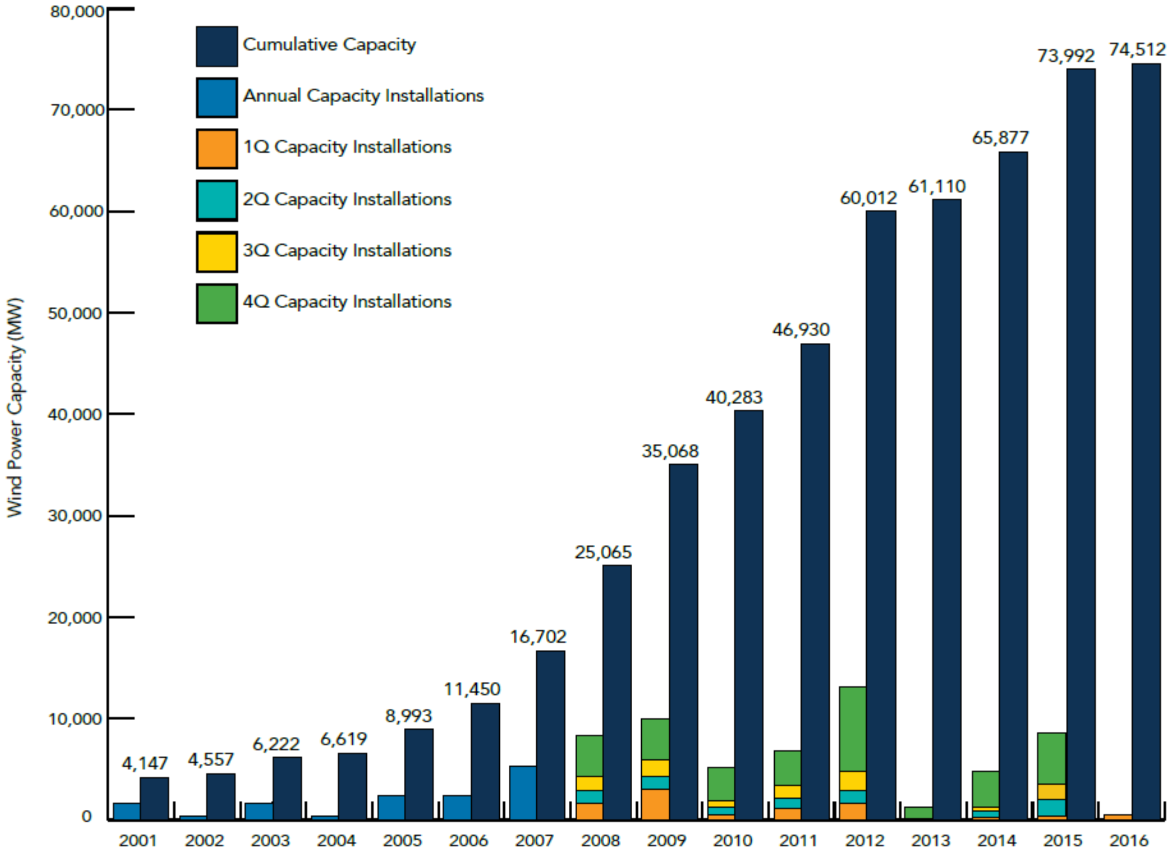


Figure 2-7: U.S. wind capacity growth (Source: AWEA [10])

Federal and state incentives and state renewable portfolio standards continue to play key roles in the growth in the wind industry. The provisions in the 2009 American Recovery and Reinvestment Act to allow investors to convert the federal production tax credit into a treasury cash grant for projects placed into service in 2009 and 2010 was a significant source of capital for the wind industry, offsetting the capital shortage caused by the 2008 financial crisis. The surge in capacity additions in 2012 is attributed to the then expected expiration of the $23/MWh federal renewable electricity production tax credit (PTC). The PTC has subsequently been extended, most recently to December 2019 by the Consolidated Appropriations Act of 2016.

Figure 2-8 is a map showing the states that have enacted some form of renewable portfolio standard or set a non-binding goal. Twenty nine states and Washington DC have binding renewable portfolio standards while eight states, including Indiana, have non-binding renewable portfolio goals.

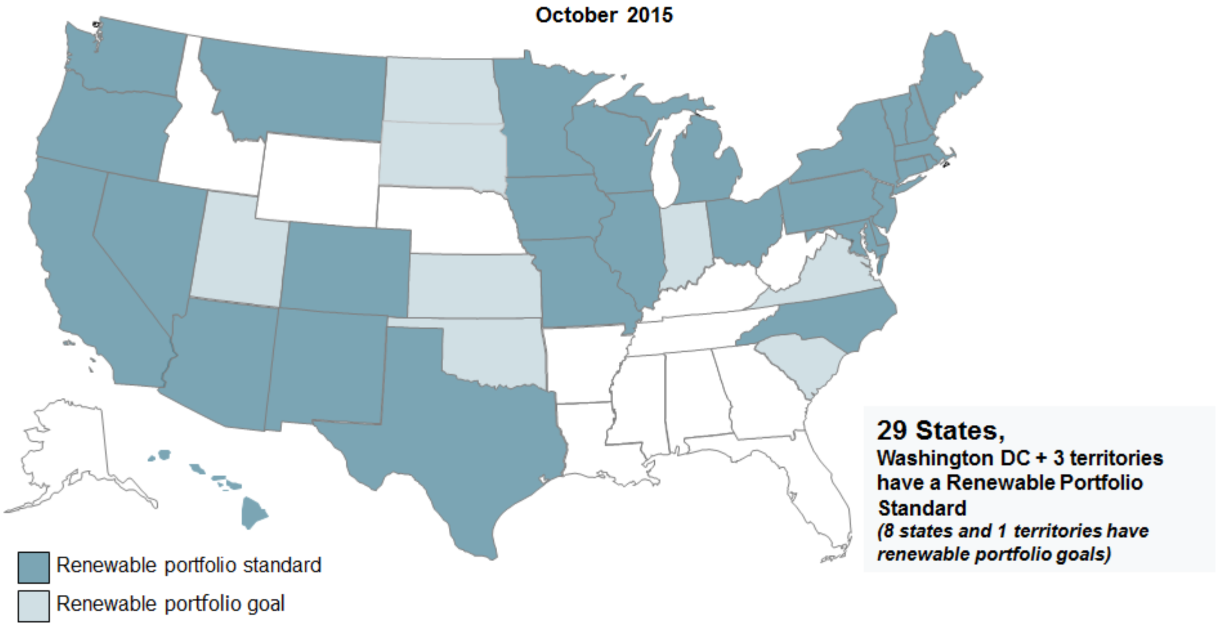
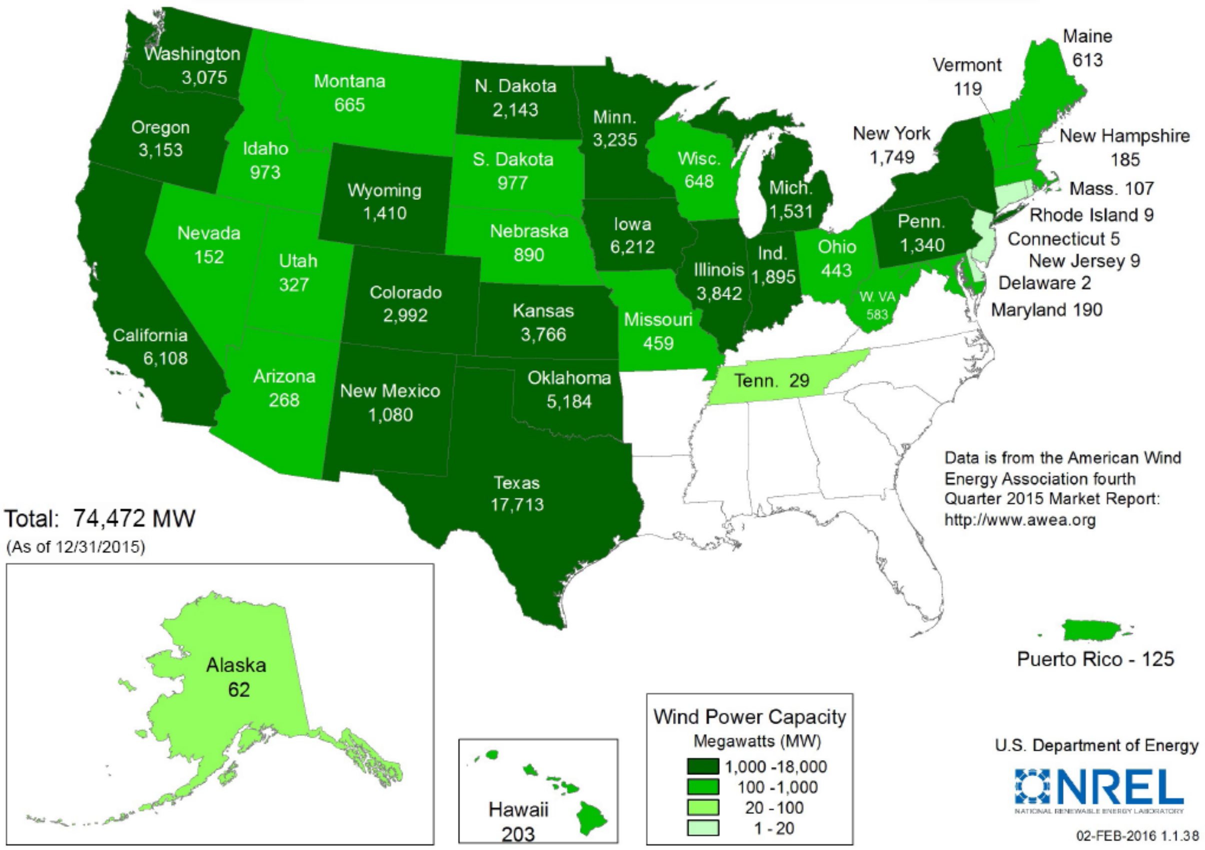


Figure 2-8: Renewable portfolio standards across the U.S. (Source: DSIRE [11])

Figure 2-9 shows the cumulative capacity of utility-scale wind energy installed in states as of the end of 2015. Texas continued to lead with a total capacity of 17,713 MW installed followed by Iowa with 6,212 MW and California with 6,108 MW. Indiana ranked 12th overall with 1,895 MW of utility-scale wind capacity at the end of 2015. In terms of wind capacity added in 2015, Texas again led with 3,615 MW followed by Oklahoma with 1,402 MW. The Amazon Wind Farm in Benton County accounted for the 150 MW capacity added in Indiana in 2014 [12].



Data is from the American Wind Energy Association fourth Quarter 2015 Market Report: http://www.awea.org

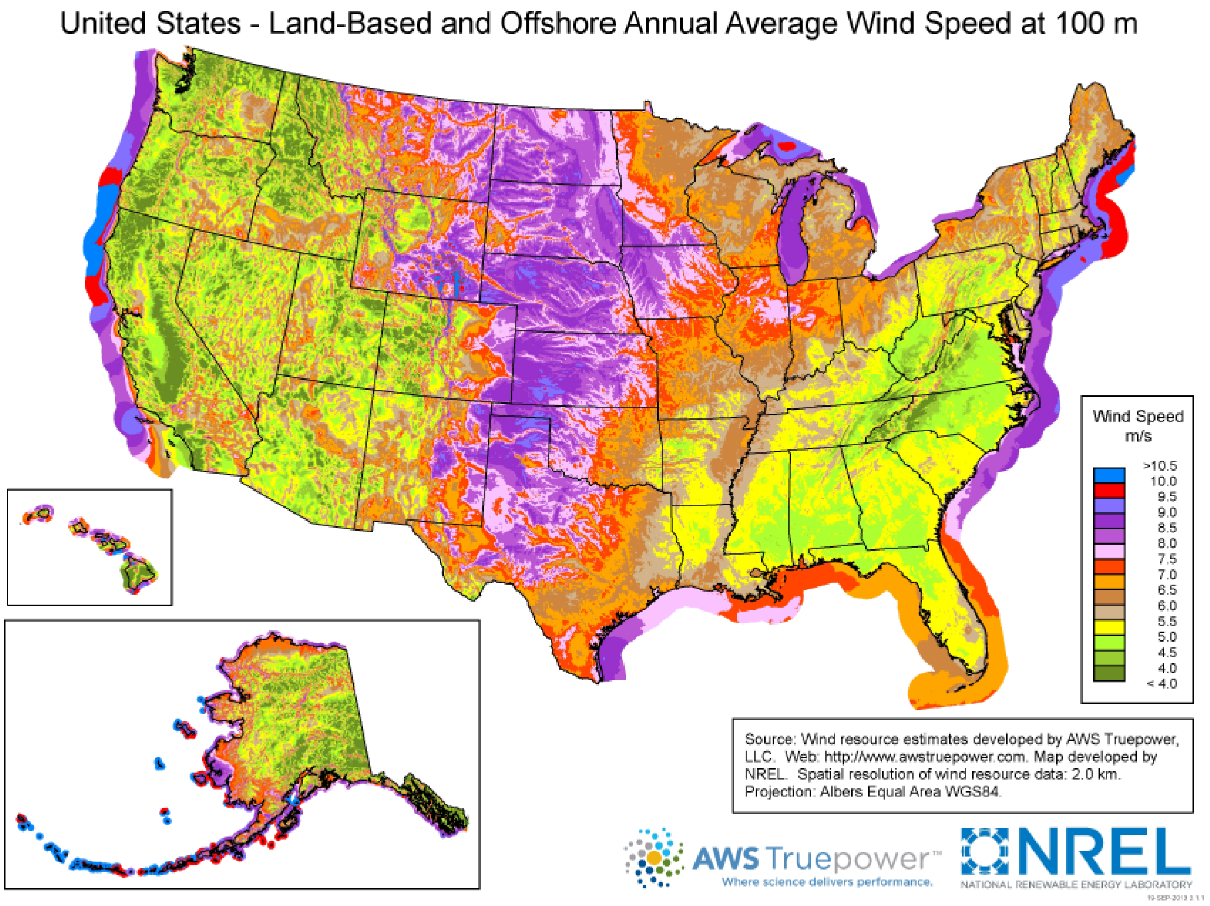
Figure 2-9: Wind power capacity by state at the end of 2015 (MW) (Source: DOE [13])

The leading five states for wind energy penetration in 2015 as a percent of total electricity generated were Iowa – 31.3 percent; South Dakota – 25.5 percent; Kansas – 23.9 percent; Oklahoma – 18.4 percent; North Dakota – 17.7 percent. Table 2-2 shows the top twenty states in capacity added in 2015, total cumulative capacity, and penetration of wind energy in 2015. The U.S. average penetration was 4.7 percent [8].

Installed Capacity (MW)				Percentage of In-State Generation	
Annual (2015)		Cumulative (end of 2015)		Actual (2015)	
Texas	3,615	Texas	17,711	Iowa	31.3%
Oklahoma	1,402	Iowa	6,209	South Dakota	25.5%
Kansas	799	California	5,662	Kansas	23.9%
Iowa	524	Oklahoma	5,184	Oklahoma	18.4%
Colorado	399	Illinois	3,842	North Dakota	17.7%
Illinois	274	Kansas	3,764	Minnesota	17.0%
New Mexico	268	Minnesota	3,235	Idaho	16.2%
North Dakota	258	Oregon	3,153	Vermont	15.4%
Minnesota	200	Washington	3,075	Colorado	14.2%
California	194	Colorado	2,965	Oregon	11.3%
South Dakota	175	North Dakota	2,143	Maine	10.5%
Maine	173	Indiana	1,895	Texas	10.0%
Indiana	150	New York	1,749	Nebraska	8.0%
Nebraska	80	Michigan	1,531	Wyoming	7.7%
Arizona	30	Wyoming	1,410	Montana	6.6%
Maryland	30	Pennsylvania	1,340	Washington	6.5%
New Hampshire	14	New Mexico	1,080	New Mexico	6.3%
Ohio	8	South Dakota	977	California	6.2%
Connecticut	5	Idaho	973	Hawaii	6.1%
New York	1	Nebraska	890	Illinois	5.5%
Rest of U.S.	0	Rest of U.S.	5,203	Rest of U.S.	1.0%
TOTAL U.S.	8,598	TOTAL U.S.	73,992	TOTAL U.S.	4.7%

Table 2-2: U.S. wind power rankings: the top 20 states (Source: LBNL [8])

The U.S. has significant wind energy potential. NREL estimates the potential rated capacity that could be installed on available windy land areas across the U.S. is approximately 11 million MW, and the annual wind energy that could be generated from these potential installed capacities is approximately 39 million gigawatt hours (GWh). This is more than nine times the electricity generated from all sources in the U.S. in 2014 [14, 15]. Figure 2-10 shows the distribution of the wind resource.



Source: Wind resource estimates developed by AWS Truepower, LLC. Web: http://www.awstruepower.com. Map developed by NREL. Spatial resolution of wind resource data: 2.0 km. Projection: Albers Equal Area WGS84.

Figure 2-10: 80-meter U.S. wind resource map (Source: NREL [16])

As can be seen in Figure 2-10 there is an abundance of wind energy resources along the U.S. coast lines and in the Great Lakes. Offshore winds tend to be of higher speed and steadier relative to onshore wind. The first offshore wind farm, the 30 MW Block Island Wind farm off of the coast of Rhode Island, is expected to be completed in the fall of 2016 [17, 18]. The proposed 1,500 MW Cape Wind project in Cape Cod, Massachusetts whose construction was planned to start in the Fall of 2014 suffered a major setback in January 2015 when its two utility customers, National Grid and Northeast Utilities, terminated the power purchase agreements to buy 77.5% of the projects output [19, 20].

In addition to resistance from local communities as demonstrated by the Cape Wind project, other factors hindering the development of offshore wind energy include its relatively higher cost and the technical challenges associated with installing wind turbines in a marine environment and connecting the generators to the onshore power grid.

The federal government, in a combined effort between DOE and the U.S. Department of the Interior, is trying to lower these barriers and expedite the deployment of substantial offshore wind generation.

This effort is explained in the 2016 update of the national offshore wind strategy report titled *National Offshore Wind Strategy: Facilitating the Development of the Offshore Wind Energy Industry in the United States* released in September 2016 [21].

2.4 Wind energy in Indiana

Like a number of other states, Indiana experienced rapid growth of wind generation capacity in 2008 and 2009. The 908 MW annual capacity additions in 2009 fell to 302 MW in 2010 and virtually no capacity additions in 2011 outside small, stand-alone community wind turbines. Figure 2-11 shows the annual and cumulative capacity additions in Indiana. The 150 MW capacity added in 2015 reflects the completion of the Amazon wind farm in Benton County.

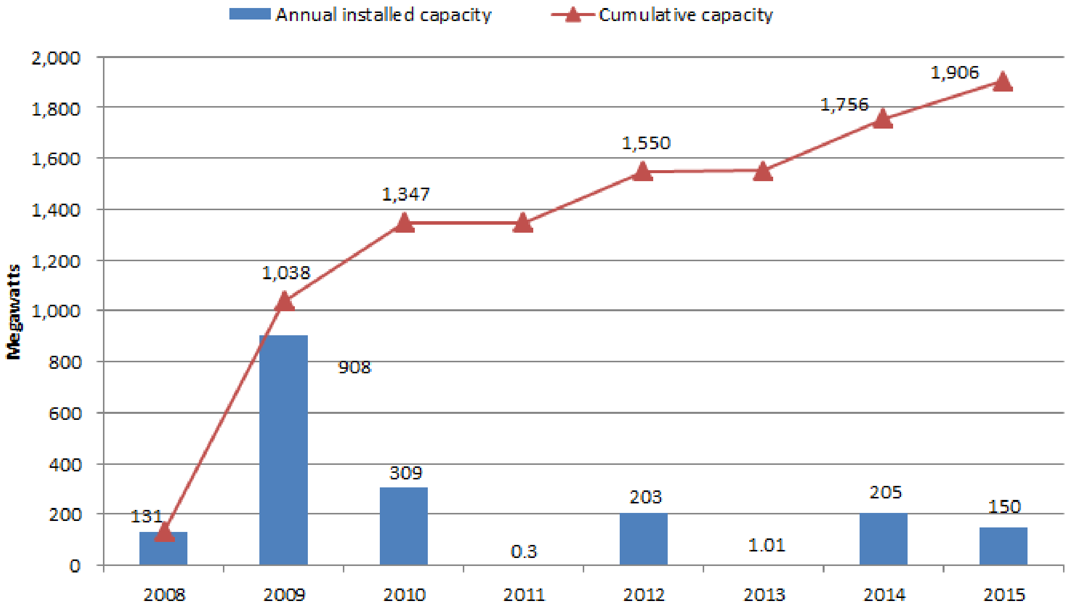


Figure 2-11: Annual wind energy capacity installation in Indiana (Data source: IURC, DOE [22 – 25])

Table 2-3 shows a list of the twelve utility scale wind farms in Indiana with a combined capacity of 1,894 MW. One 100 MW wind farm is under construction while the construction of two proposed wind farms with a combined 317 MW capacity has not yet started.

Project Name	County	Capacity (MW)	Date Completed
Benton County Wind Farm	Benton	130.5	2008
Fowler Ridge I Wind Farm	Benton	301.3	2009
Fowler Ridge II-A Wind Farm	Benton	199.5	2009
Fowler Ridge III Wind Farm	Benton	99	2009
Hoosier Wind Farm	Benton	106	2009
Meadow Lake Wind Farm I	White	199.7	2009
Meadow Lake Wind Farm II	White	99	2010
Meadow Lake Wind Farm III	White	110.4	2010
Meadow Lake Wind Farm IV	White	98.7	2010
Wildcat Wind Farm I	Madison/Tipton	200	2012
Headwaters Wind Farm	Randolph	200	2014
Amazon Wind Farm (Fowler Ridge IV)	Benton	150	2015

Project under construction

Meadow Lake Wind Farm V	White	100.8

Proposed projects

Bluff Point	Jay/Randolph	119
Spartan Wind Farm	Newton	197.8

Table 2-3: Utility Scale Wind Farms in Indiana (Data source: IURC [25])

In addition to the utility scale wind farms, community wind projects have been gaining popularity, especially with schools. Table 2-4 is a list of the community wind projects with a combined capacity of 7.8 MW of which SUFG was aware at the writing of this report.

Project Name	County	Capacity (kW)	Developer	Date Completed
Goshen College	Elkhart	10	Goshen College	2005
Randolph Eastern School Corporation	Randolph	1,000	Performance Services	2009
Union City	Randolph	1,000	Performance Services	2009
Tippecanoe Valley Schools	Kosciusko	900	Performance Services	2010
Lafayette City Bus	Tippecanoe	300	Cascade Renewable	2011
North Newton School Corporation	Newton	900	Performance Services	2012
West Central School Corporation	Pulaski	900	Performance Services	2012
Northwestern School Corporation	Howard	900	Performance Services	2012
Taylor University	Grant	100	ECI Wind and Solar	2013
Shenandoah School Corporation	Henry	900	Performance Services	2013
City of Winchester	Randolph	850	Performance Services	2014

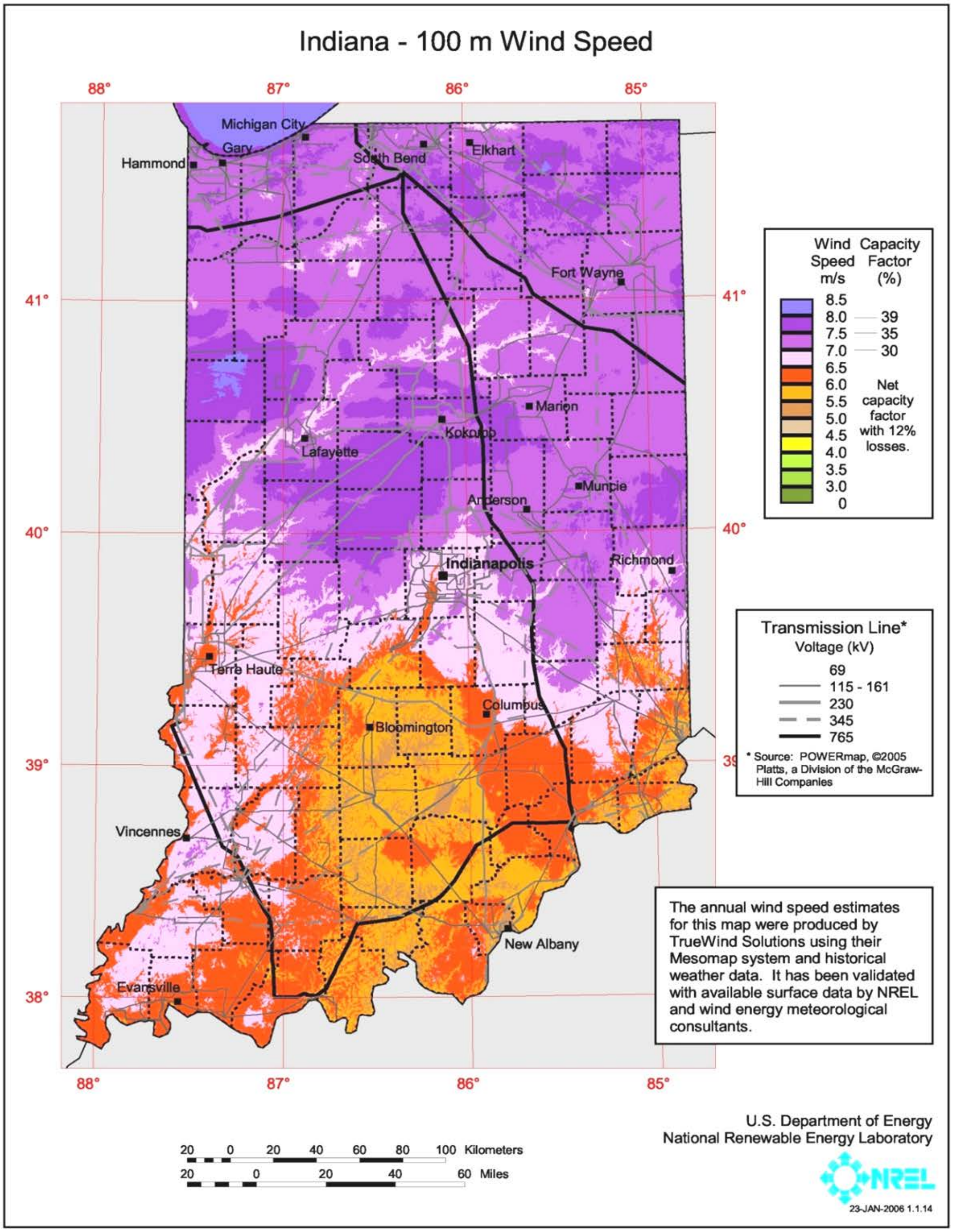
Table 2-4: Community wind projects in Indiana (Data source: [22 – 24])

Indiana utilities have a total 1,111.5 MW of wind power contracted on power purchase agreements, 697.1 MW from wind farms in Indiana and 414.4 MW from out of state wind farms. Table 2-5 shows the wind power capacity contracted to Indiana utilities.

Utility	Project	State	Power Purchase Agreement (MW)
Duke Energy	Benton County Wind Farm	Indiana	100.7
Vectren	Benton County Wind Farm	Indiana	30
Indiana Michigan Power (I&M)	Fowler Ridge I Wind Farm	Indiana	100.4
I&M	Fowler Ridge II Wind Farm	Indiana	50
I&M	Wildcat I Wind Farm	Indiana	100
I&M	Headwaters Wind Farm	Indiana	200
IPL	Hoosier Wind	Indiana	106
IPL	Lakefield Wind	Minnesota	201
NIPSCO	Buffalo Ridge	South Dakota	50.4
NIPSCO	Barton Wind Farm	Iowa	50
Hoosier Energy	Story County	Iowa	25
Wabash Valley Power Association (WVPA)	Various sources	Various	25
Indiana Municipal Power Agency (IMPA)	Crystal Lake Wind, Hancock County	Iowa	50

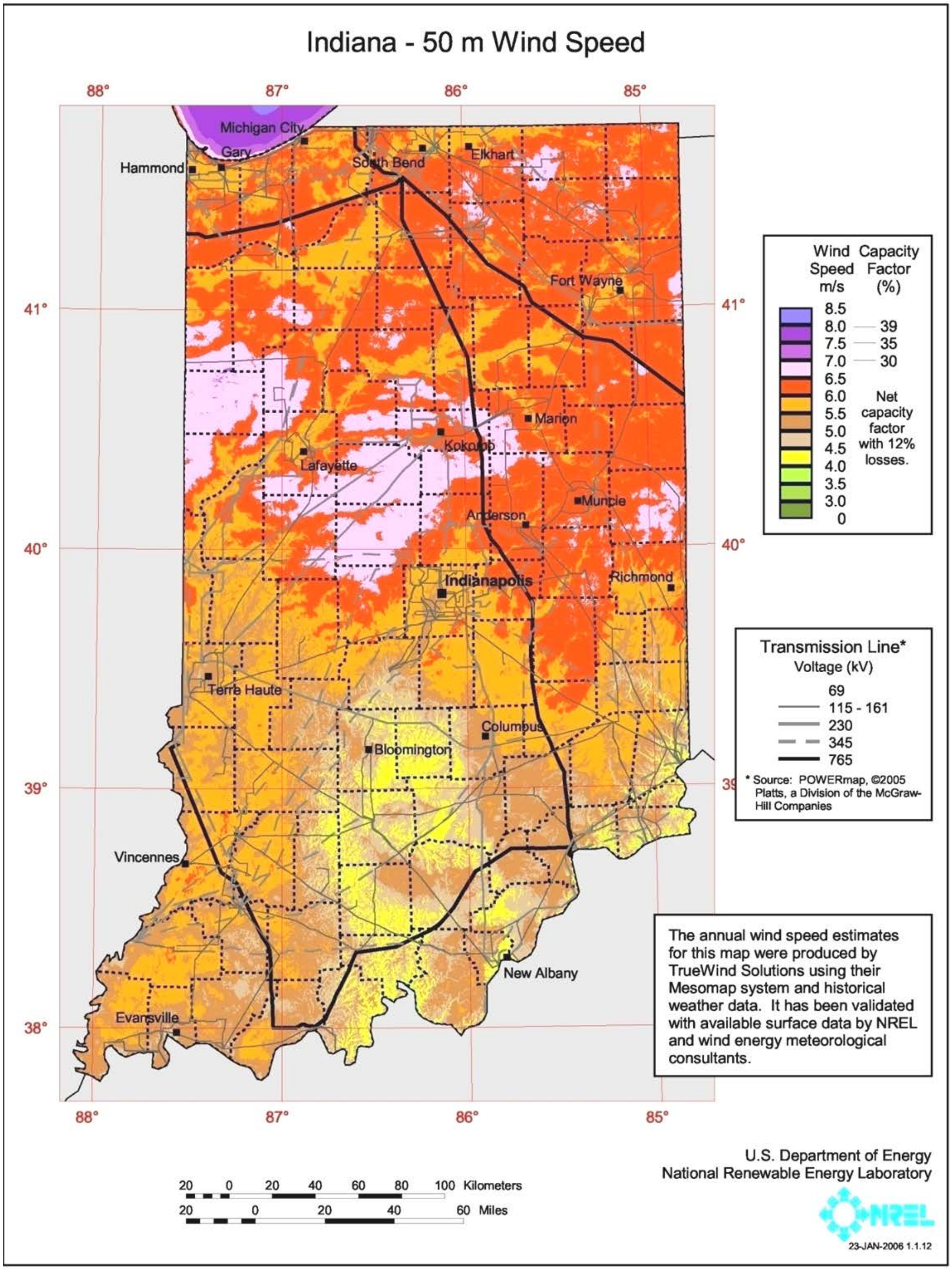
Table 2-5: Wind energy purchase agreements by Indiana utilities (Data sources: IURC, Hoosier Energy, WVPA, IMPA [25 – 28])

Figure 2-12 shows the distribution of wind energy resources at 100 meters and the location of major transmission lines, the two main factors influencing the location of utility scale wind farms while Figure 2-13 shows the distribution of the wind resource at 50m, a height at which smaller scale community wind projects operate.



The annual wind speed estimates for this map were produced by TrueWind Solutions using their Mesomap system and historical weather data. It has been validated with available surface data by NREL and wind energy meteorological consultants.

<u>Figure 2-12:</u> <u>Indiana wind speed at 100 meters height</u> (Source: OED/NREL [29])



* Source: POWERmap, ©2005 Platts, a Division of the McGraw-Hill Companies

The annual wind speed estimates for this map were produced by TrueWind Solutions using their Mesomap system and historical weather data. It has been validated with available surface data by NREL and wind energy meteorological consultants.

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National Renewable Energy Laboratory

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Figure 2-13: Indiana wind speed at 50 meters height (Source: OED/NREL [29])

2.5 Incentives for wind energy

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

Federal Incentives

- Renewable Electricity Production Tax Credit (PTC) credits wind energy producers with 2.3 cents/kWh during the first ten years of operation. The PTC was modified in 2009 to allow producers who would qualify for the PTC to opt to take the federal business energy investment tax credit (ITC). The PTC was extended to December 2019 by the Consolidated Appropriations Act of 2016 with a provision for phasing it down by reducing it by 20 percent for wind projects commencing construction in 2017, by 40 percent for projects commencing construction in 2018 and by 60 percent for projects commencing construction in 2019 [11].
- Business Energy Investment Tax Credit (ITC) credits wind projects with 30 percent of their construction cost in lieu of the production tax credit. Like the PTC the ITC expires in December 2019 and is scheduled to scale down by 20, 40 and 60 percent respectively in 2017, 2018 and 2019. The ITC for small wind projects up to 100 kW expires in December 2016 [11].
- U.S. DOE Loan Guarantee Program (Section 1703, Title IV of Energy Policy Act of 2005) provides loan guarantees for large scale innovative, high technology risk renewable energy projects that reduce the emission of pollutants [11].
- Modified Accelerated Cost-Recovery System (MACRS) allows businesses to recover investments in qualified renewable energy technologies through depreciation deductions. A 50 percent first year bonus depreciation first provided by the Economic Stimulus Act of 2008 has been extended by the Consolidated Appropriations Act of 2016 to 2019. The bonus depreciation is scaled down to 40 percent in 2018 and 30 percent in 2019 [11].
- USDA Rural Energy for America Program (REAP) promotes energy efficiency and renewable energy for agricultural producers and rural small businesses through the use of grants and loan guarantees for energy efficiency improvements and renewable energy systems. The program covers up to 25 percent of costs [11].
- Clean Renewable Energy Bonds (CREBs) are tax credit bonds designed to offset the tax liability of not-for-profit entities such as public utilities, and local and state governments that, because of their structure, do not benefit from the traditional renewable energy production tax credit (PTC) [11].
- Qualified Energy Conservation Bonds (QECBs) are qualified tax credit bonds that state, local and tribal governments may use to finance renewable energy projects and other energy conservation measures. Unlike the Clean Renewable Energy Bonds (CREBS) QECBs are not subject to U.S. Department of Treasury approval. The volume of the bonds is allocated to states in proportion to the state's percentage of the U.S. population [11].
- High Energy Cost Grant Program administered by 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 [11, 30].

- Residential Renewable Energy Tax Credit allows taxpayers to claim 30 percent of their qualifying expenditures on installation of renewable energy technologies including solar electric systems, solar water heaters, wind turbines and geothermal heat pumps [11].
- Green Power Purchasing Goal requires that 30 percent of energy used by federal agencies must be obtained from renewable resources by 2025 [11].

Indiana Incentives

- Net Metering Rule allows utility customers with renewable resource facilities having a maximum capacity of 1 MW to receive a credit for net excess generation in the next billing cycle [11].
- Renewable Energy Property Tax Exemption provides property tax exemptions for solar thermal, PV, wind, hydroelectric and geothermal systems [11].
- Community Conservation Challenge Grant provides $25,000-$100,000 in grants for community energy conservation projects that reduce energy consumption or displace the use of traditional energy sources. A total of $600,000 is allocated for 2016. Applications for the 2016 funding cycle are due by October 30 [11, 31].
- Sales and Use Tax Exemption for Electrical Generating Equipment exempts transactions involving manufacturing machinery, tools, and equipment used for the production of tangible personal property, which includes electricity, from state gross retail tax. However, only wind energy has clearly specified rules from the Department of Revenue [11].
- Clean Energy Portfolio Goal sets a voluntary goal of obtaining 4 percent between 2013 and 2018, 7 percent between 2019 and 2024, and 10 percent by 2025, of electricity from clean energy sources based on 2010 retail sales. Participation in the goal makes utilities eligible for incentives that can be used to pay for the compliance projects. The deadline to apply for incentives in the 2013 to 2018 period has expired [11].
- Northern Indiana Public Service Company (NIPSCO) offers feed-in tariff incentive rates for electricity generated from renewable resources for up to 15 years. The payment for wind turbines between from 3kW and 10kW is $0.25/kWh for projects selected in the first capacity allocation lottery (*allocation 1*) and $0.23/kW for subsequent ones (*allocation 2*). The payment for wind turbines larger than 10kW up to 200kW is $0.15/kWh for projects in *allocation 1* and $0.138 for those in *allocation 2.* The 4 MW cap for intermediate solar *allocation 1* has been met [11, 32, 33].

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3. Dedicated Energy Crops

3.1 Introduction

This section discusses biomass in the form of crops grown exclusively for use as a source of energy. Information on the use of biomass in the form of organic wastes and residues as sources of energy is presented in the section that follows (Section 4).

Unlike the use of organic wastes as an energy source, the dedicated energy crop industry in the U.S. is still in its infancy. A substantial research, development, demonstration and deployment effort, led by the U.S. Department of Energy (DOE) Bioenergy Technologies Office, is under way to build a national bioenergy industry with the objective to reduce U.S. dependence on imported oil. Biomass is unique among renewable resources in that it can also be used as feedstock to produce liquid transportation fuels and industrial chemicals. This characteristic is the primary motivation behind the research on energy crops and organic waste biomass and the associated conversion technologies [1]. This research effort is detailed in the DOE report titled *2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy* [2] and the Bioenergy Technologies Office March 2016 *Multi-Year Program Plan* [3]. The crops being considered and developed as dedicated energy crops can be grouped into three main categories – perennial grasses, woody crops and annual crops.

Perennial grasses include switchgrass, big bluestem, Indian grass, miscanthus and sugarcane. Switchgrass, big bluestem, and Indian grass are perennial grasses that are native to North America. They are already grown in a wide range of habitats and climates for pasture, hay production, soil and water conservation, and for wildlife habitat. With proper management they can remain productive for as long as ten years. Figure 3-1 shows switchgrass in the University of Vermont extension program.

The Giant Miscanthus hybrid was developed in Japan and introduced to the U.S. as a landscape plant. The main attraction of Giant Miscanthus as an energy crop is its high level of biomass production. While a great deal of research has been done establishing its potential as an energy crop, there are still barriers to overcome before it can enter large scale commercial production. They include the development of low-cost reliable propagation methods since it is a seedless sterile hybrid. In addition there is still work to be done to identify varieties suited to given regions of the country.

Figure 3-1: Switchgrass (Source: Farm Energy [4])

Sugarcane is attractive as an energy crop primarily due to its ability to store sugar (sucrose) in its stem. In addition, sugarcane ethanol is used as a fuel and is recognized to cut greenhouse gas emissions more than any other biofuel. However, sugarcane is a tropical crop and significant research is still to be done to develop varieties that do well in temperate climates.

Woody crops being developed as energy crops include poplars, willows, eucalyptus and southern pines. Poplars are well established trees native to North America. There are already commercial plantations of hybrid poplars (cottonwood) for the production of fiber, biofuels and for environmental remediation. High rates of biomass productivity, ease of propagation and management are cited as factors that make poplar attractive as an energy crop. The characteristics that make willows desirable as energy crops include high yields, ease of propagation and high energy content. Eucalyptus is being developed for the southern United States where it is grown for lumber. It has been grown commercially for lumber in Florida since the 1960s.

Southern pines are already one of the main contributors to bioenergy in the United States. Their bark and the paper processing byproduct *black liquor* are used to produce energy in pulp and paper mills. The ability to grow rapidly in a wide range of sites has made the southern pine the most important and widely cultivated timber species in the U.S., mainly for lumber and pulpwood.

The one annual crop being developed as an energy crop is sorghum. According to the DOE Biomass Program, although perennial crops are considered better than annual crops for energy production sustainability purposes, an annual crop serves well as a bridge for a new bioenergy processing facility as it awaits the establishment and full productivity of perennial crops. The factors that make sorghum attractive as an energy crop include its composition and high yield potential, drought resistance, water use efficiency, established production systems, and potential for genetic improvement [5].

Biomass, including energy crops, can be converted into energy in the following ways:

- In direct combustion the biomass is burned directly in a boiler to produce steam that can then be used to drive a turbine to generate electricity. Combustion can be done either in a dedicated biomass-only boiler or cofired with other fuels such as coal. Cofiring of biomass in coal boilers has the advantage of lowering the emission of sulfur oxides (SOx), nitrogen oxides (NOx) and net lifecycle carbon, relative to sole fired coal. However, the widespread application of cofiring with coal has been hindered by the occurrence of alkali deposits that cause slag and corrosion in boiler heat transfer surfaces in the coal boilers [6].
- In biochemical conversion processes the biomass material is broken down into sugars using either enzymes or chemical processes. These sugars are then fermented to make ethanol [7].
- In thermochemical conversion heat is used to break down the biomass material into intermediate products (synthetic gas) which can then be converted into fuels using heat, pressure and catalysts. Two common thermochemical processes are gasification and pyrolysis. Gasification is a high temperature conversion of solids into a flammable mixture of gases. Pyrolysis is a process of thermal decomposition of biomass at high temperatures in the absence of oxygen into charcoal, bio-oil and synthetic gas [8].

To take full advantage of the strengths of the different biomass-to-energy conversion processes, the DOE Biomass Program is funding the construction of integrated biorefineries that combine all processes in one plant and produce multiple products. By producing multiple products, the integrated biorefineries, like refineries in the petroleum industry, will be able to take advantage of the differences in feed stocks and intermediate products to maximize the value obtained from the biomass feedstock.

There are currently 32 DOE funded integrated biorefinery related projects spread across the United States working to develop the various bio-processing technologies needed. Two design-scale projects are used to demonstrate the integrated technologies at bench scale before scaling them to the pilot project level. At the fifteen pilot-scale projects these technologies are verified at a scale of at least one dry metric ton a day before being passed to the demonstration-scale facilities. The demonstration scale facilities are sized to a scale sufficient to provide data and equipment specifications for the final commercial level pioneer projects. There are eight demonstration-scale and seven pioneer-scale projects spread across the United States. Table 3-1 is a list of integrated biorefinery projects [9].

Project	**Location**	**Scale**	**Conversion Technology**
Elevance	Bolingbrook, IL	Design	Hybrid
Gas technology Institute	Des Plaines, IL	Design	Thermo-Pyrolysis
Algenol	Fort Myers, FL	Pilot	Algae*
American Process	Alpena, MI	Pilot	Biochemical
Amyris	Emeryville, CA	Pilot	Biochemical
Archer Daniels Midland	Decatur, IL	Pilot	Biochemical
BioProcess Algae	Shenandoah, IA	Pilot	Algae*
Frontline	Ames, IA	Pilot	Thermo-Gasification
Haldor Topsoe	Des Plaines, IL	Pilot	Thermo-Gasification
ICM	St. Joseph, MO	Pilot	Biochemical
Logos/EdenIQ Technologies	Visalia, CA	Pilot	Biochemical
Mercurius	Ferndale, WA	Pilot	Hybrid
Renewable Energy Institute	Toledo, OH	Pilot	Thermo-Gasification
Rentech ClearFuels	Commerce City, CO	Pilot	Thermo-Gasification
Solazyme	Peoria, IL	Pilot	Algae*
UOP	Kapolei, HI	Pilot	Thermo-Pyrolysis
Zeachem	Boardman, OR	Pilot	Thermo-Pyrolysis
Flambeau River Biofuels	Park Fall, WI	Demo	Thermo-Gasification
Lignol Innovations	Commerce City, CO	Demo	Biochemical
Myriant	Lake Providence, LA	Demo	Biochemical
NewPage	Wisconsin Rapids, WI	Demo	Thermo-Gasification
Pacific Biogasol	Boardman, OR	Demo	Biochemical
Red Shield Acquisition	Old Town, ME	Demo	Biochemical
Sapphire Energy	Columbus, NM	Demo	Algae*
Verenium	Jennings, LA	Demo	Biochemical
Abengoa Bioenergy	Hugoton, KS	Pioneer	Biochemical
Emerald Biofuels	Plaquemine, LA	Pioneer	Thermo-HEFA
Fulcrum Bioenergy	McCarran, NV	Pioneer	Thermo-Gasification
INEOS / New Planet Bioenergy	Vero Beach, FL	Pioneer	Hybrid
Mascoma	Kinross, MI	Pioneer	Biochemical
POET Project Liberty	Emmetsburg, IA	Pioneer	Biochemical
Red Rock Biofuels	Lakeview, OR	Pioneer	Thermo-Gasification

*Discussion of algae as a source of energy is included in Section 4 of report

Table 3-1: DOE funded integrated biorefinery projects (Data source: DOE [9])

The three commercial scale pioneer projects shown in Table 3-2 have been completed. However, only one, the POET-DSM plant in Emmetsburg, Iowa is in operation. The other two, the INEOS plant in Florida and the Abengoa plant in Kansas have been shut down since 2015.

	INEOS (Vero Beach FL)	**Abengoa (Hugoton KS)**	**POET-DSM (Emmetsburg IA)**
Began production	2013	2013	2014
Feedstock (tons per year)	Yard and wood waste (250,000)	Agricultural crop residues (325,000)	Corn stover (285,000)
Primary Process	Gasification	Enzymatic hydrolysis	Two step biotechnological process
Biofuel Output (million gallons per year)	Cellulosic ethanol (8)	Cellulosic ethanol (25)	Cellulosic ethanol (20-25)
Electricity Output	6 MW gross 2 MW net	21 MW Gross	Thermal energy output supplies plant needs

Table 3-2: Completed DOE funded integrated biorefineries (Data source: DOE [10])

3.2 Economics of energy crops

For large scale production of dedicated energy crops to occur, the price and profitability of the energy crops will have to be competitive with the current crops and other cropland uses. DOE, in the *2016 Billion-Ton Report*, used the U.S. agricultural sector simulation model (POLYSYS) to estimate the quantities of the various energy crops that would be produced at various prices. The POLYSYS model is a detailed model of the U.S. agricultural sector that includes crop supply at the county level, national crop demand and prices, national livestock demand and prices, and agricultural income.

Six types of energy crops are modeled in the POLYSYS simulation for the results presented in the *2016 Billion-Ton Report* – three perennial grasses (switchgrass, miscanthus, and energy cane), an annual energy crop (biomass sorghum) and two types of short rotation woody crops, one that is rotated by coppicing[7] (willow and eucalyptus) and one by other non-coppicing methods (poplar and pine). Switchgrass, miscanthus, and energy cane were modeled for 10-year, 15-year, and 7-year rotations, respectively. Hybrid poplar, pine and eucalyptus were modeled as growing on an 8-year rotation each, and willow was modeled as a coppiced crop over a 32-year period with harvest every 4 years.

Figure 3-2 shows the production of herbaceous and woody energy crops under the Billion-Ton study base-case scenario[8] in selected years at various farm-gate prices. At a price of $40 per dry ton energy crops do not enter the market until 2030. In 2030 they comprise approximately 21 percent of the 59 million tons of biomass offered to the market and 46 percent of the 108 million tons offered in 2040. At $60 a small of amount of biomass from energy crops enter the market in 2022. At this price 62

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[7] Coppicing is a method of woody crop management that takes advantage of the property that some plants such as willows have where new growth occurs from the stump or roots when the plant is cut down.

[8] The base-case scenario in the *2016 Billion-Ton Report* assumes 1% energy crop yield improvements per year.

percent of the 388 million tons of biomass offered in 2030 to the market is from energy crops, primarily herbaceous energy crops and in 2040 seventy percent of the 588 million tons offered to the market is from energy crops. When prices increase to $80 per ton energy crops dominate the market supplying 70 percent of the biomass in 2030 and 75 percent in 2040.

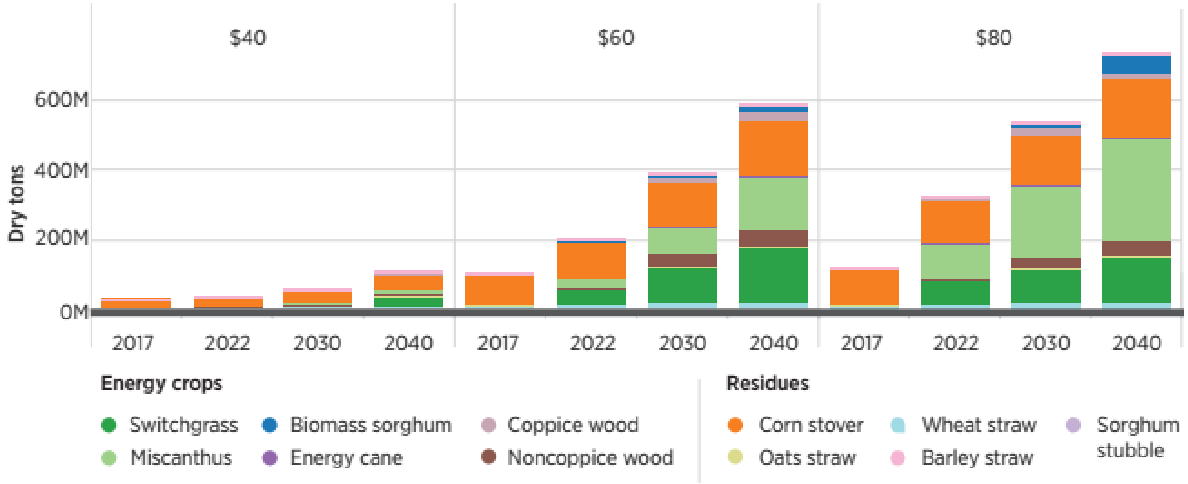

Figure 3-2: Production of energy crops at various farm-gate prices for select years (Source: DOE [2])

Figure 3-3 and 3-4 show the total potential availability of herbaceous and woody energy crops expected to be produced in 2022, 2030, and 2040 under the Billion-Ton study base case scenario.

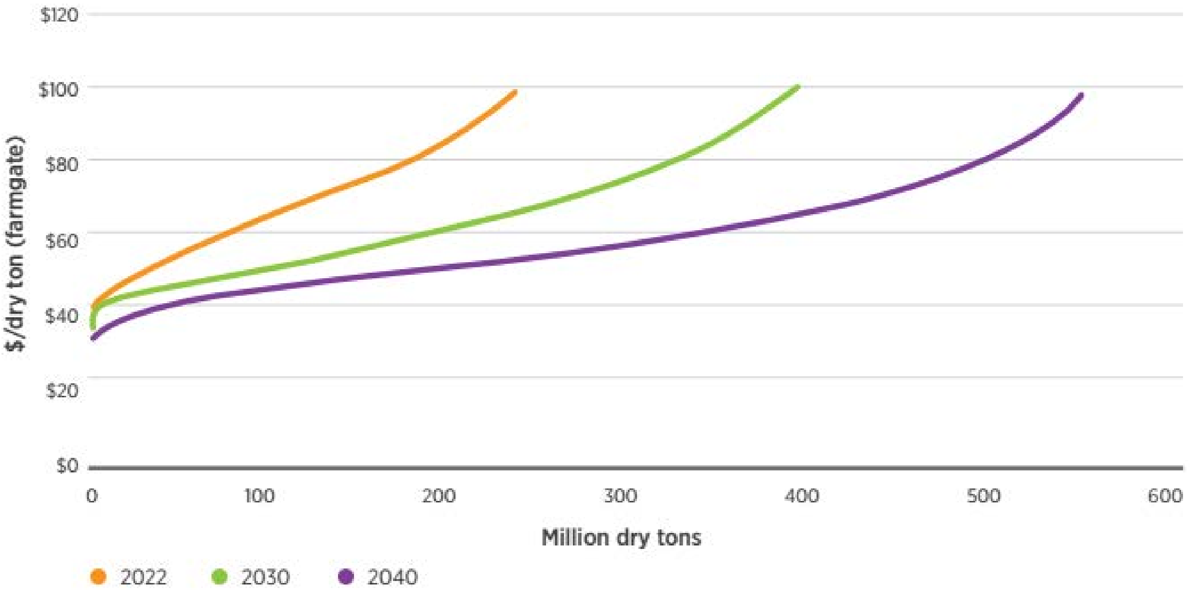

Figure 3-3: Supply curves of potential herbaceous energy crop production for select years under base-case assumptions (Source: DOE [2])

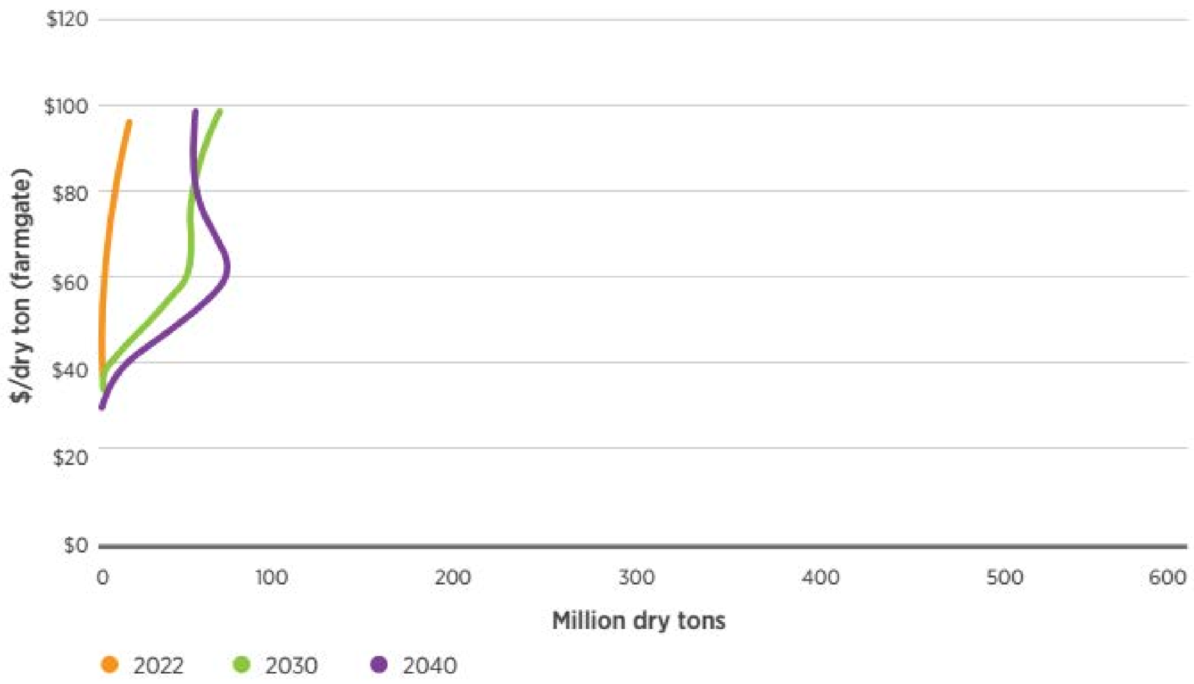

Figure 3-4: Supply curves of potential woody energy crop production for select years under base-case assumptions[9] (Source: DOE [2])

In addition to the series of Billion-Ton studies, DOE has developed a spatial web-accessible database, the *Bioenergy Knowledge Discovery Framework* (KDF), which brings together data from the various DOE supported bioenergy research efforts across the U.S [11]. The research projects whose data is integrated into the KDF include

- Biomass Resource Potential research prepared by the Oak Ridge National Laboratory whose results are presented in the 2016 *Billion-Ton Update* report referred to above,
- The Sun Grant Initiative Resource Assessment project that collects data from the energy crops field trials,
- The Feedstock Supply and Logistics Analysis research being conducted at the Idaho National Laboratory,
- The Microalgae Biofuel Potential project taking place at the Pacific Northwest National Laboratory,
- The Regional Land-Use Change Modeling project based at the Great Lakes Bioenergy Center,
- The International Projects Partnership based at the Oak Ridge National Laboratory that is working to identify areas of biodiversity concern to be avoided when planting energy crops,

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[9] The backward sloping supply curves in 2030 and 2040 show that at high biomass prices it is more profitable for the farmer to grow herbaceous energy crops (shown in Figure 3-3) than woody energy crops.

- The National Biorefinery Siting Model that seeks to develop a geographical information system (GIS) based biomass supply and biorefinery location model of the U.S.
- The Alternative Fuels and Advanced Vehicles Data Center at the National Renewable Energy Laboratory that is intended to provide interactive maps of alternative fuels infrastructure.

Corn and soybean use for biofuel production

Although corn and soybeans do not meet the strict definition of dedicated energy crops, they are included in this section in recognition of the fact that they are the largest source of renewable energy in Indiana. The ethanol and diesel biofuels experienced a rapid expansion in the mid-2000s. Before 2007 Indiana's ethanol production capacity consisted of one plant with a capacity of 100 million gallons per year (MGY). Since then twelve corn-ethanol plants with a combined capacity of 1,068 MGY have been constructed, bringing the total corn-ethanol capacity to 1,168 MGY. Towards the end of the 2000s the production of corn ethanol started outpacing the demand due to the weakened demand for gasoline associated with the recession. This has resulted in the idling of at least one plant, the 102 MGY Noble Americas plant in South Bend, reducing the producing capacity to 1,066 MGY. Table 3-3 shows the location and capacities of ethanol plants in Indiana.

Company	Location	Nameplate Capacity (MGY*)	Operating Production (MGY*)
Abengoa Bioenergy Corp.	Mt. Vernon	88	88
Cardinal Ethanol	Union City	100	100
Central Indiana Ethanol	Marion	60	60
Grain Processing Corp.	Washington	20	20
Green Plains Renewable Energy	Bluffton	120	120
Iroquois Bio-Energy Company	Rensselaer	40	40
MGPI of Indiana	Lawrenceburg	35	35
Noble Americas South Bend Ethanol (not producing)	South Bend	102	0
POET Biorefining - Alexandria	Alexandria	70	70
POET Biorefining - Cloverdale	Cloverdale	90	90
POET Biorefining - North Manchester	North Manchester	70	70
POET Biorefining - Portland	Portland	70	70
The Andersons Clymers Ethanol	Clymers	110	110
Valero Renewable Fuels	Linden	120	120
Valero Renewable Fuels	Mount Vernon	110	110

*MGY denotes million gallons per year.

Table 3-3: Ethanol plants in Indiana (Data source: Ethanol Producers Magazine [14])

Table 3-4 shows the location and capacities of the three Indiana biodiesel plants. One of them, the E-biofuels plant in Middletown is currently not producing, leaving a total 93 MGY biodiesel capacity currently operational in Indiana in two plants.

Plant Name	Year	Town/County	Estimated Capacity (MGY)
E-biofuels (not producing)	2007	Middletown/Henry	10
Integrity Biofuels	2006	Morristown/Shelby	5
Louis Dreyfus	2007	Claypool/Kosciusko	88

Table 3-4: Biodiesel plants in Indiana (Data source: Indiana State Department of Agriculture [15])

The following factors account for the biofuel plant construction in the U.S. since 2005.

- The use of corn-ethanol as an oxygenating additive in gasoline in place of the chemical MTBE. The shift from MTBE was a result of its association with ground water pollution. The replacement of MTBE was mandated both by states and the 2005 Energy Policy Act [12].
- The renewable fuel standard first enacted in 2005 and then expanded in 2007 requires that 36 million gallons of renewable fuel (15 billion gallons from corn-ethanol and the balance from advanced biofuels) must be blended into gasoline by 2022 [13].
- The enactment of the volumetric ethanol excise tax credit (VEETC) in 2004 improved the cost competitiveness of corn-ethanol with gasoline and provided long-term protection for corn-ethanol producers against price volatility in the transportation fuel market. The VEETC allowed for a 45 cents/gallon tax credit to be given to individuals who produce the mixture of gasoline and ethanol. This tax credit expired at the end of 2011.

3.3 State of energy crops nationally

As discussed previously, the energy crop industry is still in its infancy with a substantial research and development effort under way to establish a sustainable supply of biomass to satisfy the Renewable Fuel Standard mandate of 36 billion gallons of biofuels for the transportation industry per year by 2022 and also increase electricity generation from biomass. As part of this research, DOE has partnered with universities, national laboratories and the U.S. Department of Agriculture to establish a *Regional Biomass Feedstock Partnership* to conduct research, development and outreach at the regional level to address the barriers associated with the effort to establish a sustainable bioenergy industry. Figure 3-5 shows the biomass feedstock field trial locations established by the *Regional Biomass Feedstock Partnership*.

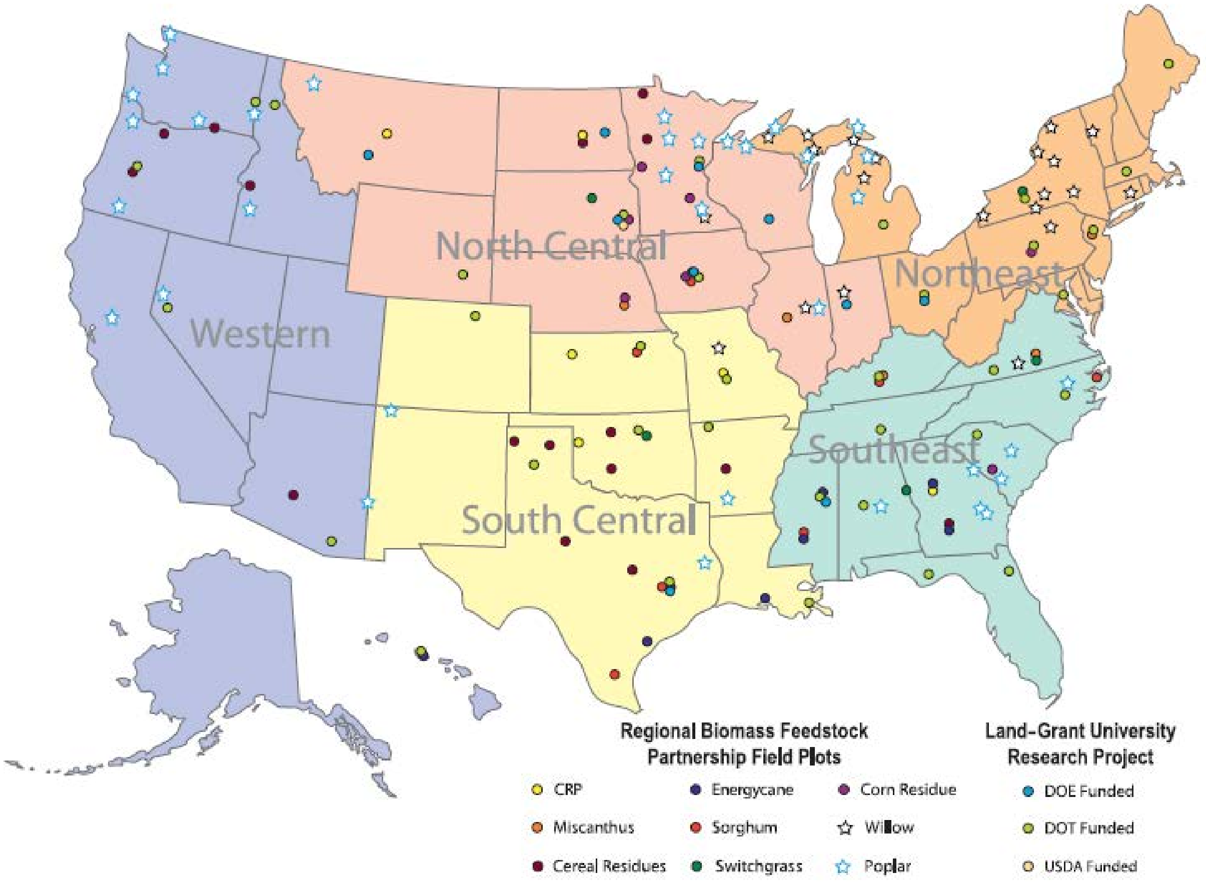

Figure 3-5: Bioenergy crop trial stations (Source DOE [16])

In addition to the field test sites the *Regional Biomass Feedstock Partnership* is also involved in education and outreach efforts to farmers and other stakeholders to prepare them for a future where energy crops are a substantial portion of the agricultural industry. The lead institutions for the five regions in the program are: South Dakota State University in the North Central region, Oregon State University in the Western region, Oklahoma State University in the South Central region, Cornell University in the Northeast, and University of Tennessee in the Southeast region [17]. At the March 2015 project peer review conference the following progress was reported on the feedstock research [18].

- The completion of field trials for seven crop years (2008 to 2014),
- Making the yield and plot treatment data publicly available by uploading it onto the DOE Knowledge Discovery Framework,
- Collecting of soil samples for sustainability analysis at multiple locations,

- Collecting of biomass samples from the field plots and sending them to the Idaho National Laboratory (INL) for composition analysis and archiving in the biomass resource library housed at INL.

3.4 Energy crops in Indiana

The results from the DOE Billion-Ton model show Indiana and other corn-belt states such as Iowa and Illinois being major producers of agricultural crop residues such as corn stover and only a limited amount of energy crops. Figure 3-6 shows the projected pattern of biomass feedstock production by the year 2030 at a biomass farm-gate price of $60 per dry ton.

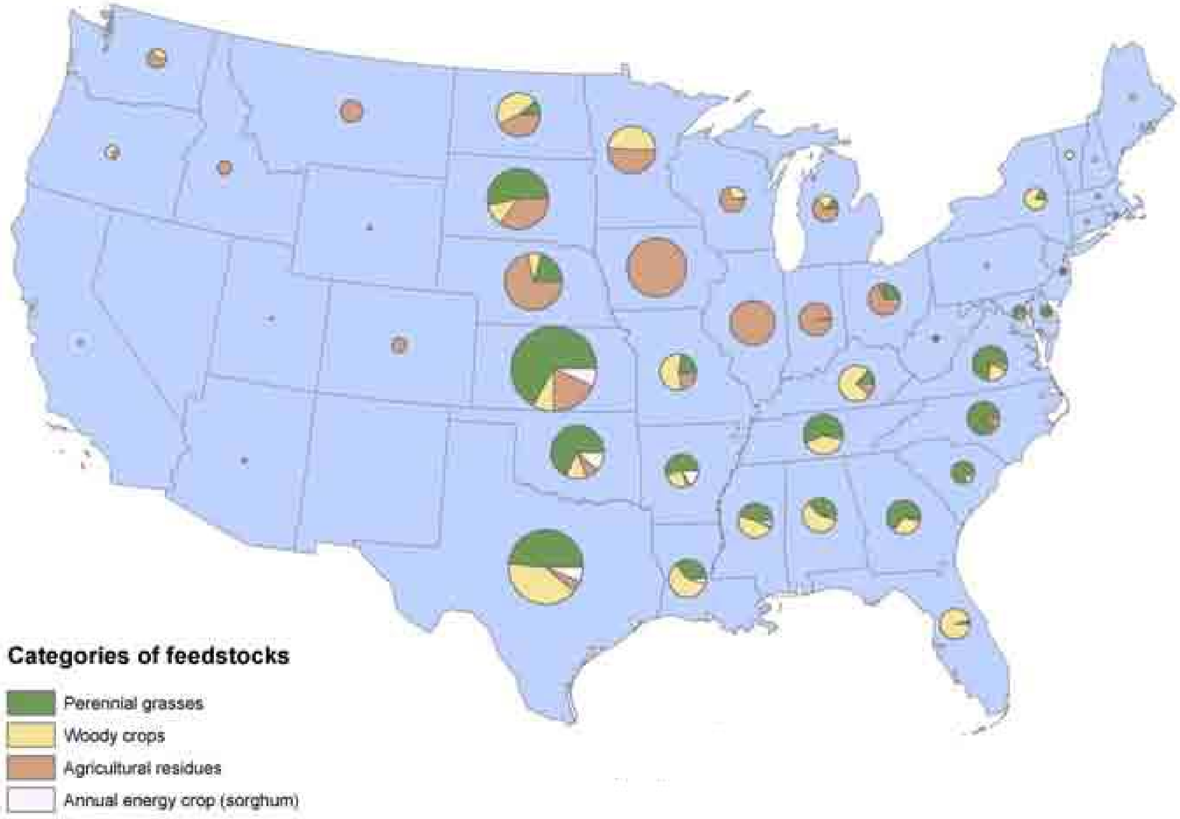

Figure 3-6: Estimated shares of energy crops and agricultural residues supplied at $60 per dry ton in 2030 (Source: DOE [5])

Figure 3-7 shows the quantities of energy crops projected to be produced in Indiana in 2030 at biomass farm-gate prices of $50, $60, $70 and $80 per dry ton. At a biomass price of $60 per dry ton, Indiana's projected production of all energy crops combined is 1.5 million dry tons. In comparison, the amount of agricultural residue biomass produced at $60 per dry ton in 2030 is projected to be 9 million dry tons. As can be seen in the figure, perennial grasses are the preferred energy crop in Indiana, followed by woody crops. At prices above $70 per dry ton some annual crops (e.g., sorghum) enter into the crop mix.

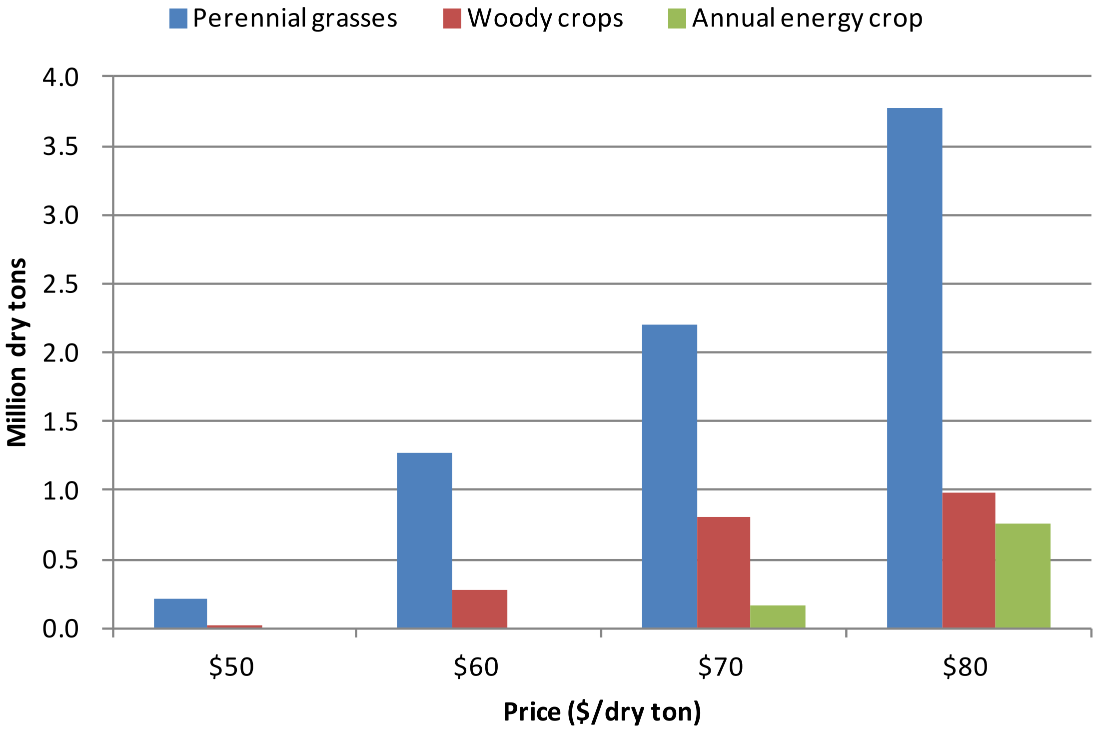

Figure 3-7: Projected production of energy crops in Indiana in 2030 (Data source: DOE [19])

In an April 2008 working paper, Brechbill and Tyner of Purdue's Agricultural Economics Department did an extensive study of the estimated 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. The table includes the farmer's choice to either: purchase and own the harvesting equipment or 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 (Data source: Brechbill & Tyner [20])

Allen, in his December 2011 Master's Thesis, estimated the cost of producing and transporting biomass from woody crops to be between $43 and $52 per dry ton [21].

In her 2013 Master's thesis, Song performed an integrated economic and environmental assessment of cellulosic biofuel production focusing on the Wildcat Creek Watershed, which is located in North-Central Indiana and is a predominately agricultural production area. The study evaluated the costs of corn stover, switchgrass and miscanthus production within the watershed by looking at three cost components: production cost, loading-unloading cost, and hauling cost for each feedstock, as is shown in Table 3-6. The opportunity cost of growing perennial grasses instead of cash crops corn and soybean is considered ($180/acre, based on the 2015 Purdue Crop Cost & Return Guide [22]). In this study, a hypothetical biorefinery plant is assumed to be located at the centroid of the watershed, demanding biomass feedstock supply from cropland across the watershed. The nine scenarios shown in Table 3-6 are considered in order to compare candidate feedstocks and corn stover removal rates [23, 24].

Crop Scenario	**Production Cost ($/dry ton)**	**Loading-unloading ($/dry ton)**	**Hauling ($/dry ton)**	**Total Cost for Watershed (Million $)**	**Unit Cost ($/dry ton)**
Baseline Corn-Soybean	0	0	0	0	0
Continuous Corn with 20% Residue Removal	54.19	5.42	5.37	21.92	64.98
Corn-Soybean with 30% Residue Removal	54.19	5.42	5.37	15.69	64.99
Corn-Soybean with 50% Residue Removal	57.08	5.42	5.37	27.79	67.86
Continuous Corn with 30% Residue Removal	54.19	5.42	5.37	33.03	64.98
Continuous Corn with 50% Residue Removal	56.98	5.42	5.36	57.56	67.75
Switchgrass	106.79	6.88	6.81	204.97	120.47
Switchgrass No Till	106.08	6.88	6.81	203.74	119.77
Miscanthus	92.66	6.88	6.84	350.78	106.37

Table 3-6: Cost by category for producing corn stover, switchgrass, and miscanthus in Wildcat Creek Watershed (Data source: Song et al. [24])

3.5 Incentives for energy crops

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

Federal Incentives

- Renewable Electricity Production Tax Credit (PTC) provides a 2.3 cents/kWh tax credit for closed-loop biomass energy technologies for ten years. Dedicated energy crops fall under the closed-loop biomass category. The PTC for closed-loop biomass was extended to December 2016 by the Consolidated Appropriations Act, 2016 [25].
- U.S. DOE Loan Guarantee Program (Section 1703, Title IV of Energy Policy Act of 2005) provides loan guarantees for large scale innovative, high technology risk renewable energy projects that reduce the emission of pollutants [25].

- Modified Accelerated Cost-Recovery System (MACRS) allows businesses to recover investments in qualified renewable energy technologies through depreciation deductions. A 50 percent first year bonus depreciation first provided for by the Economic Stimulus Act of 2008 has been extended to 2019. The bonus depreciation is reduced to 40 percent for 2018 and to 30 percent for 2019 [25].
- USDA Rural Energy for America Program (REAP) promotes energy efficiency and renewable energy for agricultural producers and rural small businesses through the use of grants and loan guarantees for energy efficiency improvements and renewable energy systems. The program covers up to 25 percent of costs [25].
- USDA Biorefinery Assistance Program offers loan guarantees for the development, construction or retrofitting of commercial-sized biorefineries. The program finances 80 percent of the cost of the biorefinery up to a maximum of $250 million [25].
- Clean Renewable Energy Bonds (CREBs) are tax credit bonds designed to offset the tax liability of not-for-profit entities such as public utilities, and local and state governments that, because of their structure, do not benefit from the traditional renewable energy production tax credit (PTC) [25].
- Qualified Energy Conservation Bonds (QECBs) are qualified tax credit bonds that state, local and tribal governments may use to finance renewable energy projects and other energy conservation measures. Unlike the Clean Renewable Energy Bonds (CREBS) QECBs are not subject to U.S. Department of Treasury approval. The volume of the bonds is allocated to states in proportion to the state's percentage of the U.S. population [25].
- High Energy Cost Grant Program administered by 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 [25].
- Green Power Purchasing Goal requires that 30 percent of energy used by federal agencies must be obtained from renewable resources by 2025 [25].

Indiana Incentives

- Net Metering Rule allows utility customers with renewable resource facilities with a maximum capacity of 1 MW to receive a credit for net excess generation in the next billing cycle [25].
- Community Conservation Challenge Grant provides $25,000-$100,000 in grants for community energy conservation projects that reduce energy consumption or displace the use of traditional energy sources. A total of $600,000 is allocated for 2016. Applications for the 2016 funding cycle are due by October 30 [25, 26].

- Sales and Use Tax Exemption for Electrical Generating Equipment exempts transactions involving manufacturing machinery, tools, and equipment used for the production of tangible personal property, which includes electricity, from state gross retail tax. However, only wind energy has clearly specified rules from the Department of Revenue [25].

- Clean Energy Portfolio Goal sets a voluntary goal of obtaining 4 percent between 2013 and 2018, 7 percent between 2019 and 2024, and 10 percent by 2025, of electricity from clean energy sources based on 2010 retail sales. Participation in the goal makes utilities eligible for incentives that can be used to pay for the compliance projects. The deadline for applying for the 2013 to 2018 incentive has expired [25].
- Northern Indiana Public Service Company (NIPSCO) offers feed-in tariff incentive rates for electricity generated from renewable resources for up to 15 years. The payment for biomass projects that are selected in the first lot in the capacity allocation process is $0.0918/kWh. NIPSCO was still accepting applications for the first capacity application process for biomass projects when this report was written [25, 27, 28].

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4. Organic Waste Biomass

4.1 Introduction

The previous section (Section 3) presented the use of organic biomass in the form of dedicated energy crops. In this section the use of biomass in the form of organic wastes and residues as a source of renewable energy is discussed. The organic waste biomass in this section is separated into two main categories: that which is in use currently as an energy source and that which is being considered for use in the future. The types of organic waste biomass already in use as energy sources include:

- Residues from the forestry and wood products industry, including material left from logging, residues from the paper and pulp industry and residues from primary wood milling;
- Municipal solid waste (MSW), which is the organic portion of the post-consumer waste collected in community garbage collection services;
- Gas extracted from landfills, which is naturally occurring gas resulting from decomposition of landfill material;
- Livestock manure, mainly from large swine and dairy farms where it is used to produce gas in bio digesters; and
- Municipal wastewater, or sewage, which is used to produce gas in bio digesters.

Organic waste biomass resources that are not yet in large-scale use as energy sources, but are being considered for future use, include:

- Agricultural crop residues, such as stalks, leaves and other material left in the fields when conventional crops such as corn are harvested; and
- Aquatic plants, such as algae that have high oil content that can be converted to biodiesel.

Residues from the forestry and wood products industry and municipal solid waste are typically used to produce electricity and heat. These feed stocks are burned directly in a boiler to produce steam that is used to drive a turbine to generate electricity and/or steam that is used directly for heat.

The other sources of organic waste based energy that are currently in use all take advantage of the production of biogas that contains a significant percentage of methane as the waste breaks down through either natural or managed decay processes. This is the case for landfill gas, livestock manure or municipal waste water that is processed through an anaerobic digester.

Anaerobic digestion of biomass waste consists of the breakdown of organic wastes by microorganisms in an oxygen deficient environment that produces biogas that can be burned as an energy source. Just like traditional fossil fuels, biogas can be used as a transportation fuel through an internal combustion engine or to generate electricity through a combustion turbine or a steam turbine. An additional benefit to converting biogas to energy is that it prevents the methane from being emitted into the atmosphere. Because methane is over 20 times more potent than carbon dioxide as a heat trapping greenhouse gas, its conversion to energy provides an added environmental benefit [1].

Biomass, including agricultural crop residues, is expected to play a significant role in the energy supply portfolio in the U.S. in the future. One of the characteristics that makes biomass a very attractive source of renewable energy is its ability to be converted both to electricity and to fuel for the transportation industry. Studies have shown that substantial energy resources in the form of biomass from crop residues could be harvested under appropriate economic conditions.

Large scale farming of algae is another area being considered as a potential source of bioenergy. Algae are simple organisms, ranging from microscopic-sized algae to seaweeds that grow to over 100 feet long. Like other plants, they utilize energy from the sun through photosynthesis to convert carbon dioxide from the air into biomass usable for energy production. Algae have several advantages over other biomass as a source of energy and especially in the production of biodiesel. These advantages include [2 - 4]:

- Algae grows more rapidly and has higher photosynthetic efficiency than other biomass;
- It has a much higher oil content than other biomass (20 to 80 times more than soybeans);
- 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 CO_2 from fossil fueled power plants; and
- Both biofuels and valuable co-products can be produced from algae.

Algae can be grown in either open ponds or in enclosed bioreactors. Although open pond algae farms are much more cost competitive, they have the disadvantages of being vulnerable to contamination by faster growing native algae, water loss through evaporation and exposure to extreme weather variations. Enclosed bioreactors overcome these drawbacks by growing the algae entirely enclosed in transparent containers of various forms. Not surprisingly, the enclosed bioreactors' main disadvantage is cost; bioreactors are much more expensive to build than open ponds. One potential application for the use of algae is the coupling of an algae bioreactor with a coal power plant to allow the power plant to provide the carbon dioxide needed for algae growth. In this way a combined benefit of producing bioenergy while reducing carbon dioxide emissions is achieved. Such an experiment was conducted at the Arizona Public Service Red Hawk power plant in 2006 and 2007 [5].

The production of algae for energy is still in the development stage. The federal government through the DOE biotechnologies research office is continuing to invest in funding the research and development to develop technologies needed to economically and sustainably produce, harvest, and convert algae into biofuels with a goal of producing 5 billion gallons of algal biodiesel per year by the year 2030 [4].

4.2 Economics of organic waste biomass

Most of the current waste biomass energy is generated and consumed in the paper and pulp industry where the paper and pulp making byproducts are combusted in combined heat and power plants to supplement the electricity and steam supply of the paper and pulp mills. Several factors have combined to make the use of these residues and byproducts as an energy source economically attractive at pulp and paper mills. They include:

- The burning of the pulp making residue (black liquor) serves not only to generate energy, but also to recover process chemicals,
- The co-location of electricity and steam demand in the mills greatly increases the efficiency of the energy conversion process, and
- The ability to sell excess generation through either the favorable provisions of the Public Utility Regulatory Policies Act of 1978 or more recently through the open transmission access associated with wholesale electricity markets provides a market for times when the plant's generation exceeds internal demand.

In the case of municipal solid waste (MSW), the need to reduce the amount of material going into landfills is the main motivation for building MSW based energy conversion facilities. Without this motivation MSW power plants would be hard to justify financially since they are some of the most expensive plants to build and operate. In the June 2016 Energy Information Administration (EIA) plant cost estimates, the MSW power plant was listed as having the highest capital cost at over $8,511/kW among the technologies considered and the highest fixed O&M cost at over $404/kW [6].

Similarly, other organic waste streams such as animal waste, wastewater treatment and landfills generate methane-rich biogas. The reduction of greenhouse gas emissions is an added benefit to the process of converting the biogas to energy. Further, the energy conversion efficiency, and therefore economics, can be improved by co-location of both heat and electricity demand. The anaerobic digesters used to produce the biogas in all cases except landfill gas provide a demand for the heat to maintain optimum temperatures for the microorganisms.

Agricultural crop residues are not currently being collected for use as bioenergy feedstock because it is not yet profitable for farmers. However, it is expected that biomass, including agricultural crop residues, will play a substantial role in the national effort to diversify the transportation fuel supply away from petroleum. In 2005 the U.S. Department of Agriculture (USDA) and the U.S. Department of Energy (DOE) issued a joint report from a study investigating the viability of using energy from biomass to replace 30 percent of U.S. petroleum consumption by the year 2030, titled *Biomass Feedstock for a Bioenergy and Bioproducts Industry: the Technical Feasibility of a Billion-Ton Annual Supply* [7], and in 2011 an update to that report and an associated online database of the results of the study, the *Bioenergy Knowledge Discovery Framework* (KDF) was released [8]. In the 2016 update to this *Billion-ton* study the amount of crop residue that would be produced at various farm-gate prices was estimated using an agricultural sector model (POLYSYS). Residue production is estimated in conjunction with energy crop production and other cropland uses to account for the competition between uses for the available cropland. Figure 4-1 shows the supply curves of primary crop residues for select years under the 2016 billion-ton study base-case assumptions. The crop residues in Figure 4-1 include corn stover, cereal (wheat, oats, and barley) straws, and sorghum stubble. Table 4-1 shows the potential supply of secondary agricultural wastes at select prices and years [9].

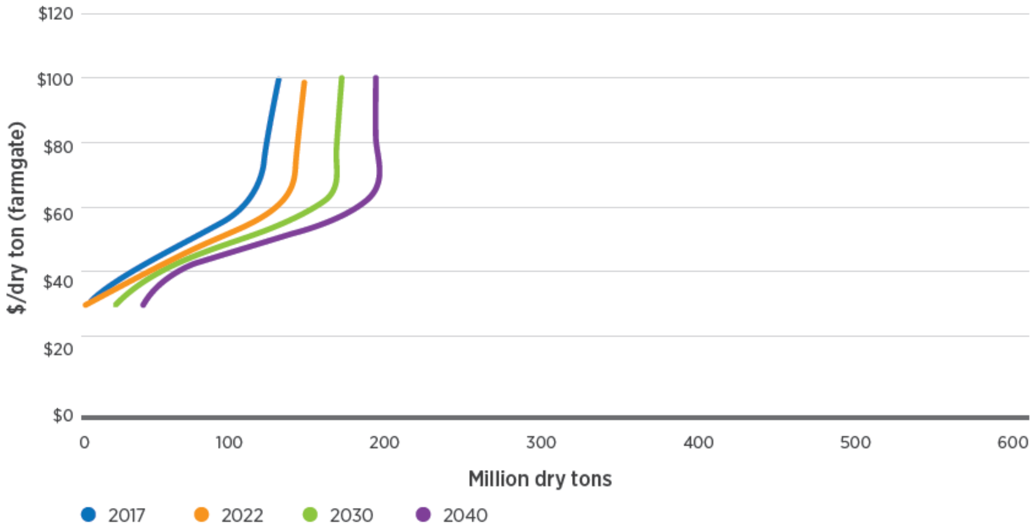
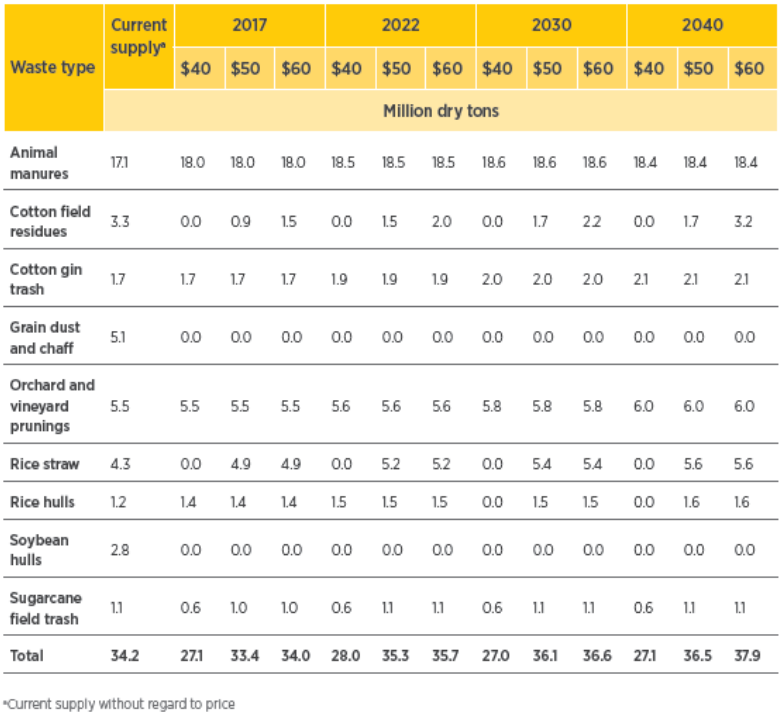


Figure 4-1 Supply curves of potential production from primary crop residues for select years under *2016 Billion-ton* study base-case assumptions[10] (Source: DOE [9])



Waste type	Current supply[a]	2017			2022			2030			2040		
		$40	$50	$60	$40	$50	$60	$40	$50	$60	$40	$50	$60
	Million dry tons												
Animal manures	17.1	18.0	18.0	18.0	18.5	18.5	18.5	18.6	18.6	18.6	18.4	18.4	18.4
Cotton field residues	3.3	0.0	0.9	1.5	0.0	1.5	2.0	0.0	1.7	2.2	0.0	1.7	3.2
Cotton gin trash	1.7	1.7	1.7	1.7	1.9	1.9	1.9	2.0	2.0	2.0	2.1	2.1	2.1
Grain dust and chaff	5.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Orchard and vineyard prunings	5.5	5.5	5.5	5.5	5.6	5.6	5.6	5.8	5.8	5.8	6.0	6.0	6.0
Rice straw	4.3	0.0	4.9	4.9	0.0	5.2	5.2	0.0	5.4	5.4	0.0	5.6	5.6
Rice hulls	1.2	1.4	1.4	1.4	1.5	1.5	1.5	0.0	1.5	1.5	0.0	1.6	1.6
Soybean hulls	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sugarcane field trash	1.1	0.6	1.0	1.0	0.6	1.1	1.1	0.6	1.1	1.1	0.6	1.1	1.1
Total	**34.2**	**27.1**	**33.4**	**34.0**	**28.0**	**35.3**	**35.7**	**27.0**	**36.1**	**36.6**	**27.1**	**36.5**	**37.9**

[a] Current supply without regard to price

Table 4-1: Summary of secondary agricultural wastes potential at select prices and years under *2016 Billion-ton* study base-case assumptions (Source: DOE [9])

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[10] The backward sloping supply curves show that at high biomass prices it is more profitable for the farmer to grow energy crops than primary food crops.

In a USDA funded study at Iowa State University published in 2012 [10], the U.S.-wide supply curve for corn stover was estimated. Unlike the USDA/DOE billion-ton study which estimated the stover price at the farm gate, the price in this study estimated the price at the bioenergy plant gate. That is, it includes the cost of handling, storage and shipping costs associated with getting the stover to the bioenergy processing plant. According to this study the minimum price at which stover would be available for the bioenergy industry is $37.5 per ton, which is lower than the $40/ton minimum price modeled for corn stover in the billion-ton study. Figure 4-2 shows the U.S.-wide corn stover supply curve from the Iowa State University study.

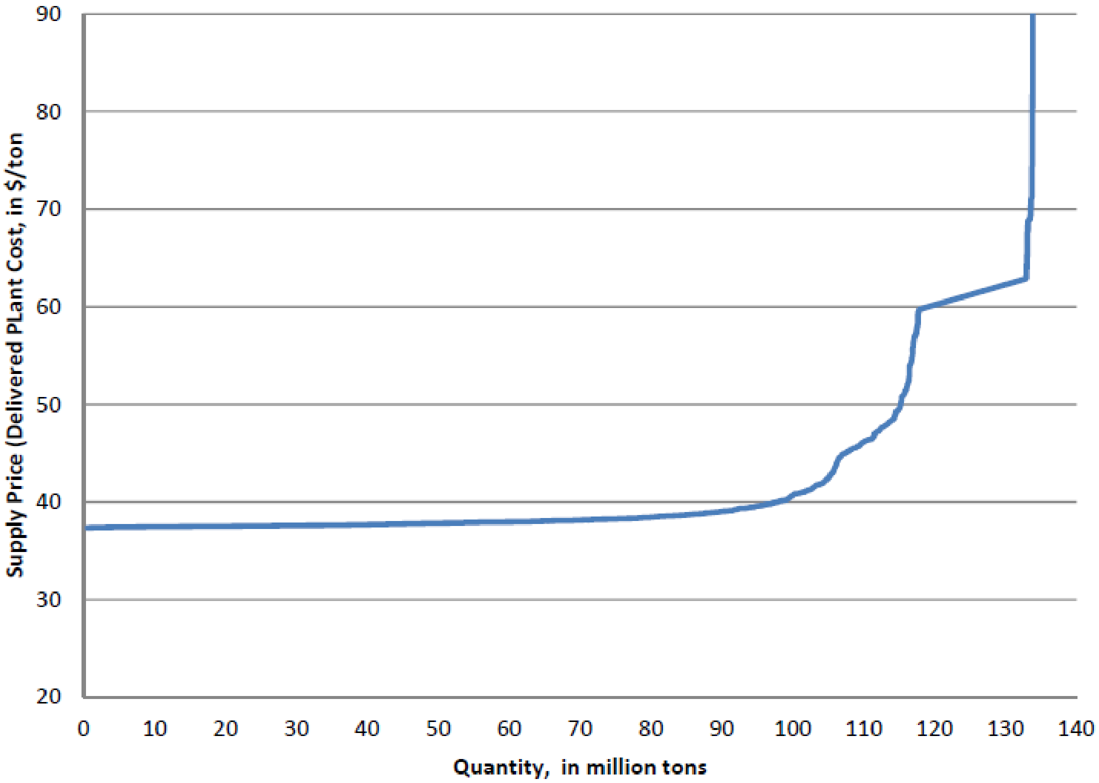


Figure 4-2: U.S. corn stover supply curve (Source: USDA [10])

Although the concept of using algae for energy production has been proven at the laboratory level, no commercial scale sustainable production facility has been established yet. In 2009 DOE, using funds provided for by the *American Recovery and Reinvestment Act* of 2009, established the *National Alliance for Advanced Biofuels and Bioproduct*s (NAABB), a consortium of industry, universities and national laboratories to advance research in various facets of the algal biofuels industry [11]. According to the NAABB final report, the consortium has developed and demonstrated, at a pilot level, technology improvements which when combined can reduce the cost of producing algal biodiesel from $240/gallon to $7.50/gallon. It still remains for this technology to be applied at a commercial scale [12].

4.3 State of organic waste biomass nationally

Historically organic waste biomass, and in particular residues from the wood products industry, has been one of the main sources of renewable energy in the U.S. As can be seen in Figure 4-3, wood and wood-derived fuels have been second only to hydroelectricity as a source of renewable energy. Until the increase in wind and biofuels in the last decade, wood and wood-derived fuels comprised nearly half of the renewable energy consumed in the U.S. In 2015 wood was relegated to third place as the source of renewable energy consumed in the U.S., contributing 21 percent behind hydro's 25 percent and biofuel's 22 percent contribution.

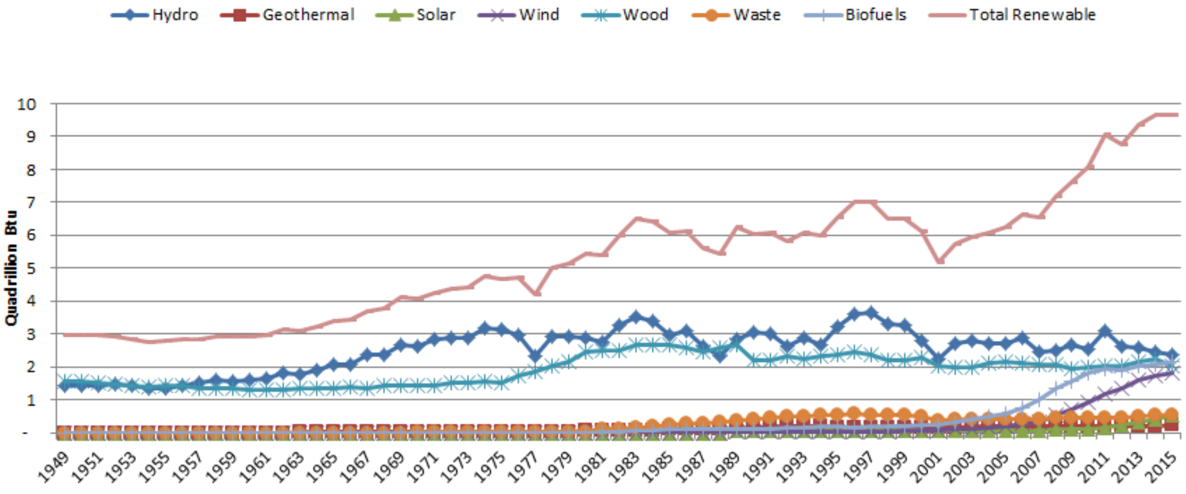


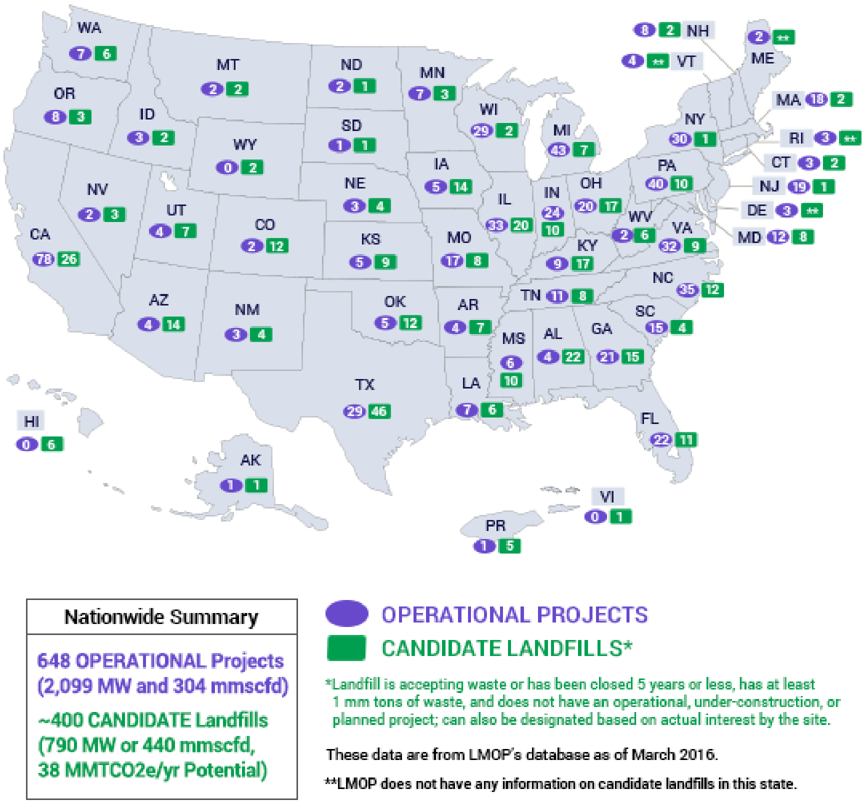
Figure 4-3: U.S. renewable energy consumption 1949-2015 (Source: EIA [13])

Although not as large a source as wood and wood-derived fuels, municipal solid waste (MSW) has also been a significant contributor to the nation's renewable energy mix. According to the national association of the waste to energy industry (the Energy Recovery Council) there were 77 MSW to energy plants operating in 22 states in the U.S. Of these plants, 59 had electricity as their only energy product; fifteen generated both electricity and steam, while three plants produced only steam. The combined electricity generating capacity installed in these plants was 2,547 MW. If the steam generated from the eighteen steam-only and cogenerating plants were to be converted to electricity, the Energy Recovery Council estimated that the total electricity generating capacity would increase to 2,747 MW. Table 4-2 shows the locations of MSW energy conversion plants in the U.S. Details about Indiana's one MSW energy conversion facility are given in Section 4.4.

State	Number of facilities
Alabama	1
California	3
Connecticut	5
Florida	11
Hawaii	1
Indiana	1
Iowa	1
Maine	3
Maryland	2
Massachusetts	7
Michigan	2
Minnesota	8
New Hampshire	1
New Jersey	5
New York	10
Oklahoma	1
Oregon	1
Pennsylvania	6
Utah	1
Virginia	4
Washington	1
Wisconsin	2

Table 4-2: Location of the 77 solid waste to energy plants in the U.S. (Data source: Energy Recovery Council [14])

Another organic waste stream in use as a source of energy is landfill gas. According to the EPA there were 648 landfills with operational energy conversion projects as of April 2016 with a combined capacity of 2,099 MW electricity generation and 304 million standard cubic feet per day (mmscfd) of gas for thermal energy production. In addition, there were 400 ‘candidate’ landfills that have the size and capacity necessary to support energy projects. These candidate landfills have the potential for 790 MW of electricity generation and 440 mmscfd of gas for thermal energy conversion. Figure 4-4 shows the location of operational and candidate landfill gas energy projects in the U.S [15].



Legend
mmscfd – million standard cubic feet per day;
MMTCO2e/yr – million metric ton of carbon dioxide-equivalent per year

Figure 4-4: Landfill gas projects (Source: EPA [15])

Livestock manure is in use currently as an energy source with 247 anaerobic digester biogas recovery systems in operation on livestock farms in the U.S. as of January 2014. The majority of these digesters (202) were on dairy farms, but there were also 39 on swine farms, 8 on beef farms, 7 on poultry farms, and 8 on mixed cattle/swine farms [16]. In a 2011 report *Market Opportunities for Biogas Recovery Systems at U.S. Livestock Facilities* EPA estimated that there were 8,241 dairy and swine farms that could support biogas recovery systems with a combined potential electric generating capacity of 1,667 MW supplying approximately 13 million MWh of electricity per year [17]. Table 4-3 shows the top states with the potential for electricity generation from livestock farms. Biogas is more readily recovered from swine and dairy farms because the manure is handled in the wet slurry state that is hospitable to the waste-digesting microorganisms.

	Number of Candidate Farms	Methane Emissions Reductions (Thousand Tons)	Methane Production Potential (billion ft^3/ year)	Energy Generation Potential (Thousand mmBtu/ year)	Electricity Generation Potential (Thousand MWh/year)
Swine Farms					
Iowa	1,997	301	21.5	6,243	1,829
North Carolina	939	203	13.2	3,826	1,121
Minnesota	707	63	7.3	2,119	621
Illinois	350	39	4.3	1,240	363
Missouri	154	34	3.5	1,028	301
Indiana	296	31	3.5	1,011	296
Oklahoma	56	51	3.4	997	292
Nebraska	177	27	3.2	927	272
Kansas	80	22	2.3	681	199
Texas	10	25	1.6	477	140
Remaining 40 States	830	109	10.6	3,096	907
Sub Total	5,596	905	74.4	21,645	6,341
Dairy Farms					
California	889	341	27.9	8,104	2,375
Idaho	203	99	8.9	2,601	762
New Mexico	110	64	5.3	1,553	455
Texas	155	66	5.0	1,463	429
Wisconsin	251	41	4.5	1,316	386
Washington	125	35	3.4	1,003	294
Arizona	54	44	3.1	898	263
Michigan	107	26	2.9	838	246
New York	111	18	2.1	603	177
Colorado	54	22	2.0	595	174
Remaining 40 States	588	152	14.6	4,244	1,243
Sub Total	2,647	908	79.7	23,218	6,804
U.S. Total	**8,243**	**1,813**	**154.1**	**44,863**	**13,145**

Table 4-3: Top ten states for potential electricity generation from swine and dairy farms (Data source: AgStar [17])

Municipal wastewater is yet another waste stream that is being used as a source of energy and that has potential for substantial expansion. According to the EPA 2011 study there were 104 waste treatment facilities that were capturing biogas and using it for electricity generation in combined heat and power (CHP) plants with a total 190 MW generating capacity. An additional 1,351 facilities had installed anaerobic digesters but not CHP plants. EPA estimated that if these facilities installed electricity generating equipment they could support a further 411 MW of electricity generation and 38,000 mmBtu per day of thermal energy [18]. In addition to the units listed in Table 4-4 SUFG is aware of an electricity generating plant at a second location in Indiana, giving the state a total capacity of 195 kW. More information about these plants is given in Section 4.4.

State	Number of Sites	Capacity (MW)
AR	1	1.73
AZ	1	0.29
CA	33	62.67
CO	2	7.07
CT	2	0.95
FL	3	13.50
IA	2	3.40
ID	2	0.45
IL	2	4.58
IN	1	0.13
MA	1	18.00
MD	2	3.33
MI	1	0.06
MN	4	7.19
MT	3	1.09
NE	3	5.40
NH	1	0.37
NJ	4	8.72
NY	6	3.01
OH	3	16.29
OR	10	6.42
PA	3	1.99
TX	1	4.20
UT	2	2.65
WA	5	14.18
WI	5	2.02
WY	1	0.03
Total	104	189.8

Table 4-4: Wastewater treatment combined heat and power systems in the U.S. (Data source: EPA [18])

Although crop residues are not in use today as a source of energy, they are the most readily available biomass feedstocks. According to the USDA/DOE Billion-Ton study referred to in Section 4.2, corn stover is the most abundant untapped source of biomass currently available from croplands. In the 2016 update of the Billion-Ton study, the total amount of agricultural residues projected to be produced in 2017 at a farm-gate price of $60 per dry ton is estimated at 89 million tons of corn stover, 13 million tons of wheat straw and one million ton of other types of grain crop residues [19].

4.4 Organic waste biomass in Indiana

Organic waste biomass, in particular wood residue and byproducts, has historically been the main source of renewable energy consumed in Indiana contributing over 80 percent of the renewable energy up to the 1980s, and over 60 percent in the 1990s. It was not until the rapid growth in corn ethanol production in the 2000s that waste biomass was overtaken by ethanol as the leading source of renewable energy consumed in Indiana. Figure 4-5 shows the contribution of the various renewable resources to the total annual energy consumed in Indiana since 1960. The types of industries using wood residue and byproducts include the paper and pulp industry that has traditionally used the paper-making byproducts for cogeneration of electricity and process heat.

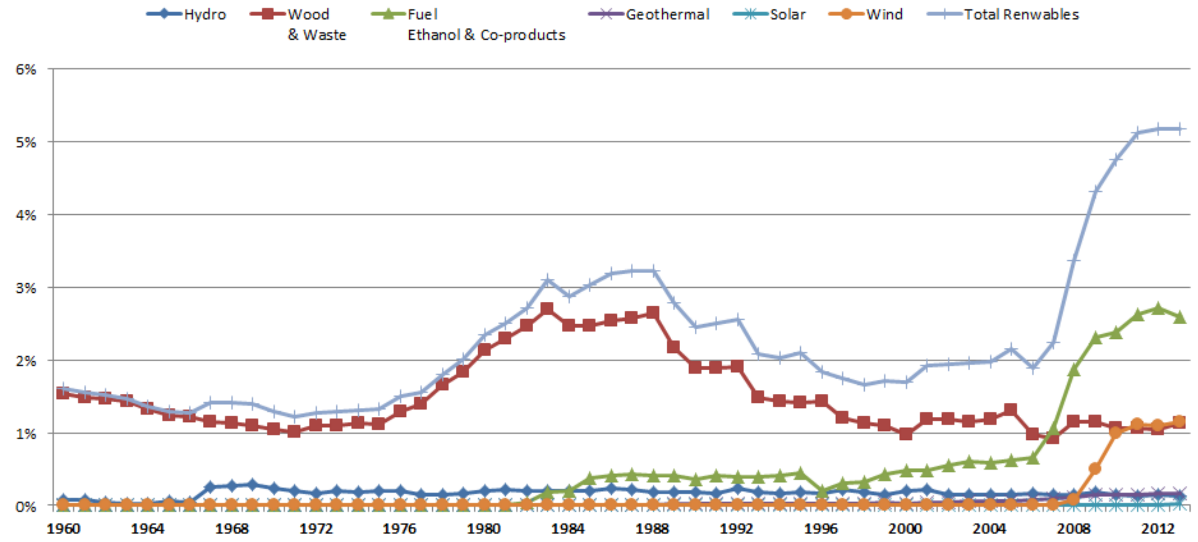


Figure 4-5: Renewables share of Indiana total energy consumption (1960-2013) (Source EIA [20])

Municipal solid waste is another major source of energy from waste biomass in Indiana, for example the Covanta Energy Corporation's Indianapolis facility uses municipal solid waste to generate steam 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 pounds of steam per ton of solid waste [21].

The other organic waste biomass that is a significant source of energy in Indiana is landfill gas. According to the EPA Landfill Methane Outreach Program there are 21 landfill gas electricity generating projects in Indiana with a combined 66.6 MW installed generating capacity. Table 4-5 provides a list of operational landfill gas electricity generating plants in Indiana in the EPA database. Wabash Valley Power Association (WVPA), with 42.4 MW listed in the EPA database, is the most active user of landfill gas for electricity generation. According to WVPA January 2016 Integrated Resource Plan their capacity is 4.8 MW higher than is listed by the EPA, and in addition they have one 6.4 MW project under construction in White County expected to be commissioned in 2016 [22].

Project Developer	Landfill Name	County	Generating Capacity (MW)	End User
	National Serv-All LF	Allen	6.4	General Motors Company
Aria Energy; Republic Services	County Line LF	Fulton	6	
Energy Systems Group	Blackfoot Landfill	Pike	3.2	Vectren Energy Delivery
Energy Systems Group	Munster LF	Lake	1.1	NIPSCO
Granger Energy	South Side Landfill Inc.	Marion	4	Rolls-Royce
Hoosier Energy	Clark-Floyd LF	Clark	2.14	Hoosier Energy
Hoosier Energy	Clark-Floyd LF	Clark	1.4	Hoosier Energy
WVPA	Deercroft RDF	LaPorte	3.2	WVPA
WVPA	Deercroft RDF	LaPorte	3.2	WVPA
WVPA	Earthmovers LF	Elkhart	4	WVPA
WVPA	Jay County LF	Jay	2.4	WVPA
WVPA	Liberty Landfill	White	3.2	WVPA
WVPA	Liberty Landfill	White	3.2	WVPA
WVPA	Oak Ridge RDF	Cass	3.2	WVPA
WVPA	Prairie View RDF	St. Joseph	3.2	WVPA
WVPA	Prairie View RDF	St. Joseph	3.2	WVPA
WVPA	Twin Bridges RDF	Hendricks	3.2	WVPA
WVPA	Twin Bridges RDF	Hendricks	3.2	WVPA
WVPA	Twin Bridges RDF	Hendricks	3.2	WVPA
WVPA	Wheeler RDF	LaPorte	0.8	WVPA
WVPA; WM Renewable Energy	Twin Bridges RDF	Hendricks	3.2	WVPA

Table 4-5: Electricity generating plants in Indiana landfills (Data source: EPA [23])

Giraldo in his 2013 Master’s thesis [24] estimated that 10 other landfills in Indiana had the technical characteristics necessary to support an additional 16.9 MW of electricity generating capacity as shown in Table 4-6.

Facility Name	Amount of garbage disposed on landfill (tons)	Potential electricity generation capacity (kW)
Clinton county	1,170,254	560
New Paris Pike	1,900,000	870
Decatur Hills	1,363,442	900
Hoosier 2	2,143,024	1,030
Bartholomew county 2	1,468,927	1,170
Medora Sanitary	2,509,000	1,200
Wabash Valley	4,488,770	2,290
County Line	4,694,835	2,400
United Refuse	7,125,327	2,440
Sycamore Ridge	4,579,067	4,060

Table 4-6: Potential electricity generating capacity in Indiana landfills (Data source: Giraldo [24])

Another source of biomass fuel used for electricity generation in Indiana is the anaerobic digestion of animal manure. There are 11 anaerobic digester projects installed in Indiana as shown in Table 4-7. The Culver Duck Farm project is unique in that it does not process the animal manure, but rather the by-products (offal and blood) from a duck processing plant. Table 4-7 shows the locations and electricity generating capacities of anaerobic digesters in Indiana farms arranged in decreasing installed electricity generating capacity. The combined installed generating capacity of these digesters is 16.65 MW. In addition, the Fair Oaks Dairy Farm has installed purification and compression equipment to produce biogas to run milk delivery trucks [25]. The potential to expand biogas production from livestock farms is substantial given that Indiana is ranked among the top ten with potential for producing 3.5 billion cubic feet of biogas per year from livestock manure digesters in 296 farms [17].

Farm/ Project Name	County	Year Operational	Animal Type	Population Feeding Digester	Biogas End Use(s)	Installed Capacity (kW)
Bio Town Ag, Inc.	White	2011	Swine and Cattle	5,300	Cogeneration	6,300
Green Cow Power LLC	Elkhart	2014	Dairy, food & biodiesel processing waste	1,500	Electricity	3,150*
Culver Duck Farm (processing plant)	Elkhart	2013	Ducks	105,000 gallons processing byproducts per week	Electricity	1,200#
Fair Oaks Dairy - Digester 2	Jasper	2008	Dairy	9,000	Cogeneration, CNG	1,090
Waste No Energy	White	2013	Swine and Cattle	4,300	Cogeneration	1,060
Hidden View	Jasper	2007	Dairy	3,500	Cogeneration	950
Homestead Dairy	Marshall	2013	Dairy	2,100	Electricity	800
Bos Dairy	Jasper	2005	Dairy	3,600	Electricity	700
Herrema Dairy	Jasper	2002	Dairy	3,750	Cogeneration	700
Fair Oaks Dairy - Digester 1	Jasper	2004	Dairy	3,000	Electricity	700
Windy Ridge Dairy	Jasper	2006	Dairy	7,000	Flared full time	0

*Data from Renewable Energy from Waste magazine website [26];

#Data from 2G Energy Corporation website [27]

Table 4-7: Operational Anaerobic Digesters in Indiana (Data source EPA [16], Purdue University Extension [28])

It is estimated that 144 concentrated animal feeding operations (CAFO) had the size and manure handling processes necessary to support an additional 20 MW of electricity generating capacity as shown in Table 4-8.

Operation type (size in head)	Number of candidate farms	Potential electrical generation capacity per farm (kW)	Potential electrical generation capacity per category (kW)
Dairy (500-999)	17	175	2,975
Dairy (1000-2499)	12	365	4,380
Dairy (2500 or more)	3	1,204	3,612
Hog farrow-to-wean (1000-1999)	4	22	88
Hog farrow-to-wean (2000-4999)	2	53	106
Hog farrow-to-wean (5000 or more)	2	184	368
Hog farrow-to-finish (1000-1999)	14	20	280
Hog farrow-to-finish (2000-4999)	14	43	602
Hog farrow-to-finish (5000 or more)	16	194	3,104
Hog finish only (1000-1999)	18	28	504
Hog finish only (2000-4999)	22	68	1,496
Hog finish only (5000 or more)	14	181	2,534
Hog nursery (1000-1999)	2	12	24
Hog nursery (2000-4999)	3	18	54
Hog nursery (5000 or more)	1	38	38
Total	144		20,165

Table 4-8: Potential electricity generating capacity in Indiana concentrated animal feeding operations (Data source: Giraldo [24])

Another biomass waste stream that is currently in use as a source of energy in Indiana is municipal wastewater. SUFG is aware of a total of 195 kW of electricity generating capacity in wastewater treatment plants (WWTP) in the cities of Jasper (65 kW) and West Lafayette (130 kW). The West Lafayette facility is also equipped to take in food related waste from Purdue University and other local businesses [29]. It is estimated that wastewater treatment plants in 17 Indiana cities had the volume and processing infrastructure necessary to support an additional 10 MW of electricity generating capacity as shown in Table 4-9.

Facility name	Average flow (MGD)	Potential electricity generation capacity (kW)
Noblesville WWTP	5.0	130
Speedway WWTP	5.5	143
Shelbyville WWTP	6.8	177
Elkhart WWTP	8.3	216
J.B. Gifford WWTP	8.5	221
William Edwin Ross WWTP	9.0	234
Anderson WWTP	12.0	312
Mishawaka WWTP	12.0	312
Evansville Eastside WWTP	18.0	468
Muncie WWTP	19.0	494
Lafayette WWTP	20.7	537
Terre Haute WWTP	24.0	624
Hammond WWTP	27.0	702
City of South Bend WWTP	36.0	936
Gary Sanitary District	50.0	1,300
Fort Wayne WPCP	62.0	1,612
Carmel South WWTP	95.0	2,470
Total		**10,888**

Table 4-9: Potential electricity generating capacity in Indiana wastewater treatment plants (Data source: Giraldo [24])

Figure 4-6 shows the amount of agricultural and forest biomass residue potentially available for energy production in Indiana in 2030 at various bioenergy feedstock prices according to the 2016 billion-study KDF database referred to earlier in this section. As can be seen in the figure, the most abundant residue available is corn stover increasing from approximately 4.9 million dry tons per year at an offer price of $50 per dry ton to 6.2 million dry tons per year at the higher price $60 per dry ton.

Figure 4-6: Estimated biomass production potential in Indiana (Data source: DOE [19])

Assuming an energy content of 7,500 Btu/lb for agricultural residues, 9,000 Btu/lb for wood, and 8,500 Btu/lb for manure the total energy available from the residues collected when the price is $60 per dry ton would be 109 trillion Btu. This is approximately 4 percent of Indiana's annual energy consumption of 2,900 trillion Btu. If this energy was converted to electricity in a power plant operating at 21 percent efficiency it would result in 6,700 GWh of electric energy, approximately 6 percent of Indiana's 115,000 GWh annual electricity generation.

Two Indiana companies (Algaewheel and Stellarwind Bio Energy) are involved in algae development. In 2010 Algaewheel installed an algae based wastewater treatment system at the city of Reynolds as part of the Biotown USA initiative. The algae based system improves the waste treatment facility's energy efficiency by replacing the mechanical aeration system with an algae wheel that utilizes the symbiotic relationship between the algae and the waste treatment bacteria. Oxygen produced by algae serves as food for the bacteria while the bacteria in turn converts the wastewater bio-solids into food for the algae. In addition the algae produced is a biofuel that can be used in-house to supplement the facility's energy needs or sold to provide a revenue stream [30]. Stellarwind, on the other hand, is focused on producing oil from algae that has the potential for use in producing transportation fuels [31].

4.5 Incentives for organic waste biomass

The following incentives have been available to assist in the use of organic waste biomass.

Federal Incentives

- Renewable Electricity Production Tax Credit (PTC) provides 1.2 cents/kWh for open-loop biomass, landfill gas and municipal solid waste energy technologies. Organic waste biomass falls under the open-loop category. The PTC for open-loop biomass projects was extended to December 2016 by the Consolidated Appropriations Act 2016 [32].
- U.S. DOE Loan Guarantee Program (Section 1703, Title IV of Energy Policy Act of 2005) provides loan guarantees for large scale innovative, high technology risk renewable energy projects that reduce the emission of pollutants [32].
- Business Energy Investment Tax Credit (ITC) credits up to 30 percent of expenditures on qualified renewable energy systems. Municipal solid waste is the only biomass that qualifies for the ITC [32].
- Modified Accelerated Cost-Recovery System (MACRS) allows businesses to recover investments in qualified renewable energy technologies through depreciation deductions. A 50 percent first year bonus depreciation first provided for by the Economic Stimulus Act of 2008 has been extended to 2019. The bonus depreciation is reduced to 40 percent for 2018 and to 30 percent for 2019 [32].
- USDA Rural Energy for America Program (REAP) promotes energy efficiency and renewable energy for agricultural producers and rural small businesses through the use of grants and loan guarantees for energy efficiency improvements and renewable energy systems. The program covers up to 25 percent of costs [32].
- USDA Biorefinery Assistance Program offers loan guarantees for the development, construction or development of commercial-sized biorefineries. The program finances 80 percent of the cost of the biorefinery up to a maximum of $250 million [32].
- Clean Renewable Energy Bonds (CREBs) are tax credit bonds designed to offset the tax liability of not-for-profit entities such as public utilities, and local and state governments that, because of their structure, do not benefit from the traditional renewable energy production tax credit (PTC) [32].
- Qualified Energy Conservation Bonds (QECBs) are qualified tax credit bonds that state, local and tribal governments may use to finance renewable energy projects and other energy conservation measures. Unlike the Clean Renewable Energy Bonds (CREBS) QECBs are not subject to U.S. Department of Treasury approval. The bonds are allocated to states in proportion to the state's percentage of the U.S. population [32].

- High Energy Cost Grant Program administered by 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 [32].

- Green Power Purchasing Goal requires that 30 percent of energy used by federal agencies must be obtained from renewable resources by 2025 [32].

Indiana Incentives

- Net Metering Rule allows utility customers with renewable resource facilities with a maximum capacity of 1 MW to receive a credit for net excess generation in the next billing cycle [32].
- Community Conservation Challenge Grant provides $25,000-$100,000 in grants for community energy conservation projects that reduce energy consumption or displace the use of traditional energy sources. A total of $600,000 is allocated for 2016. Applications for the 2016 funding cycle are due by October 30 [32, 33].
- Sales and Use Tax Exemption for Electrical Generating Equipment exempts transactions involving manufacturing machinery, tools, and equipment used for the production of tangible personal property, which includes electricity, from state gross retail tax. However, only wind energy has clearly specified rules from the Department of Revenue [32].
- Clean Energy Portfolio Goal sets a voluntary goal of obtaining 4 percent between 2013 and 2018, 7 percent between 2019 and 2024, and 10 percent by 2025, of electricity from clean energy sources based on 2010 retail sales. Participation in the goal makes utilities eligible for incentives that can be used to pay for the compliance projects. The deadline to apply for incentives in the 2013 to 2018 period has expired [32].
- Northern Indiana Public Service Company (NIPSCO) offers feed-in tariff incentive rates for electricity generated from renewable resources for up to 15 years. The payment for biomass projects that are selected in the first lot in the capacity allocation process is $0.0918/kWh. The 4 MW cap for intermediate solar allocation 1 has been met [32, 34, 35].

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5. Solar Energy

5.1 Introduction

Solar energy is captured and converted into various forms of energy in two main ways: directly to electricity using photovoltaic cells and indirectly using solar thermal conversion technologies. The two conversion methods and associated technologies are presented in this report, starting with solar thermal conversion technologies in this section followed by photovoltaic cells in Section 6.

Solar thermal energy is captured using solar collectors, of which there are two main types: concentrating and non-concentrating collectors. Concentrating collectors use mirrors of various configurations to focus the solar energy onto a receiver containing a working fluid that is used to transfer the heat to a conversion engine. Concentrating collectors are typically used for electricity generating projects while non-concentrating collectors are typically used for applications such as water and space heating.

The most commonly used non-concentrating collectors are flat-plate designs. Flat-plate collectors consist of a flat-plate absorber, a transparent cover that allows solar energy to pass through while reducing heat loss, a heat-transport fluid flowing through tubes, and a heat insulating backing. 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 [1].

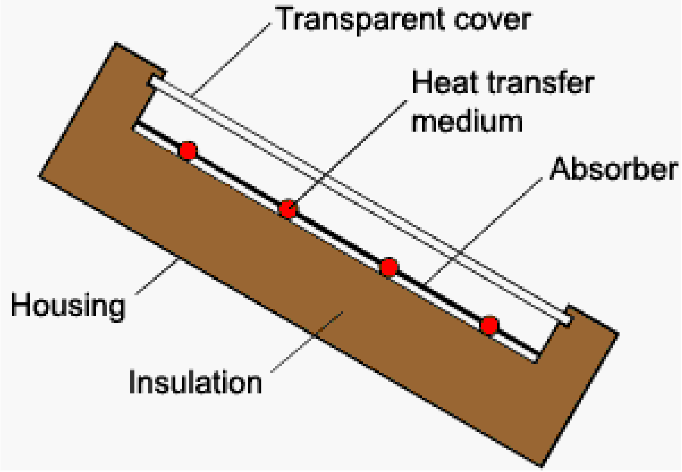

Figure 5-1: Cross-section layout of a flat-plate collector (Source: SolarServer [1])

The four main types of thermal concentrating solar power (CSP) systems are parabolic trough, linear Fresnel, solar power tower, and solar dish/engine system.

The parabolic trough CSP system has trough shaped collectors with a parabolic cross section and a receiver tube located at the focal line of the trough as shown in Figure 5-2. A working fluid is used to transport the heat from the receivers to heat exchangers. Trough CSP systems in use for utility scale electricity generation are typically coupled with a fossil-fuel fired boiler to supplement the supply of heat when the solar energy collected is not adequate. Trough systems can also be coupled with facilities to store the hot working fluid, thereby providing the ability for the plant to be dispatched to match system demand. The parabolic trough system is the most developed and widely used CSP technology in the U.S. and worldwide, with 1,289 MW out of the total 1,806 MW of installed CSP capacity in the U.S. being parabolic trough based.

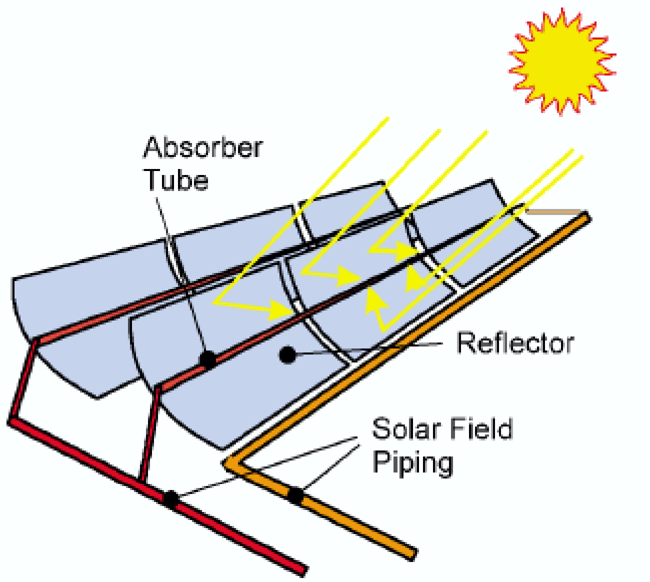

Figure 5-2: A parabolic trough CSP system (Source: NREL [2, 3])

The linear Fresnel CSP system functions a lot like the parabolic trough system except for the collectors where the parabolic trough is replaced with a series of flat or slightly curved mirrors that focus the radiation onto a receiver tube as shown in Figure 5-3. There is currently one linear Fresnel project in operation and one under construction in the U.S. The operating one is the 5 MW Kimberlina plant in Bakersfield, California and the one under construction is the 5 MW Tucson Electric Power Sundt Boost project in Tucson, Arizona [4].

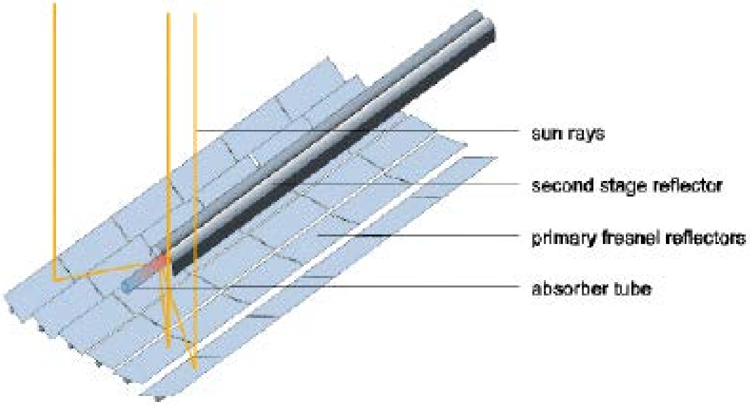

Figure 5-3: A linear Fresnel CSP system (Source: IEA [2, 3])

The power tower CSP system utilizes thousands of flat sun-tracking mirrors, or heliostats which concentrate the solar energy on a tower-mounted heat exchanger as shown in Figure 5-4. This system avoids the heat lost during transportation of the working fluid to the central heat exchanger in a trough-based CSP system. Power tower CSP systems 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]. There are three power tower projects in the U.S.: the 392 MW Ivanpah project in the Mojave Desert in California, the 110 MW Crescent Dunes project in Tonopah, Nevada and the 5 MW Sierra Sun Tower plant in Lancaster, California [6].

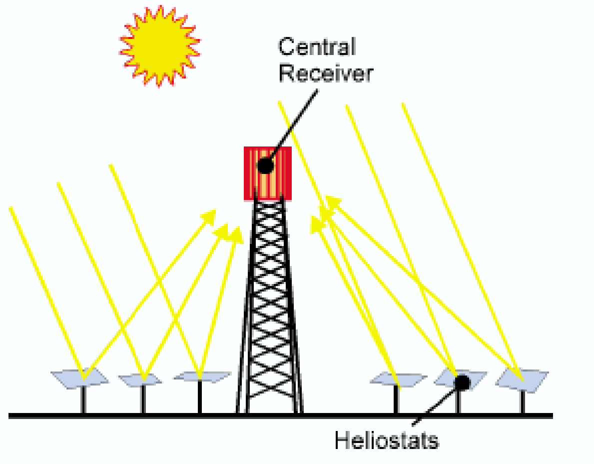

Figure 5-4: A power tower CSP system (Source: NREL [2, 3])

The dish/engine system utilizes a parabolic shaped dish that focuses the sun's rays to a receiver at the focal point of the dish as shown in Figure 5-5. An engine/generator located at the focal point of the dish converts the absorbed heat into electricity. Many of these dish systems may be combined to make a utility-scale power plant. The dish/engine design results in the highest efficiency of the solar thermal designs [2]. The dish/engine system does not use any cooling water which puts it at an advantage over the other three systems. However, it is the least developed of the three CSP technologies with several challenges to be overcome in the design of the reflectors and the solar collectors. The only dish/engine CSP plant in the U.S. is a 1.5 MW project at the Tooele Army Depot in Utah [6].

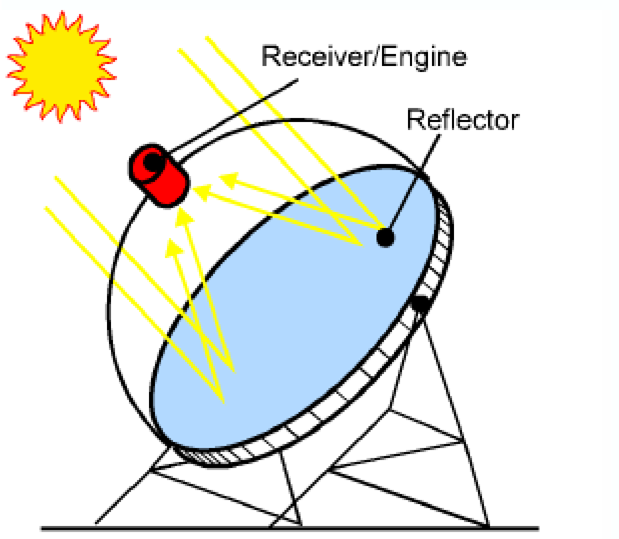

Figure 5-5: A dish/engine CSP system (Source: NREL [2, 3])

5.2 Economics of solar technologies

Table 5-1 shows the overnight capital cost[11] estimates for CSP power plants currently in operation in the U.S. for which they were available from the National Renewable Energy Laboratory (NREL) [6]. The per kilowatt cost varies widely, ranging from a low of $2,250/kW for the Colorado Integrated Solar Project in Palisades, Colorado to a high of $8,000/kW for the Solana Station in Phoenix, Arizona.

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[11] Overnight capital cost "*is an estimate of the cost at which a plant could be constructed assuming that the entire process from planning through completion could be accomplished in a single day*" [7]. The overnight cost concept is used to avoid the impact of the differences in financing methods chosen by project developers on the estimated costs.

Project Name	Developer, Owner	Location	Capacity (MW)	Technology	Online Date	Capital cost ($/kW)	Thermal storage (hours)
Solana Generating Station	Abengoa	Phoenix, Arizona	250	Parabolic Trough	2013	8,000	6
Martin Next Generation Solar Energy Center	Florida Power & Light	Indian Town Florida	75	Parabolic Trough	2010	6,351	None
Ivanpah Solar Electric Generating System	BrightSource Energy	Primm, CA	377	Power Tower	2013	5,836	None
Mojave Solar Project	Abengoa	Harper Dry Lake, California	280	Parabolic Trough	2014	5,714	None
Saguaro Power Plant	Arizona Public Service	Red Rock, AZ	1.16	Parabolic Trough	2006	5,172	None
Nevada Solar One	Acciona	Boulder City, Nevada	64	Parabolic Trough	2007	4,156	0.5
Colorado Integrated Solar Project	Xcel Energy /Abengoa Solar	Palisade, Colorado	2	Parabolic Trough	2010	2,250	None

Table 5-1: Estimated capital cost of CSP plants in the U.S. (Sources NREL [6])

Figure 5-6 shows the overnight capital cost estimates of utility scale electricity generating technologies given in the June 2016 EIA update of generating plant costs [7] sorted in order of decreasing capital cost. The solar thermal technology's capital cost of approximately $4,168 /kW is in the mid-range among the renewable technologies between the low end of wind generation at $1,644/kW and the high end $8,511/kW for municipal solid waste based generation technology.

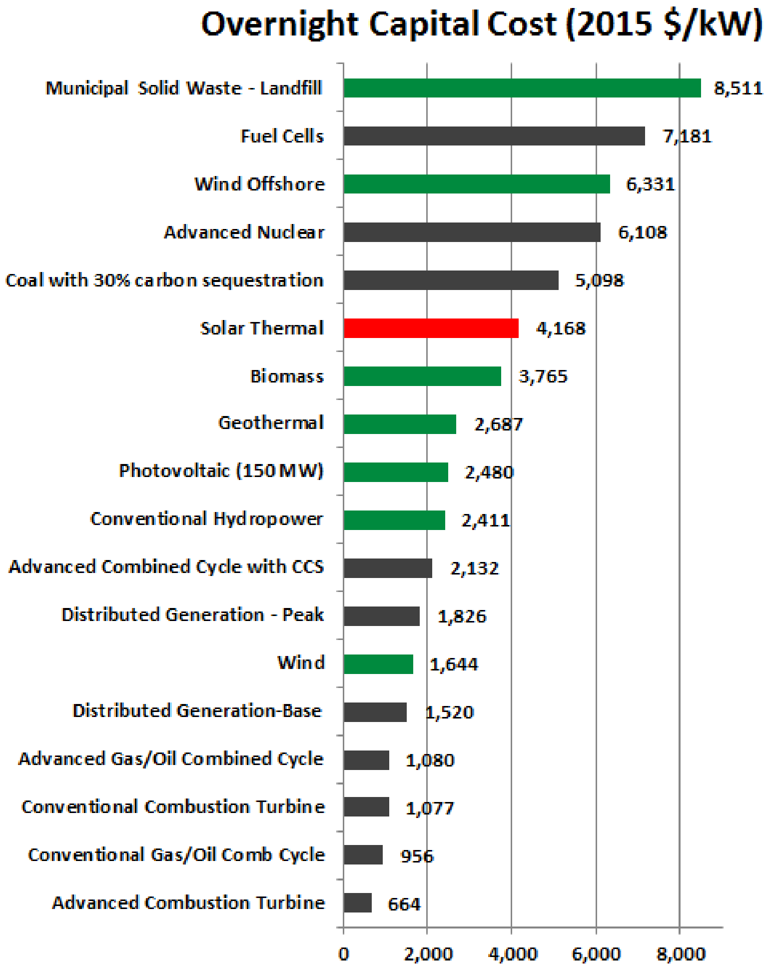


Figure 5-6: Estimated capital cost of generating technologies (Data source: EIA [7])

Figure 5-7 shows the estimate of the fixed and variable operating and maintenance (O&M) costs. As can be seen in Figure 5-7 solar thermal technology has moderate O&M cost, with a zero variable O&M cost and a fixed annual O&M cost of $69/kW. This fixed annual O&M cost is higher than that of photovoltaic technologies which is estimated at $21/kW for large scale photovoltaic plants systems.

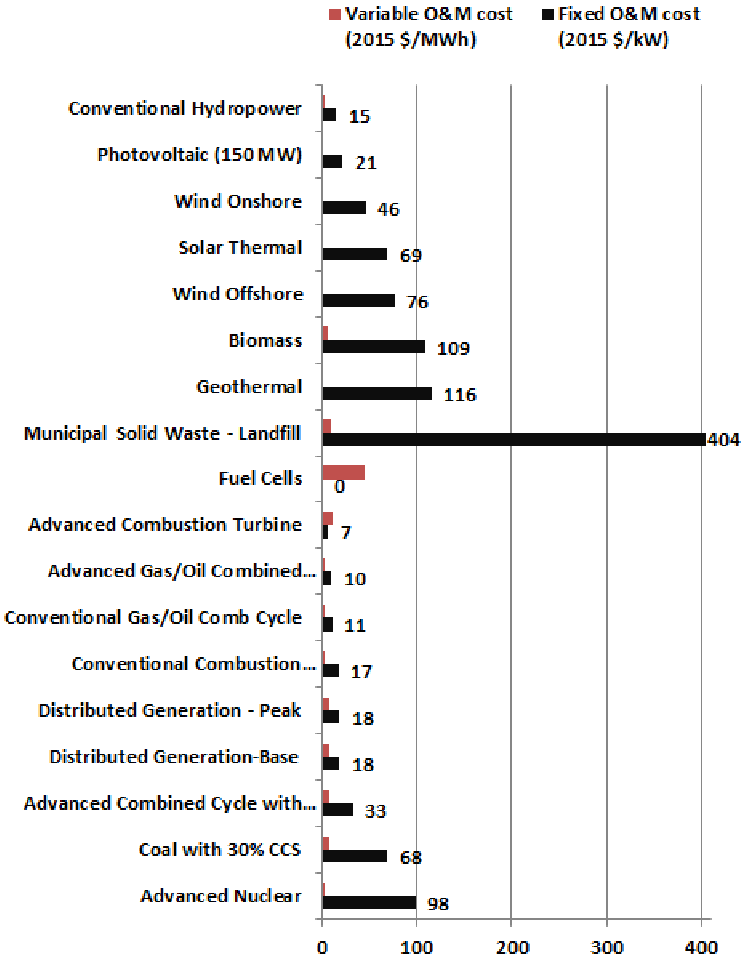
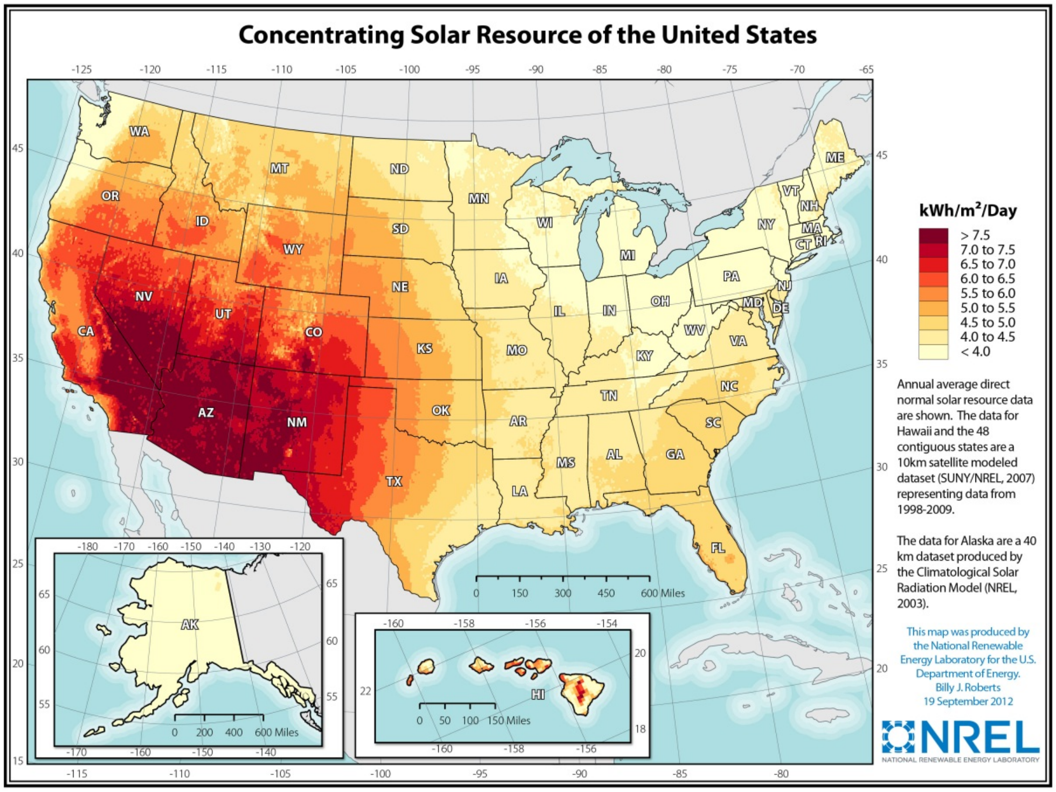


Figure 5-7: Operating and maintenance cost of generating technologies (Data source: EIA [7])

5.3 State of solar energy nationally

As can be seen in Figure 5-8, there are substantial solar resources available in the U.S., especially in the southwestern region.


Concentrating Solar Resource of the United States

Annual average direct normal solar resource data are shown. The data for Hawaii and the 48 contiguous states are a 10km satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998-2009.

The data for Alaska are a 40 km dataset produced by the Climatological Solar Radiation Model (NREL, 2003).

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.
Billy J. Roberts
19 September 2012

Figure 5-8: Concentrating solar power resource in the U.S. (Source: NREL [8])

Like the PV systems presented in Section 6, there has been a surge in the installation of CSP capacity in the U.S. in the last 10 years. After a period of approximately 15 years when no new CSP capacity was built in the U.S., the first major project, the 64 MW Nevada Solar One CSP project in Boulder City, Nevada was commissioned in 2007. Figure 5-9 shows the annual and cumulative capacity additions in the U.S.

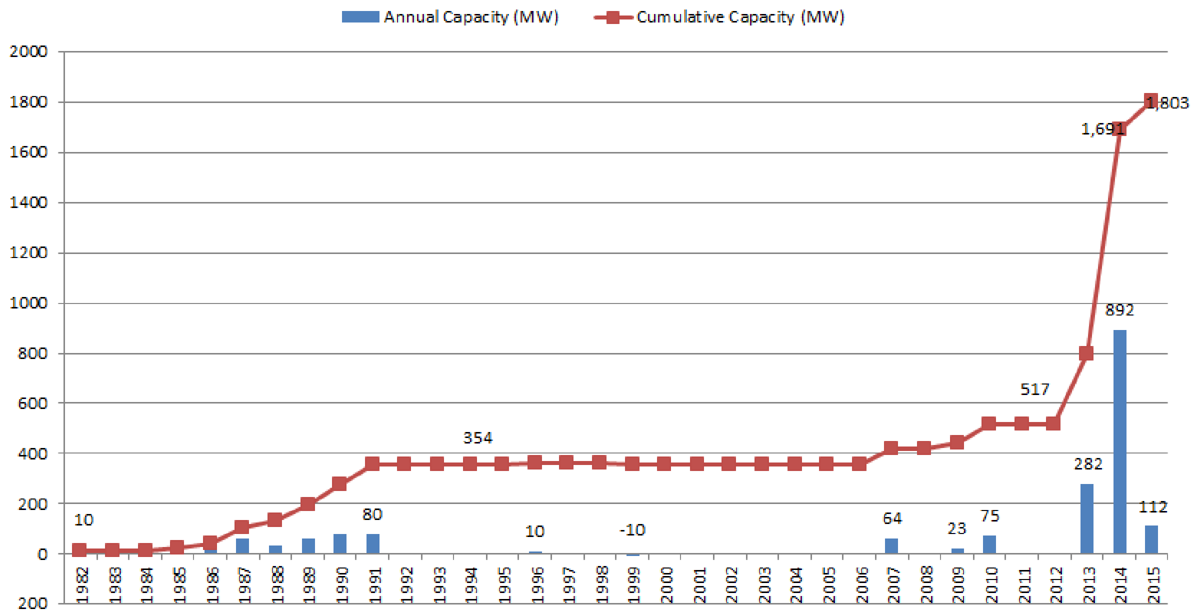


Figure 5-9: Solar thermal power capacity installed in the U.S. (Data sources: NREL [6], SEIA [9], IREC [10], Go Solar [11])

Since 2005 a total of fourteen CSP projects with a combined installed capacity of 1,449 MW have been added, bringing the total CSP installed capacity in the U.S. to 1,803 MW. Five of these large projects, with a combined capacity of 1,282 MW, were completed in 2013 - 2015. The largest of these is the 392 MW Ivanpah power tower in the Mojave Desert in California. The other four are the 280 MW Solana project near Gila Bend, Arizona; the 250 MW Genesis project in Riverside County, California; the 250 MW Mojave solar project also located in the Mojave Desert of California and the 110 MW Crescent Dunes project in Tonopah, Nevada. Table 5-2 contains a list of CSP projects in operation in the U.S. as of the writing of this report. A 5 MW linear fresnel project under construction at the Tucson Electric Power Sundt power plant is expected to be commissioned before the end of 2016 [4].

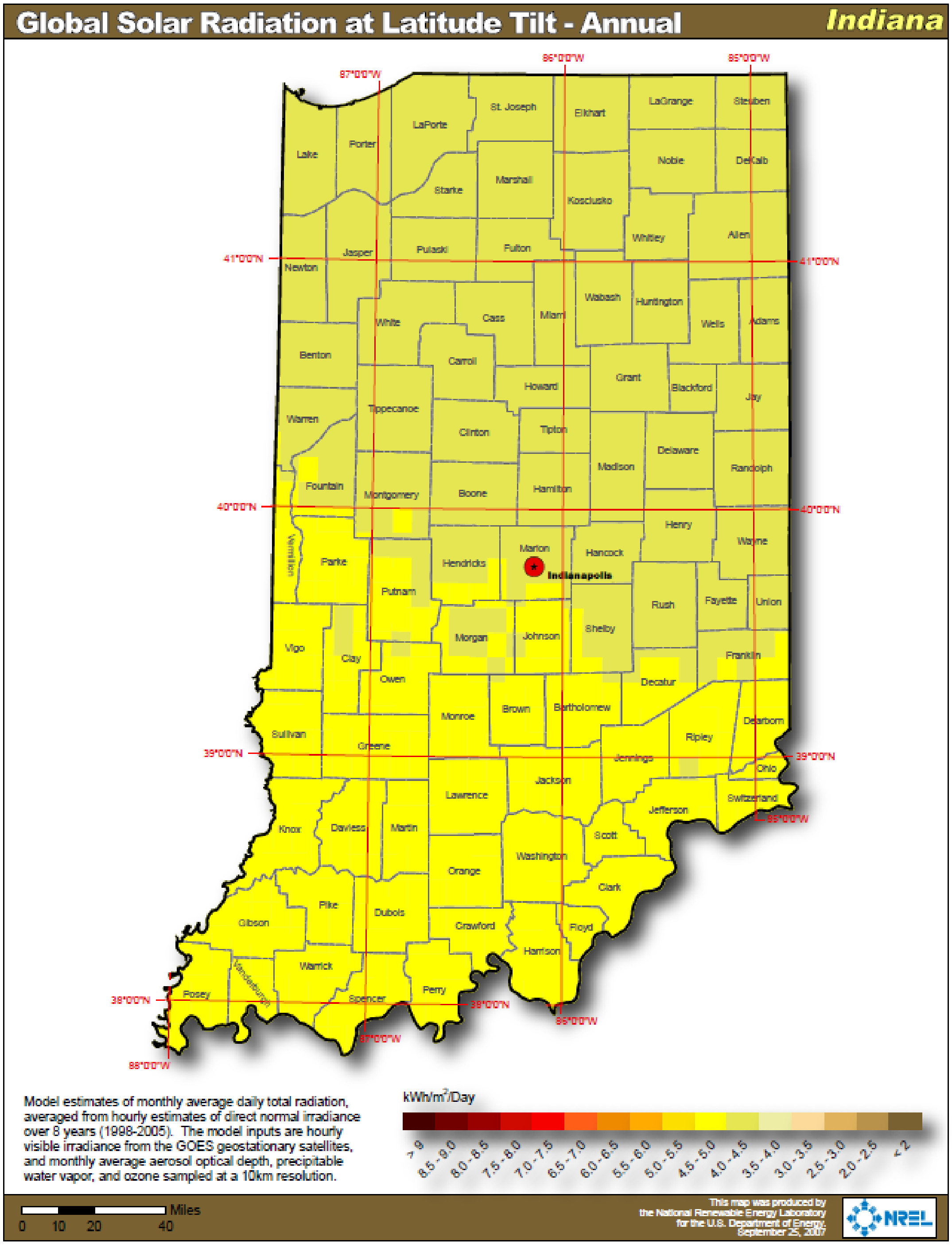
Project Name	**State**	**Capacity (MW)**	**Technology**	**Online Date**
Solar Energy Generating Systems (SEGS) I	CA	14	Parabolic trough	1985
SEGS II	CA	30	Parabolic Trough	1986
SEGS III	CA	30	Parabolic Trough	1987
SEGS IV	CA	30	Parabolic Trough	1987
SEGS V	CA	30	Parabolic Trough	1988
SEGS VI	CA	30	Parabolic Trough	1989
SEGS VII	CA	30	Parabolic Trough	1989
SEGS VIII	CA	80	Parabolic Trough	1990
SEGS IX	CA	80	Parabolic Trough	1991
Saguaro Solar Power Plant	AZ	1	Parabolic Trough	2005
Nevada Solar One	NV	75	Parabolic Trough	2007
Kimberlina	CA	5	Linear Fresnel	2009
Sierra SunTower	CA	5	Power Tower	2009
Holaniku at Keahole Point	HI	2	Parabolic Trough	2009
Martin Next Generation Solar	FL	75	Parabolic Trough	2010
Tooele Army Depot	UT	1.5	Dish/engine	2013
Solana	AZ	280	Parabolic Trough	2013
Ivanpah Solar Energy	CA	392	Power Tower	2014
Genesis Solar Energy Project	CA	250	Parabolic Trough	2014
Mojave Solar	CA	250	Parabolic Trough	2014
Crescent Dunes	NV	110	Power Tower	2015
Stillwater GeoSolar Hybrid	NV	2	Parabolic Trough	2015

Table 5-2: Operating concentrating solar power plants in the U.S. (Data sources: NREL [6], CSPToday [12], SEIA [9])

5.4 Solar energy in Indiana

As can be seen in the U.S. solar radiation map (Figures 5-8), Indiana is in a region of the country that has comparably low annual average solar radiation. This combined with the relatively low retail electricity rates makes Indiana a less than ideal location for multi-megawatt CSP plants compared to such states as California, Arizona, Nevada, and Florida. The 1,689 MW of solar thermal power plants in the U.S. are located in five states as follows: California – 1,256 MW, Arizona – 281 MW, Florida – 75 MW, Nevada – 75 MW, and Hawaii – 2 MW. However, there is some potential for water heating applications of solar thermal technologies in Indiana.

Figure 5-10 shows the solar radiation available to a flat collector facing south in Indiana. Flat plate collectors are typically used for water heating applications. As can be seen in the figure, the southern half of the state has more radiation available.



Model estimates of monthly average daily total radiation, averaged from hourly estimates of direct normal irradiance over 8 years (1998-2005). The model inputs are hourly visible irradiance from the GOES geostationary satellites, and monthly average aerosol optical depth, precipitable water vapor, and ozone sampled at a 10km resolution.

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy. September 25, 2007

<u>Figure 5-10:</u> <u>Direct normal solar radiation (flat-plate collector) in Indiana</u> (Source: NREL [13])

5.5 Incentives for solar energy

The following incentives are available for solar thermal energy projects:

Federal Incentives

- U.S. DOE Loan Guarantee Program (Section 1703, Title IV of Energy Policy Act of 2005) provides loan guarantees for large scale innovative, high technology risk renewable energy projects that reduce the emission of pollutants [14].
- Business Energy Investment Tax Credit (ITC) credits up to 30 percent of expenditures on solar systems. The credit scales down to 26 percent in 2020, 22 percent in 2021 and 10 percent in subsequent years [14].
- Modified Accelerated Cost-Recovery System (MACRS) allows businesses to recover investments in qualified renewable energy technologies through depreciation deductions. A 50 percent first year bonus depreciation first provided for by the Economic Stimulus Act of 2008 has been extended to 2019. The bonus depreciation is reduced to 40 percent for 2018 and to 30 percent for 2019 [14].
- USDA Rural Energy for America Program (REAP) promotes energy efficiency and renewable energy for agricultural producers and rural small businesses through the use of grants and loan guarantees for energy efficiency improvements and renewable energy systems. The program covers up to 25 percent of costs [14].
- Clean Renewable Energy Bonds (CREBs) are tax credit bonds designed to offset the tax liability of not-for-profit entities such as public utilities, and local and state governments that, because of their structure, do not benefit from the traditional renewable energy production tax credit (PTC) [14].
- Qualified Energy Conservation Bonds (QECBs) are qualified tax credit bonds that state, local and tribal governments may use to finance renewable energy projects and other energy conservation measures. Unlike the Clean Renewable Energy Bonds (CREBS) QECBs are not subject to U.S. Department of Treasury approval. The volume of the bonds is allocated to states in proportion to the state's percentage of the U.S. population [14].
- USDA High Energy Cost Grant Program 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 [14, 15].
- Residential Renewable Energy Tax Credit allows taxpayers to claim 30 percent of their qualifying expenditures on installation of renewable energy technologies including solar electric systems, solar water heaters, wind turbines and geothermal heat pumps [14].
- Green Power Purchasing Goal requires that 30 percent of energy used by federal agencies must be obtained from renewable resources by 2025 [14].
- Energy Efficiency Mortgage can be used by homeowners to finance a variety of energy efficiency measures, including renewable energy technologies, in new or existing homes. The federal government supports these loans by insuring them through the Federal Housing

Authority or the Department of Veterans Affairs [14].

Indiana Incentives

- Solar Access Laws 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 [14].
- Net Metering Rule qualifies renewable resource facilities with a maximum capacity of 1 MW for net metering. The net excess generation is credited to the customer in the next billing cycle [14].
- Renewable Energy Property Tax Exemption provides property tax exemptions for solar thermal, PV, wind, hydroelectric and geothermal systems [14].
- Community Conservation Challenge Grant provides \$25,000-\$100,000 in grants for community energy conservation projects that reduce energy consumption or displace the use of traditional energy sources. A total of \$600,000 is allocated for 2016. Applications for the 2016 funding cycle are due by October 30 [14, 16].
- Clean Energy Portfolio Goal sets a voluntary goal of obtaining 4 percent between 2013 and 2018, 7 percent between 2019 and 2024, and 10 percent by 2025, of electricity from clean energy sources based on 2010 retail sales. Participation in the goal makes utilities eligible for incentives that can be used to pay for the compliance projects. The deadline to apply for incentives in the 2013 to 2018 period has expired [14].
- Northern Indiana Public Service Company (NIPSCO) offers feed-in tariff incentive rates for electricity generated from renewable resources for up to 15 years. The payment for solar systems from 5kW to under 10kW is \$0.17/kWh for the projects selected in the first capacity allocation lottery (*allocation 1*) and \$0.1564/kW for subsequent ones (*allocation 2*). The payment for solar systems larger than 10kW up to 200kW is \$0.15/kWh for projects in *allocation 1* and \$0.138 for those in *allocation 2.* The 4 MW cap for intermediate solar *allocation 1* has been met. [14, 17, 18].

5.6 References

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6. Photovoltaic Cells

6.1 Introduction

Unlike the solar thermal systems discussed in Section 5 of this report, photovoltaic (PV) cells convert solar energy directly into electricity without having to first convert it to heat. In addition, since PV cells use both direct and indirect sunlight, their use is more geographically widespread than solar thermal systems that require access to direct solar radiation. Figure 6-1 shows the layout and functioning of a PV cell. When the photons in sunlight strike the surface of a photovoltaic cell, some of them are absorbed. The absorbed photons cause free electrons to migrate in the cell, thus causing “holes.” The resulting imbalance of charge between the cell’s front and back surfaces creates a voltage potential like the negative and positive terminals of a battery. When these two surfaces are connected through an external load, electricity flows [1].

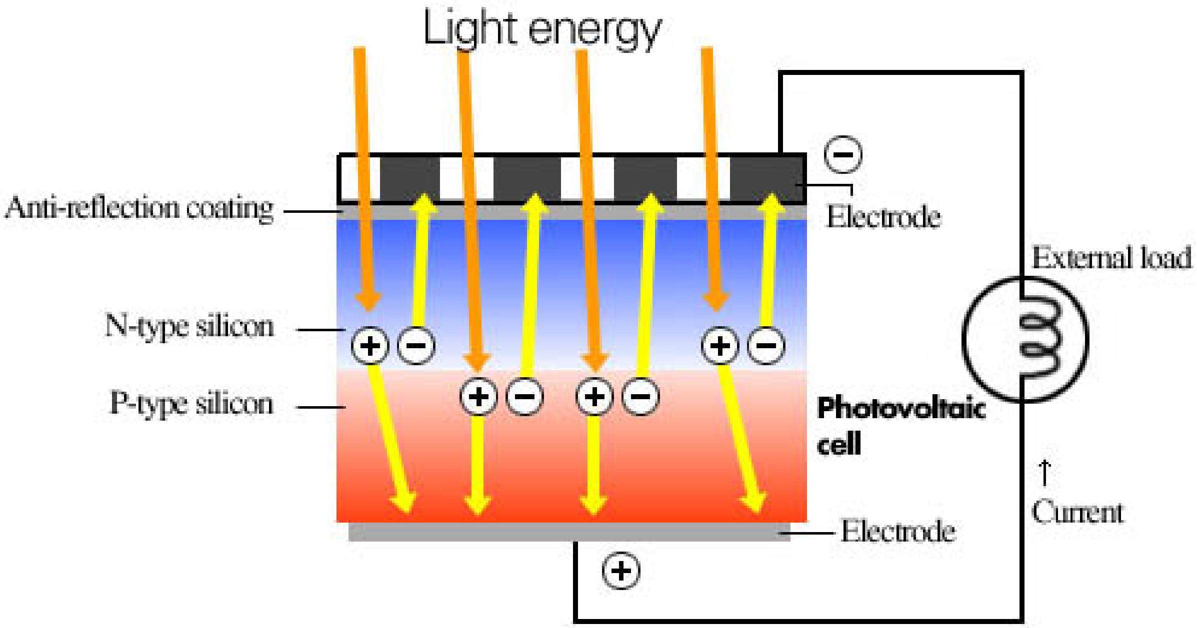

Figure 6-1: Photovoltaic cell operation (Source: EIA [2])

The photovoltaic cell is the basic building block of a PV system. Individual cells range in size from 0.5 to 4 inches across with a power output of 1 to 2 watts (W). To increase the power output of the PV unit, the cells are interconnected into a packaged, weather-tight module, typically with a 50-100 W power output as shown in Figure 6-2. Several PV modules are then connected to form an array.

A complete PV system will include other components such as inverters[12] and mounting systems [1, 3].

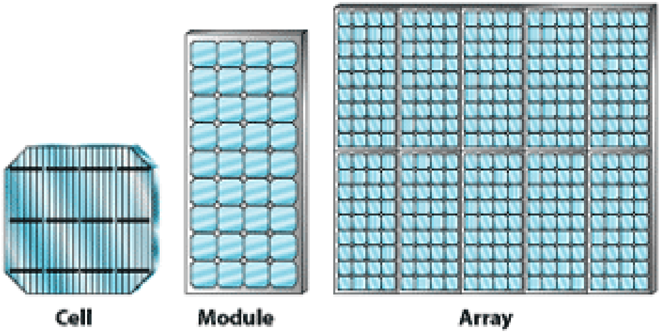

Figure 6-2: Illustration of a cell, module and array of a PV system (Source: EERE [3])

There are currently three main types of PV cell technologies in commercial use: crystalline silicon, thin-film and concentrating PV cells. Other PV cells being developed use new materials instead of silicon, including solar dyes, solar inks and organic polymers. The crystalline silicon cell is the most common PV cell technology and was the first PV technology to be developed. It was developed in the 1950s and was initially used to power satellites and smaller items like watches and electronic calculators. As the prices of PV systems declined, their use spread to other areas such as highway signs and other facilities remote from the electricity grid. In more recent years PV power systems have gained more widespread application as grid-connected generating resources with over 25 gigawatts (GW) of grid-connected PV systems installed in the U.S. since 2000 [4, 5].

Unlike crystalline silicon cells, thin-film cells are made by depositing thin layers of non-crystalline (amorphous) silicon or other photovoltaic material on low-cost substrate material. As a result, thin-film PV cells have a lower cost per unit of area than crystalline silicon cells. However, since they have a lower energy conversion efficiency, this cost advantage is reduced by the required larger surface area relative to a crystalline silicon PV system with the same power rating. One of the main advantages of thin-film PV cells is that they can be made into flexible panels that are easily fitted onto building structures such as roofing shingles, facades and glazing on sky lights

The third category of photovoltaic cell technology in commercial use is the concentrating photovoltaic cell (CPV) technology. CPV systems use optical lenses to focus the sun's rays onto small, high efficiency PV cells thus reducing the amount of photovoltaic material needed. Unlike the other photovoltaic technologies, CPV systems require direct sunlight and therefore their viability is restricted to sunny locations. At the writing of this report the SUFG was aware of twelve CPV systems in operation in the U.S. with a combined capacity of 60 MW [6, 7]. The largest of these is

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[12] Inverters change the direct current (DC) produced by the PV array to alternating current (AC) for household or business use or for injection into the power grid.

the 30 MW Alamosa Solar Generating Station installed in Alamosa, Colorado in 2012. Figure 6-3 shows the layout of a CPV cell.

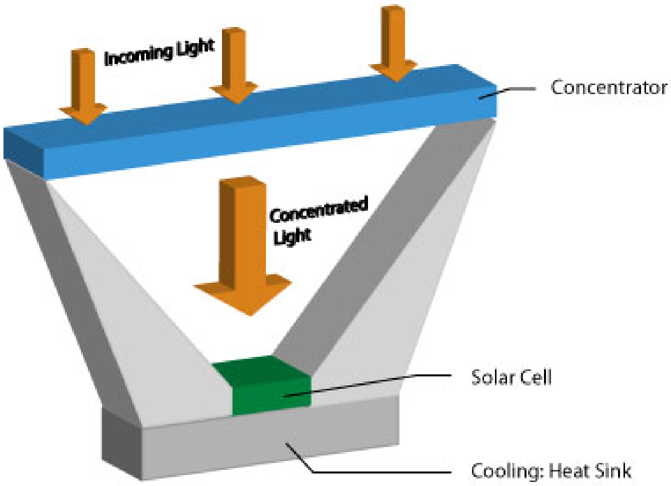
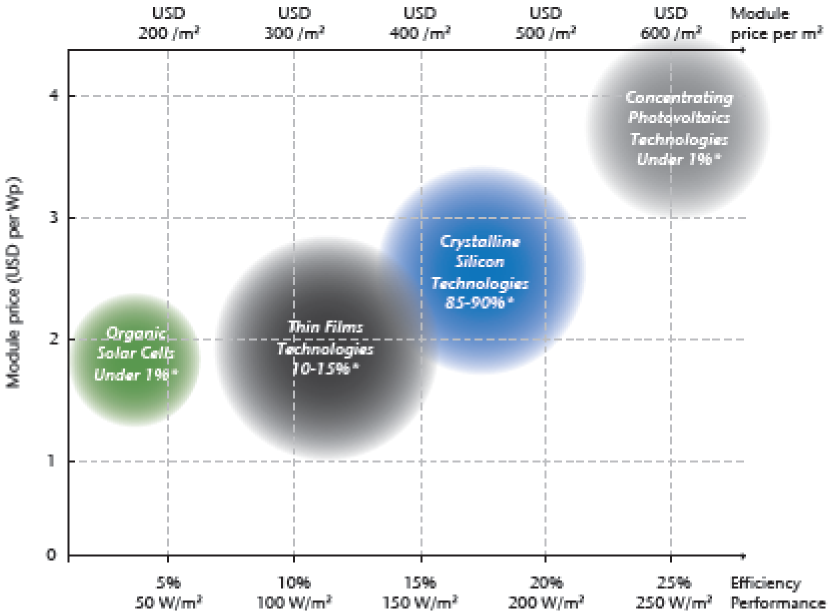


Figure 6-3: Illustration of concentrating photovoltaic cell (Source: Green Rhino Energy [8])

Figure 6-4 shows an overview of the costs, efficiencies, and energy output per unit of surface area of various PV cell technologies given by the International Energy Agency (IEA) in their 2010 roadmap. As can be seen in the figure, the crystalline silicon technology occupies a mid-range in the cost/efficiency continuum, thin-film technology's lower cost comes with a lower efficiency and the CPV technology's higher efficiency is coupled with proportionally higher cost. Figure 6-4 also shows the costs and efficiency of organic cells; however, this technology is still in the development phase. According to DOE limitations in their efficiency and their long-term reliability remain significant barriers to their commercial deployment [9].



*percentage share of 2008 global market

Figure 6-4: Performance and price of different PV technologies (Source IEA [1])

6.2 Economics of PV systems

Since 2008 the Lawrence Berkeley National Laboratory (LBNL) has issued an annual "*Tracking the Sun*" report that provides historical trends in the installed price of PV systems in the U.S. Starting in 2013 the report was split into two with one dedicated to utility-scale systems (ground-mounted with capacity greater than 5 MW) and the other to residential and non-residential systems (roof-mounted and all ground-mounted up to 5 MW). Figure 6-5 shows the price trends for the residential and non-residential systems up to 5 MW while Figure 6-6 shows the price trends for utility-scale systems. The system installed price shown in the figures is the upfront cost not including any financial incentives.

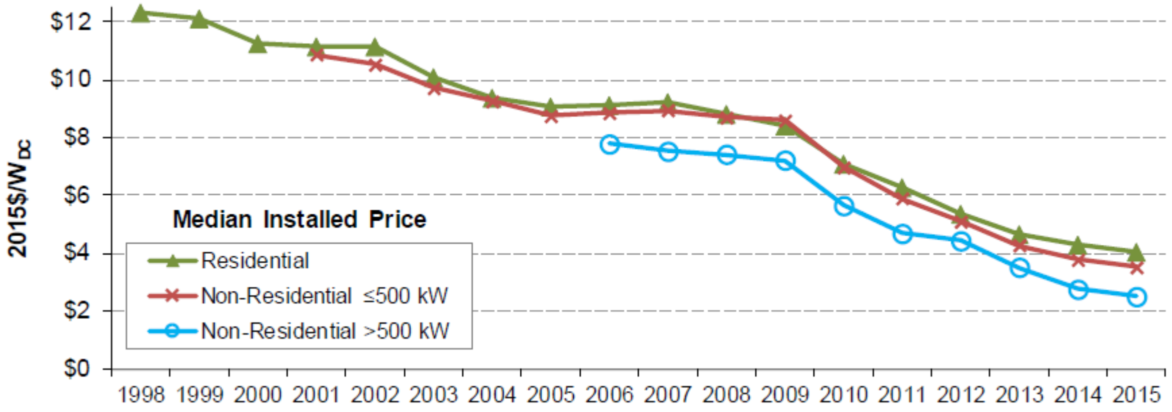


Figure 6-5: Installed price (\$/W$_{DC}$[13]) trends for residential and commercial PV systems (Source: LBNL [10])

As can be seen in Figure 6-5 the installed price for residential and commercial systems has been in steady decline over the entire period represented in the sample. According to the 2015 *Tracking the Sun VIII* report [11] the halt in the declining trend between 2005 and 2009 is attributed to a supply shortage as the PV suppliers struggled to keep pace with the rapid growth in PV installations worldwide. The steady decline in installed price resumed in 2010 dropping from approximately \$8/W in 2009 to \$4.1/W in 2015 for residential systems, \$3.5/W for non-residential systems up to 500kW and \$2.5/W for non-residential systems greater than 500 kW.

Figure 6-6 shows the installed price of the utility-scale PV projects in the Berkeley Labs database based on the year of the projects' commissioning. Over the time frame in the graph the capacity-weighted average price has dropped from \$5.8/W for the projects commissioned in the 2007-2009 period to \$3.8/W for the projects commissioned in 2013. Although there was an overall decline in installed prices, there is a wide spread in prices between individual projects, ranging from \$2.2/W to \$5.6/W for projects commissioned in 2013.

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[13] The direct current (DC) subscript in \$/W$_{DC}$ denotes that the price of the PV unit does not include the cost of the inverters needed to convert DC to AC.

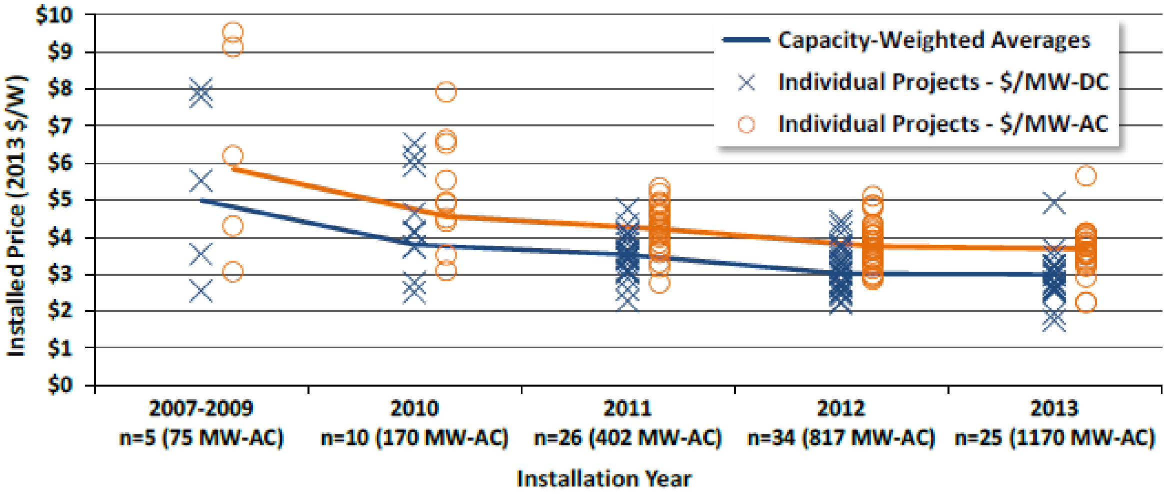

Figure 6-6: Installed price of utility-scale PV systems over time (Source: LBNL [12])

Figure 6-7 shows the construction cost in $/kW of utility side PV systems installed in the U.S. in 2013. The data included in this chart is for PV systems 1 MW or more installed on the utility side of the meter; that is, it does not include residential and other customer side distributed installations. As can be seen from the chart, the average cost of $3,705/kW is very close to the $3.8/W average price for the utility scale PV projects in the LBNL data shown in Figure 6-6.

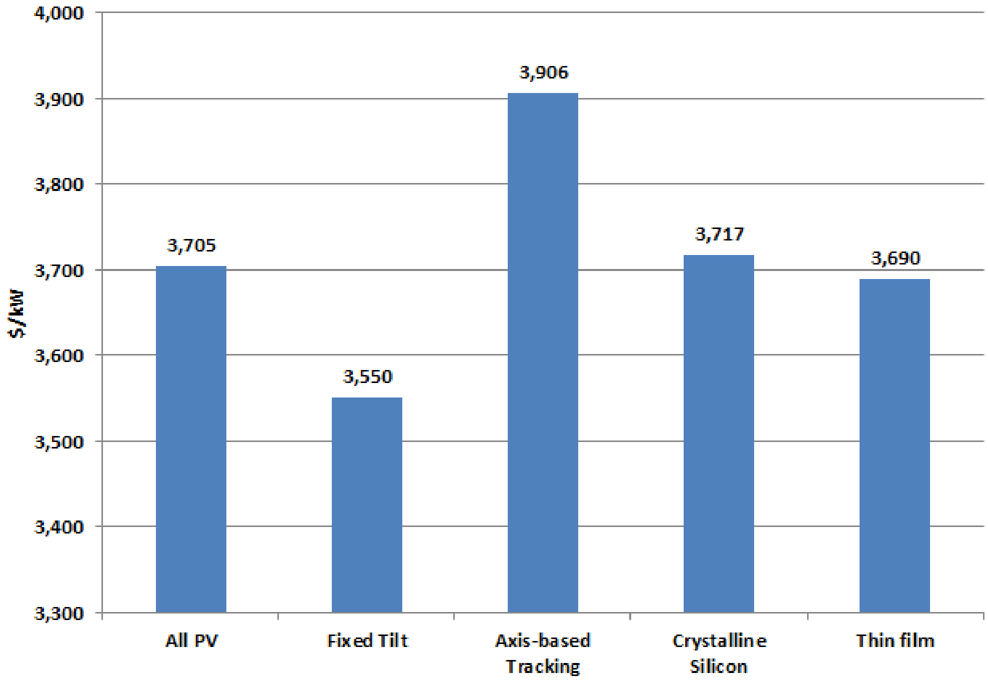

Figure 6-7: Average cost of PV systems of at least 1 MW installed in the U.S. in 2013 (Data Source: EIA [13])

Figure 6-8 shows EIA's estimates of the capital cost of utility scale photovoltaic electricity generating plants alongside other utility scale electricity generating technologies. The photovoltaic capital cost is mid-range among the renewable technologies at $2,480/kW. Onshore wind has the lowest estimated capital cost among the renewables at $1,644/kW and municipal solid waste has the highest at $8,511/kW.

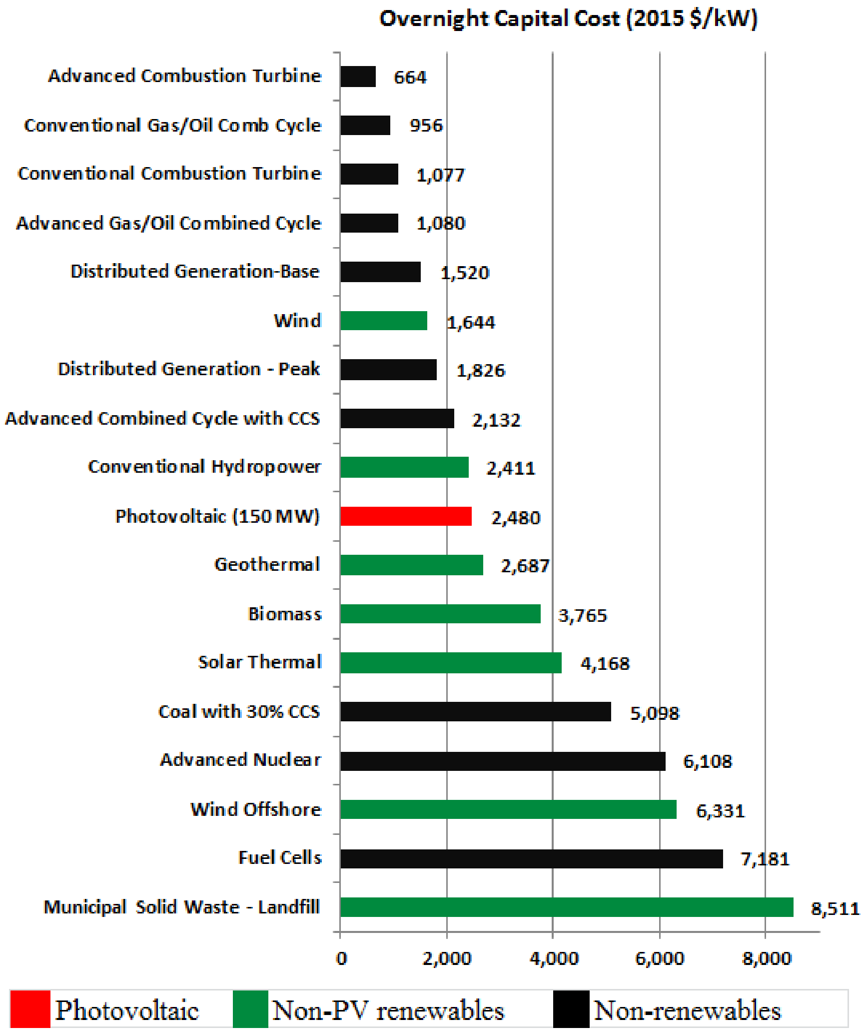

Figure 6-8: Estimated capital cost of generating technologies (Data source: EIA [14])

Figure 6-9 shows EIA's estimated fixed and variable O&M cost for utility scale photovoltaic electricity generating plants alongside other utility scale electricity generating technologies. The photovoltaic technology has among the lowest fixed O&M cost at $21/kW among the renewable energy technologies and virtually no variable O&M cost

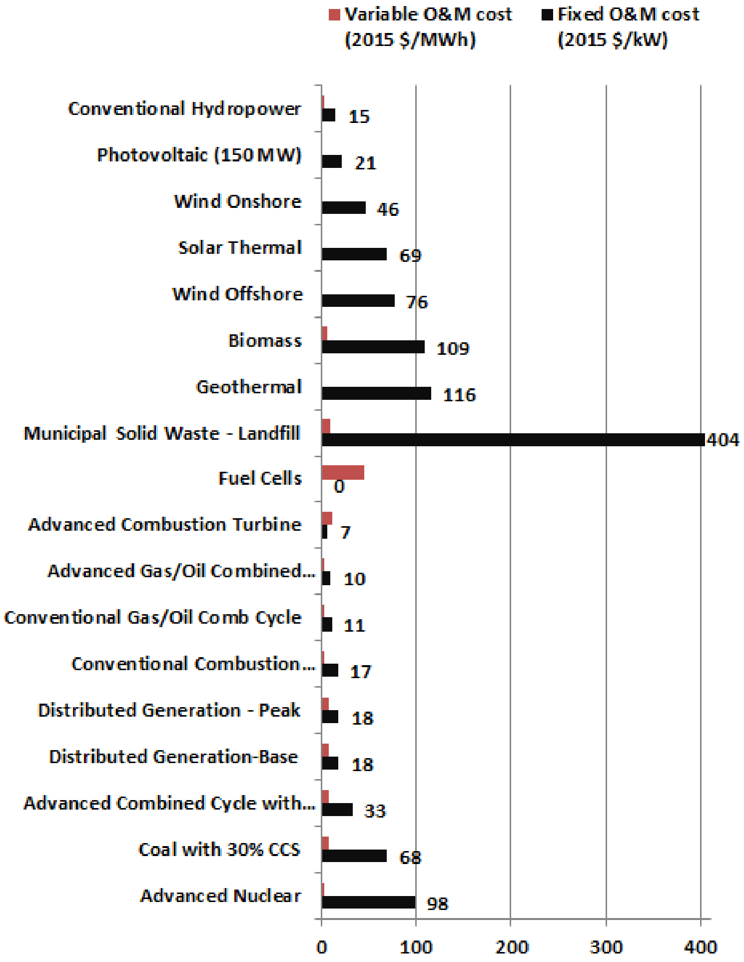

Figure 6-9: Estimated fixed and variable O&M cost of generating technologies (Data source: EIA [14])

6.3 State of PV systems nationally

PV installed capacity in the U.S. has been increasing rapidly in the last few years, growing from a mere 4 MW in 2000 to 25,592 MW at the end of 2015. Figure 6-10 shows the annual and the cumulative installed capacity of grid-connected PV systems in the U.S.

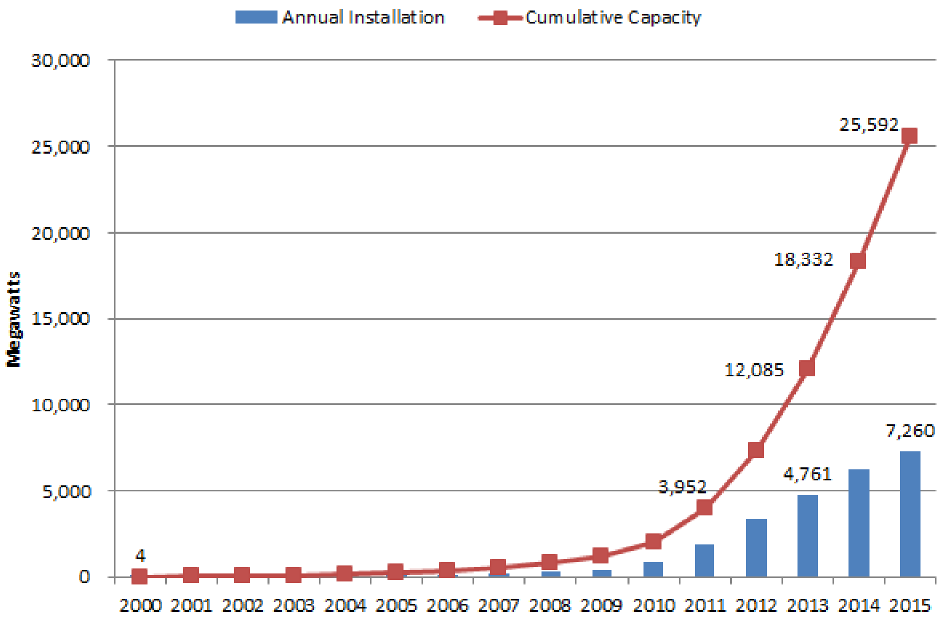

Figure 6-10: Grid-connected U.S. PV installed 2000 to 2015 (Data source: SEIA [15])

The main factors behind this rapid expansion have been state and federal financial incentives, state renewable portfolio standards (RPS) with specific provisions for solar technologies and the declining costs of PV panels. At the state level, 21 states and the District of Columbia have a RPS with a specific quota for solar or for customer-side distributed generation. PV systems are the most common renewable energy technologies in use for residential customer-side distributed generation. Figure 6-11 shows the various forms of solar provisions in state RPSs. Sixteen states and the District of Columbia offer rebates for PV projects and 46 states offer some form of financial incentive for PV projects [16].

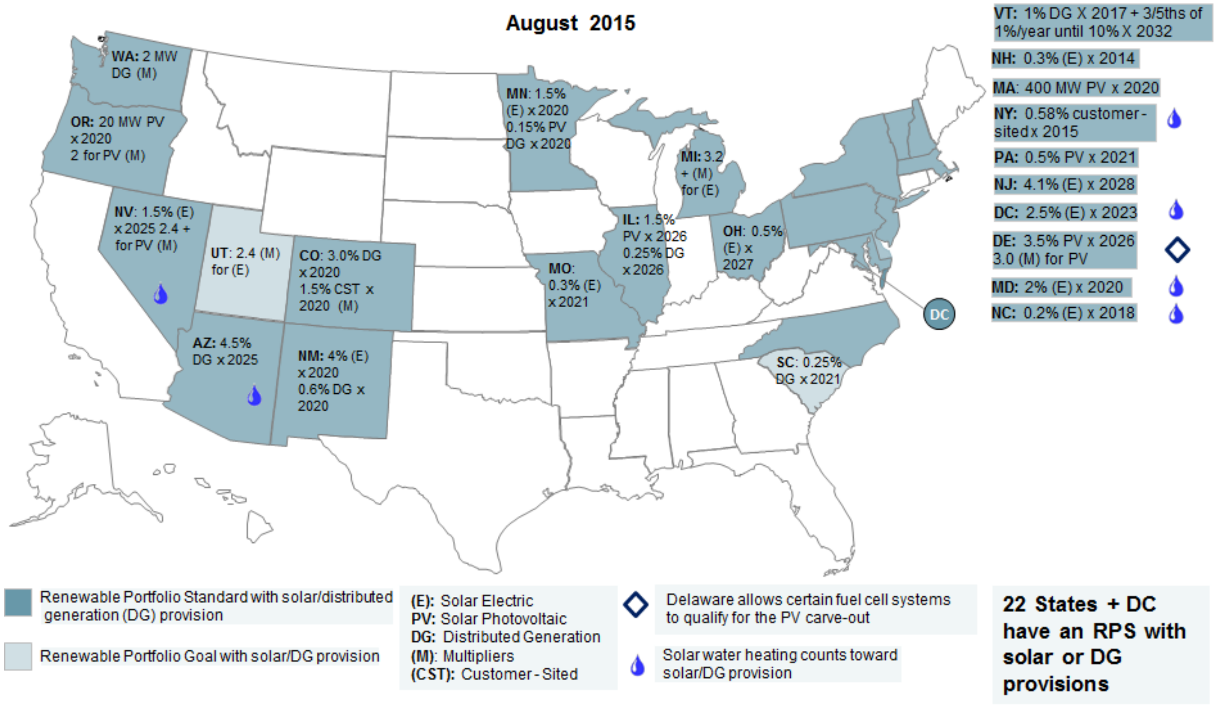

Figure 6-11: Renewable portfolio standards with solar carve-outs (Source: DSIRE [16])

Federal financial incentives introduced in 2008 and 2009 have added to the accelerated growth, especially in multi-megawatt utility scale projects. These federal incentives are:

- The extension and modification of the 30 percent investment tax credit (ITC) to remove the $2,000 cap on personal ITC and to allow electric utilities access to the ITC [16];
- The provision by the American Recovery and Reinvestment Act (ARRA) for a 30 percent cash grant in lieu of the ITC and the production tax credit, commonly known as the *1603 Treasury Grant Program* [17], and
- The provision in ARRA for funds for a U.S. Department of Energy (DOE) loan guarantee program targeted towards renewable energy resources and transmission projects commonly referred to as the Energy Policy Act *Section 1705 Program* [18].

The two ARRA funded programs, the *1603 Treasury Grant Program* and the Energy Policy Act *Section 1705 Program*, are no longer active having been retired at the end of 2011. However, DOE still has the authority issue the loan guarantees under the older Section 1703 program. The ITC in its current state is authorized through 2019 after which the amount of credit will be reduced gradually over a period of four years from 30 percent to 10 percent for solar systems.

Table 6-1 lists PV projects in the U.S. having a capacity 30 MW and above, all of which have been constructed since 2009.

Project Name	Developer	Capacity (MW)	Online Date	City/County	State
McCoy Solar Energy Center	NextEra	750	2016	Riverside County	CA
Solar Star	SunPower	579	2015	Rosamond	CA
Desert Sunlight	First Solar /Nextra	550	2015	Riverside County	CA
Topaz Solar Farm	First Solar	550	2014	Santa Mar	CA
Copper Mountain Solar	Sempra	458	2010 - 2015	Boulder City	NV
Agua Caliente	First Solar	290	2013	Dateland	AZ
Antelope Valley Solar	First Solar	250	2013	Lancaster	CA
Silver State South Solar	First Solar	250	2016	Primm	NV
California Valley Solar	SunEdison	250	2013	San Luis Obispo	CA
Mount Signal Solar Farm	8minutenergy	206	2014	Calexico	CA
Imperial Valley Solar	AES Solar	200	2013	Calexico	CA
Centinela Solar Energy	LS Power	175	2014	Calexico	CA
Mesquite Solar	Sempra	170		Tonopah	AZ
Solar Gen 2	First Solar	150		Brawley	CA
Campo Verde	First Solar	139	2013	El Centro	CA
Imperial Solar Energy Center South	First Solar	130	2013	Calexico	CA
Arlington Valley Solar	LS Power	125	2013	Arlington	AZ
Quinto Solar PV Project	SunPower	110	2016	Los Banos	CA
Catalina Solar I	EDF	110	2013	Rosamond	CA
Redhills Renewable Energy	Scatec Solar	104	2015	Iron Count	UT
Regulus Solar	SunPower	75	2014	Bakersfield	CA
Alpine Solar Project	First Solar	66	2013	Lancaster	CA
Warsaw Farm	Strata Solar	65	2015	Duplin	NC
North Star Solar	North Star Solar	63	2015	Mendota	CA
Red Horse 2	D. E. Shaw	51		Cochise County	AZ
Pavant Solar Farm	Juwi Solar Inc.	50	2015	Millard Co	UT
Alpaugh	GCL-Poly /Solar Solutions	50	2013	Alpaugh	CA
Silver State North Solar Project	First Solar	50	2012	Primm	NV
Macho Springs Solar Project	First Solar	50		Deming	NM

Table 6-1: PV systems with capacity of 50 MW and above installed in the U.S. (Data source: SEIA [6]

6.4 PV systems in Indiana

Similar to the nation, Indiana has seen a rapid growth in the amount of PV capacity installed in the last five years. According to the *Open PV Project* database maintained by NREL [19], there were 748 PV installations in Indiana totaling 130 MW at the end of May 2016. This was 5 MW less than the 135 MW total installed capacity reported to the IURC as of the end of July 2016. Reliable Indiana installed capacity totals for June and July were not available from the NREL *Open PV* database at the writing of this report. Figure 6-12 the shows the annual and cumulative PV capacity installations in Indiana as obtained from the NREL *Open PV Project* database and the IURC. As can be seen from Figure 6-12, 84 percent of that capacity (113 MW) was installed in 2013 and 2014.

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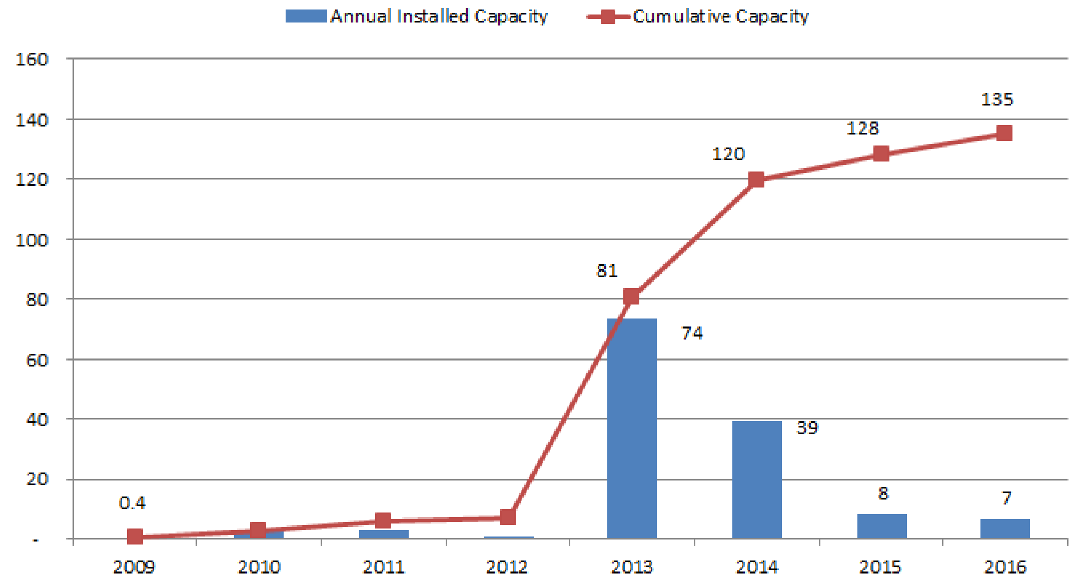

Figure 6-12: Indiana installed PV capacity (Data source NREL [19, 20])

Table 6-2 lists the PV installations in Indiana with a capacity greater than one MW.

Project	Location (County)	Capacity (MW_{AC})
Indianapolis Airport (I, IIA, IIB)	Marion	20.02
Indy Solar 1&II (Franklin Township)	Marion	20.00
Indianapolis Motor Speedway	Marion	9.00
Indy Solar No. 3 (Decatur Township)	Marion	8.64
Maywood / Vertellus	Marion	8.00
Lifeline Data Centers	Marion	4.00
CWA Authority	Marion	3.83
Duke Realty #129	Marion	3.40
Duke Realty #98	Marion	3.40
Crawfordsville Solar Park	Montgomery	3.00
Frankton Solar Park	Madison	3.00
Peru Solar Park	Miami	3.00
Rexnord Industries	Marion	2.80
Equity Industrial	Marion	2.73
Grocers Supply Company	Marion	2.73
Duke Realty #87	Marion	2.72
Lake County Solar, LLC - East Chicago	Lake	2.00
Lake County Solar, LLC - Griffith	Lake	2.00
Pendleton Solar Park	Madison	2.00
GSA Bean Finance Center	Marion	1.80
Citizens Energy (LNG North)	Marion	1.50
Lincoln Solar, LLC	Cass	1.50
Middlebury Solar, LLC	Elkhart	1.50
Portage Solar, LLC	Porter	1.50
Lanesville Solar	Harrison	1.10
Hobart Solar, LLC	Lake	1.00
New Castle Solar	Henry	1.00
Omnisource	Marion	1.00
Rensselaer Solar Farm	Jasper	1.00
Richmond Solar Farm	Wayne	1.00
Scotland Solar	Greene	1.00
Tell City Solar Park	Perry	1.00
Valparaiso Solar, LLC	Porter	1.00
Waterloo Solar, LLC	Dekalb	1.00

Table 6-2: PV systems in Indiana with capacity 1 MW and above (Data source: IURC [20])

Indiana utilities have several PV projects under development. The largest of these is a 17 MW project by Duke Energy at the Crane Naval Support Activity Center [21]. In addition, Duke has signed power purchase agreements totaling 20 MW with four PV projects under construction in Clay, Howard, Sullivan and Vigo Counties [22]. Indiana Michigan Power (I&M) has approval from the IURC to build five PV projects with a combined total of 15.7 MW in its service territory. The status of the projects is as shown in Table 6-3.

Project	Location	Capacity (MW)	Status
Deer Creek	Marion	2.5	Commissioned Dec 2015
Twin Branch	Mishawaka	2.6	commissioned Aug 2016
Olive	New Carlisle	5	commissioned Aug 2016
Watervliet	Watervliet (Michigan)	4.6	Under construction
To be determined	To be determined	1	Approved by IURC

Table 6-3: Indiana Michigan Power solar PV projects (Data source: I&M [23-27])

The Indiana Municipal Power Agency (IMPA) has plans to add five 10 MW projects in the next five years [28]. Hoosier Energy is in the process of adding ten 1 MW solar arrays across its member service territories. At least three of these projects had been completed at the writing of this report [29, 30].

As explained previously, the factors being credited with the rapid growth in the PV market in the last few years include federal, state and utility incentives. The federal incentives include the renewal and expansion of the investment tax credit to remove the $2,000 cap on personal tax credit and to allow electric utilities access to the investment tax credit. In addition, the 2009 American Recovery and Reinvestment Act provided for an alternative 30 percent cash grant in lieu of the investment tax credit and provided additional funds for renewable energy projects in the DOE loan guarantee program. The favorable factors in Indiana include the feed-in tariffs by IPL and NIPSCO and the expansion of the Indiana net metering rule to include all customer classes and systems up to 1 MW. The IPL feed-in-tariff expired in 2013. While it was in place, it paid $0.24/kWh for systems between 20 and 100 kW and $0.20/kWh for systems greater than 100kW up to 10 MW.

Although the first phase of the NIPSCO feed-in-tariff has expired, a second phase with a 10 MW allocation for solar projects has been in place since March 2015. The first phase of the NIPSCO feed-in-tariff had offered $0.30/kWh for electricity and the associated renewable credits for units less than 10 kW and $0.26 for solar facilities up to 2 MW.

The purchase rates for the second phase of the NIPSCO feed-in tariff are arranged into two categories referred to as *allocation 1* and *allocation 2* as shown in Table 6-4.

Technology	**Nameplate Range (kW)**	**Purchase Rate per kWh**		**Total system capacity available (MW)**
		Allocation 1	**Allocation 2**	
Micro Solar	5 – 10	$0.17	$0.1564	2
Intermediate Solar	> 10 – 200kW	$0.15	$0.138	8
Micro Wind	3 – 10	$0.25	$0.23	1
Intermediate Wind	> 10 – 200	$0.15	$0.138	1
Biomass	100 – 1,000	$0.0918	≤ $0.0918	4

Table 6-4: Purchase rates under NIPSCO renewable feed-in tariff (Data source: NIPSCO [31, 32])

The total capacity allocated for the NIPSCO feed-in-tariff phase two is 16 MW assigned to the two purchase rate categories (*allocation 1* and *allocation 2*) as follows

- For micro solar, micro wind and intermediate wind projects, the full system capacity limit for the technology as shown in Table 6-4 is made available to *allocation 1* by a lottery process. If any room is available after this process more projects will be accepted into the feed-in-tariff under the *allocation 2* category with a lower purchase rate as shown in Table 6-4.

- For intermediate solar (10 – 200kW), half of the 8 MW cap is available for *allocation 1* which runs from March 4, 2015 to March 4, 2017. The remaining 4 MW capacity will be made available under the *allocation 2* rate beginning March 4, 2017. The 4 MW cap for intermediate *solar allocation 1* has been met. Any further projects in this range (10 – 200kW) will be considered under the *allocation 2* category beginning March 4, 2017

- For biomass projects, half the system wide capacity limit for the technology is available for the *allocation 1* category from March 4, 2015 to March 4, 2017. The other half will be available in a reverse auction under the *allocation 2* category from March 4, 2017.

Table 6-5 shows the renewable generation contracted by Indiana utilities through their feed-in tariffs, and Table 6-6 shows generation contracted to Indiana utilities through the net metering programs.

	Wind (kW)	**Photovoltaic (kW)**	**Biomass (kW)**	**Total (kW)**
IPL	0	94,365	0	94,365
NIPSCO	180	15,440	14,348	29,968
Total kW	**180**	**109,805**	**14,348**	**124,333**

Table 6-5: Renewable generation contracted under feed-in tariffs (Data source: IURC [20])

	Wind (kW)	**Solar (kW)**	**Total (kW)**
Duke	2,212	3,904	6,116
Indiana Michigan	254	820	1,074
IPL	50	1,402	1,452
NIPSCO	2,100	811	2,911
Vectren	4	1,186	1,190
Total	**4,620**	**8,123**	**12,743**

Table 6-6: Renewable generation contracted under net metering (Data source: IURC [20])

6.5 Incentives for PV systems

Federal Incentives

- U.S. DOE Loan Guarantee Program (Section 1703, Title IV of Energy Policy Act of 2005) provides loan guarantees for large scale innovative, high technology risk renewable energy projects that reduce the emission of pollutants [16].
- Business Energy Investment Tax Credit (ITC) credits up to 30 percent of expenditures, with no maximum credit, on solar PV installations. The credit scales down to 26 percent in 2020, 22 percent in 2021 and 10 percent in subsequent years [16].
- Modified Accelerated Cost-Recovery System (MACRS) + Bonus Depreciation allows businesses to recover investments in qualified renewable energy technologies through depreciation deductions. A 50 percent first year bonus depreciation, provided by the Economic Stimulus Act of 2008, has been extended to 2019. The bonus depreciation is reduced to 40 percent for 2018 and to 30 percent for 2019 [16].
- USDA Rural Energy for America Program (REAP) promotes energy efficiency and renewable energy for agricultural producers and rural small businesses through the use of grants and loan guarantees for energy efficiency improvements and renewable energy systems. The program covers up to 25 percent of costs [16].
- Clean Renewable Energy Bonds (CREBs) are tax credit bonds designed to offset the tax liability of not-for-profit entities such as public utilities, and local and state governments that,

because of their structure, do not benefit from the traditional renewable energy production tax credit (PTC) [16].

- Qualified Energy Conservation Bonds (QECBs) are qualified tax credit bonds that state, local and tribal governments may use to finance renewable energy projects and other energy conservation measures. Unlike the Clean Renewable Energy Bonds (CREBS) QECBs are not subject to U.S. Department of Treasury approval. The volume of the bonds is allocated to states in proportion to the state's percentage of the U.S. population [16].
- High Energy Cost Grant Program administered by 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 [16, 33].
- Residential Renewable Energy Tax Credit allows taxpayers to claim 30 percent of their qualifying expenditures on installation of renewable energy technologies including solar electric systems, solar water heaters, wind turbines and geothermal heat pumps [16].
- Green Power Purchasing Goal requires that 30 percent of energy used by federal agencies must be obtained from renewable resources by 2025 [16].
- Energy Efficiency Mortgage program provides mortgages that 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 the Federal Housing Authority or the Department of Veterans Affairs [16].

Indiana Incentives

- Solar Access Laws 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; they allow parties to voluntarily enter into solar-easement contracts which are enforceable by law [16].
- Net Metering Rule qualifies renewable resources with a maximum capacity of 1 MW for net metering in Indiana. The net excess generation is credited to the customer in the next billing cycle. The aggregate capacity limit is set at 1 percent of the utility's most recent summer peak [16].
- Renewable Energy Property Tax Exemption provides property tax exemptions for solar thermal, PV, wind, hydroelectric and geothermal systems [16].
- Community Conservation Challenge Grant provides $25,000-$100,000 in grants for community energy conservation projects that reduce energy consumption or displace the use of traditional energy sources. A total of $600,000 is allocated for 2016. Applications for the 2016 funding cycle are due by October 30 [16, 34].

- Sales and Use Tax Exemption for Electrical Generating Equipment exempts transactions involving manufacturing machinery, tools, and equipment used for the production of tangible personal property, which includes electricity, from state gross retail tax. However, only wind energy has clearly specified rules from the Department of Revenue [16].

- Clean Energy Portfolio Goal sets a voluntary goal of obtaining 4 percent between 2013 and 2018, 7 percent between 2019 and 2024, and 10 percent by 2025, of electricity from clean energy sources based on 2010 retail sales. Participation in the goal makes utilities eligible for incentives that can be used to pay for the compliance projects. The deadline to apply for incentives in the 2013 to 2018 period has expired [16].
- Northern Indiana Public Service Company (NIPSCO) offers feed-in tariff incentive rates for electricity generated from renewable resources for up to 15 years. The payment for solar systems from 5kW to under 10kW is $0.17/kWh for the projects selected in the first capacity allocation lottery (allocation 1) and $0.1564/kW for subsequent ones (allocation 2). The payment for solar systems larger than 10kW up to 200kW is $0.15/kWh for projects in allocation 1 and $0.138 for those in *allocation 2*. The 4 MW cap for intermediate solar *allocation 1* has been met. [16, 31, 32].

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7. Hydropower

7.1 Introduction

Hydroelectric energy is produced by converting the kinetic energy of falling water into electrical energy. The moving water rotates a turbine, which in turn spins a generator to produce electricity. The harnessing of moving water to perform work has been in use for thousands of years with the Greeks having used it to grind wheat more than 2,000 years ago. The evolution of the hydropower turbine began in the mid-1700s in Europe with the published work of Bernard Forest de Bélidor, a French engineer. The first use of a water driven dynamo in the U.S. was in 1880 in Grand Rapids, Michigan followed closely by Niagara Falls, New York where they were used to provide street lighting. Unlike modern hydropower plants, these two projects used direct current technology. The first modern alternating current hydropower plant in the world was installed in Appleton, Wisconsin in 1882. It generated enough electricity to light the inventor’s home, the power plant and one neighboring building [1, 2].

From these beginnings hydroelectricity quickly rose to become one of the principal sources of electricity in the U.S. At the beginning of the 20th century hydropower provided over 40 percent of the electricity generated in the U.S. With the rise of other fuels, such as coal, nuclear, natural gas and wind, the role of hydroelectricity has dropped steadily to the point that it supplied only 6 percent of the total electricity generated in 2014. Although the quantity of hydropower as a proportion of the total electricity generated has diminished, it remains the main source of renewable electricity accounting for almost half the renewable electricity generated in the U.S. in 2014 [3, 4].

There are several different types of hydropower facilities today. They include [5]:

- Impoundment hydropower: These facilities use a dam to store water. Water is then released through the turbines to meet electricity demand or to maintain a desired reservoir level. Figure 7-1 shows a schematic of this type of facility.
- Pumped storage: When electricity demand and price are 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 and price are higher.
- Diversion projects: These facilities channel some of the water through a canal or penstock. They may require a dam but are less obtrusive than impoundment facilities.
- Run-of-river projects: These facilities utilize the flow of water of the river and require little to no impoundment. Run-of-river plants can be designed for large flow rates with low head[14] or small flow rates with high head.

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[14] Head is the elevation difference between the water level above the turbine and the turbine itself. Higher head results in greater potential energy.

- Microhydro projects: These facilities are small in size (about 100 kW or less) and can utilize both low and high heads. They are typically used in remote locations to serve the power needs of a single nearby home or business.

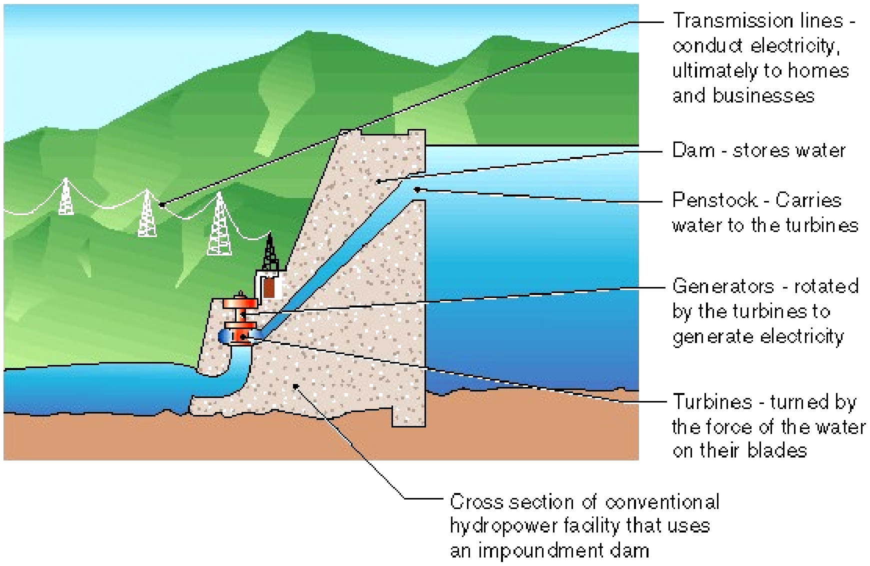

Figure 7-1: Schematic of impoundment hydropower facility (Source: DOE [6])

In addition to the type of facility, 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. There are two main groups of turbines used in hydro power projects – the impulse and the reaction turbine types. The impulse turbine type uses the velocity of the water while the reaction turbine uses both the velocity of the water and the pressure drop as the water passes through the turbine. The impulse turbine is more suited to a high head, low flow application while the reaction turbine is more suited to a lower head, faster flow situation [7].

7.2 Economics of hydropower

Hydropower projects are very capital intensive and the cost is very site specific. Figure 7-2 shows the construction costs for U.S. hydropower projects from 1985 to 2015 normalized to 2014 dollars obtained from the 2014 DOE *Hydropower Market Report*. The projects are arranged in three groups: c*onduits, new stream-reach development and non-powered dams*. *Conduit* hydropower projects are those constructed on water conveyance conduits put in place primarily for irrigation or water supply. *New stream-reach development* projects are small capacity hydropower projects that can be built on streams with minimal environmental impact, while *non-powered dams* are exactly that, hydropower projects added to dams already in place for other purposes, such us storage, irrigation or navigation [8].

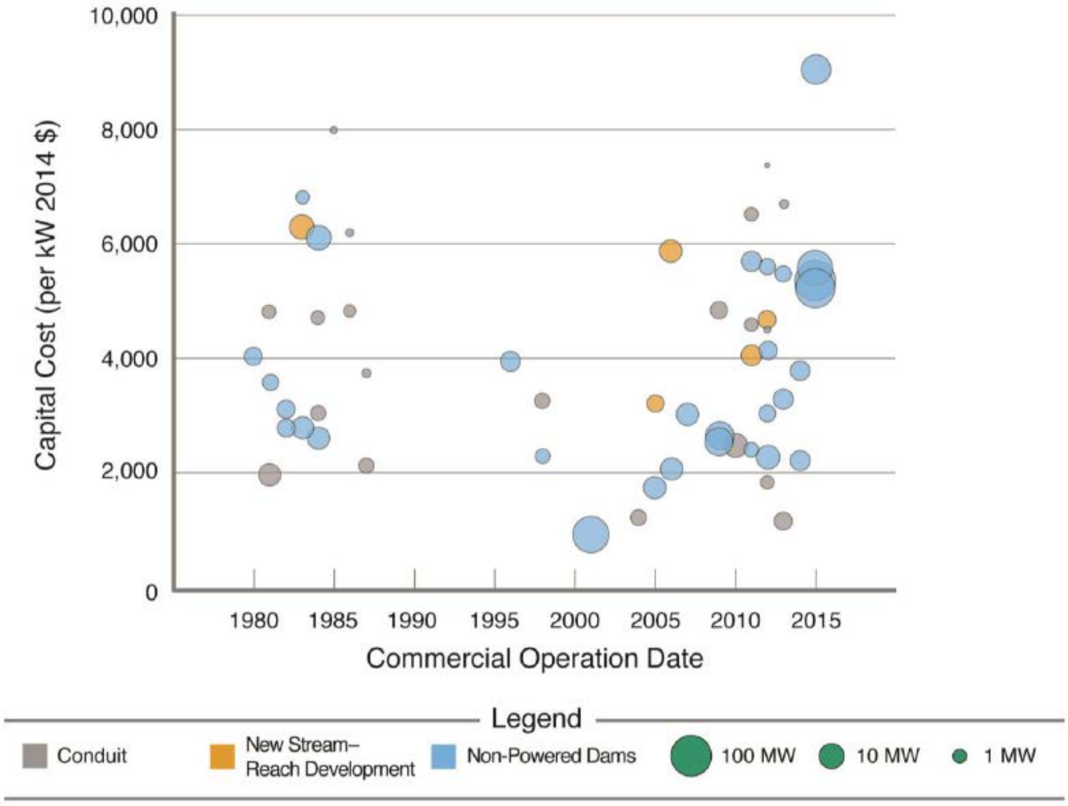

Figure 7-2: U.S. hydropower construction cost by project type and size (Source: DOE [8])

Table 7-1 shows the capital costs estimates from various sources. The capital cost estimates range from as low as $1,700/kW in 1996 dollars done by Idaho National Laboratory (INL) to $9,417/kW cost in 2014 dollars estimate for the Susitna project in Alaska.

Project		Time[*]	Initial Capital Costs ($/kW)[**]
Idaho National Lab estimates		1996	1,700-2,300
EIA estimates	Hydroelectric	2013	2,936
	Pumped Storage	2013	5,288
Hawaii Pumped Storage Hydroelectric Project (Maui Electric Co.)	Umauma	2005	1,966
	East/WestWailuaiki		3,011
	Big Island		2,432-2,842
	Maui		3,477
Susitna-Watana Project (Alaska)		2014	9,417
American Municipal Power (AMP)	Belleville	1999	2,857
	Cannelton	2009	4,951
	Smithland	2010	6,226
	Meldahl	2010	4,504
	Willow Island	2011	7,889
	Robert C. Byrd	2015	6,250
	Pike Island	NA	7,414

[*] Time the project's cost estimate was made or the project's expected start date.
[**] The basis year for the capital cost estimates is 1996 for INL, 2012 for EIA and 2005 for the Hawaii pumped hydro project. The basis year for the AMP and the Alaska projects was not available. The document on which the AMP capital cost estimates were obtained was dated 2011, and 2014 for the document from which Alaska project was obtained.

Table 7-1: Initial capital costs of hydropower projects (Data sources: INL, EIA, Maui Electric Company, Susitna-Watana Project 2014 Annual Report, Alaska Energy Authority [9-14])

Once constructed, hydroelectric power plants have a major cost advantage since the fuel (water) is virtually free and also because they have very low O&M costs. According to the June 2016 EIA updated electricity generating technologies cost estimates [10], hydroelectric plants have one of the lowest O&M costs among electricity generating technologies. Figure 7-3 shows the fixed and variable O&M costs of various generating technologies. As can be seen in the Figure 7-3, hydroelectricity's variable O&M costs are estimated at $2.62/MWh and the fixed O&M cost of $15/kW for a conventional hydroelectric plant is the second lowest after natural gas combustion turbines.

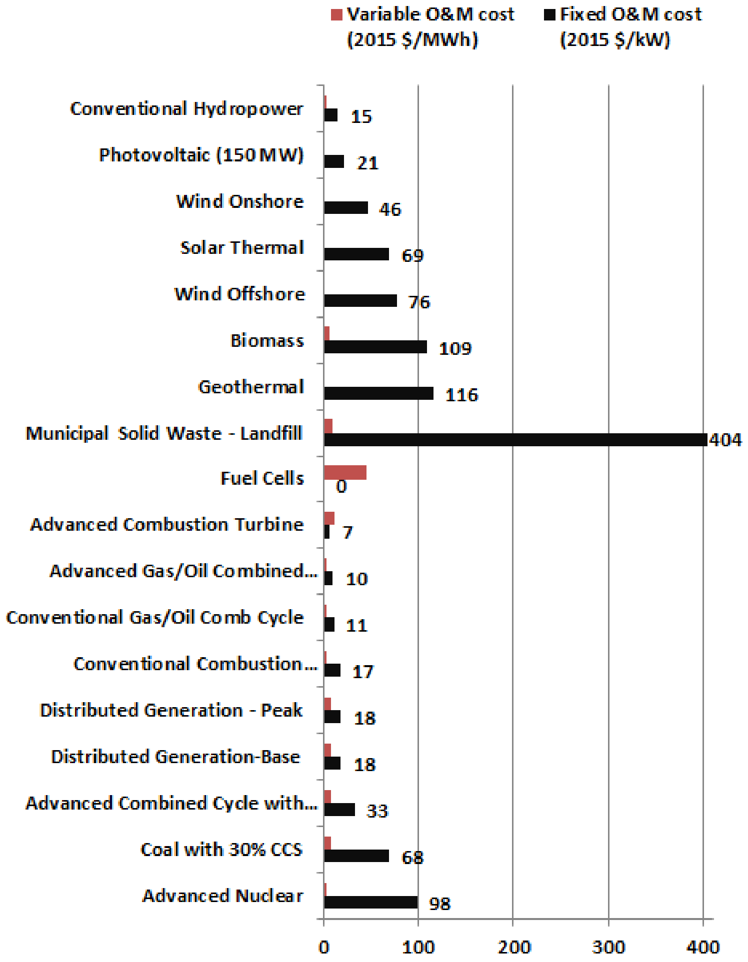

Figure 7-3: Variable and fixed O&M costs of generating technologies (Data source: EIA [10])

7.3 State of hydropower nationally

Hydropower has historically been the primary source of renewable energy in the U.S. Figure 7-4 shows the amount of electricity generated from renewable resources from 1949 to 2015. In the early parts of the 20th century, hydroelectricity accounted for virtually all the renewable electricity consumed in the U.S. with all other renewable resources combined contributing less than one percent up to 1974. Although this dominance of hydroelectricity has steadily eroded over time, it still accounts for almost half of the renewable electricity generated and a quarter of the renewable energy consumed in the U.S. In 2015 hydroelectricity accounted for 46 percent of the renewable electricity generated and 25 percent of the total renewable energy consumed in the U.S.

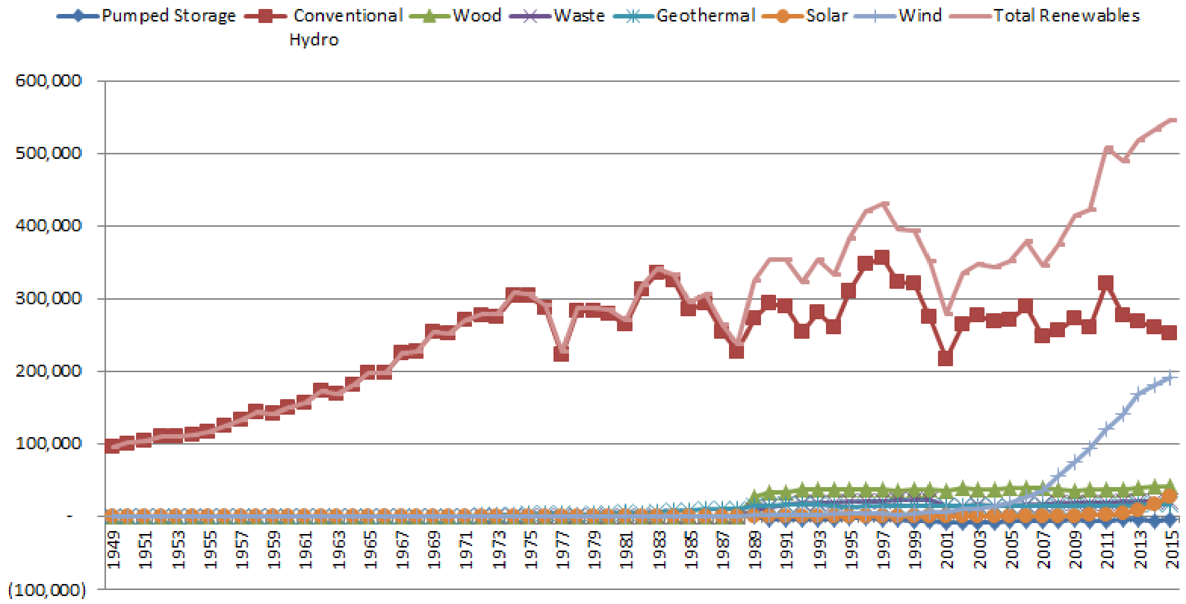

Figure 7-4: Net renewable electricity generation in the U.S. (1949-2015) (Data source: EIA [4])

The total installed hydropower capacity in the U.S. consists of 79.6 gigawatts (GW) of conventional hydro distributed over 2,198 projects and 21.6 GW of pumped hydro plants in 42 projects [8]. Table 7-2 is a list of the ten largest hydropower plants in the U.S.

Hydropower Plant	River	State	Capacity (MW)	Year of completion
Grand Coulee	Columbia	Washington	6,180	1942
Chief Joseph	Columbia	Washington	2,457	1958
John Day	Columbia	Oregon	2,160	1971
Bath County*	Little Back Creek	Virginia	2,100	1985
Robert Moses - Niagara	Niagara	New York	1,950	1961
The Dalles	Columbia	Oregon	1,805	1957
Ludington*	Lake Michigan	Michigan	1,872	1973
Raccoon Mountain	Tennessee River	Tennessee	1,530	1978
Hoover	Colorado	Nevada	1,434	1936
Pyramid/Castaic*	California Aqueduct	California	1,250	1973

*pumped hydropower stations

Table 7-2: Ten largest hydropower plants in the U.S. (Data source: EIA [15], USSD [16])

Table 7-3 shows the top ten hydro states ranked by their hydroelectricity output in 2014 and Table 7-4 shows the top ten hydro states ranked by installed hydro capacity at the end of 2014.

Approximately sixty percent of the hydroelectricity generation in 2014 was from the top four states of Washington, Oregon, New York, and California.

1. Washington	79,463,144		6. Alabama	9,466,872
2. Oregon	35,261,936		7. Idaho	9,002,210
3. New York	26,086,902		8. Tennessee	8,900,650
4. California	16,531,340		9. Arizona	6,118,261
5. Montana	11,482,751		10. South Dakota	5,498,214

Table 7-3: Top ten U.S. hydropower generating states in 2014 (MWh) (Data source: EIA [17])

1. Washington	21,185		6. Arizona	2,721
2. California	10,175		7. Montana	2,758
3. Oregon	8,523		8. Idaho	2,708
4. New York	4,713		9. Tennessee	2,616
5. Alabama	3,271		10. Georgia	2,048

Table 7-4: Top ten U.S. hydropower capacity states at end of 2014 (MW) (Data source: EIA [18])

In 2012 DOE released an assessment of the hydropower potential available at hydro sites that had dams already in place but no power generation equipment installed. According to the DOE there were a total of 80,000 such non-powered dams providing services such as navigation, water supply and recreation. The combined electricity generating potential at these sites was assessed at 12 GW [19]. Figure 7-5 shows the location of the non-powered dams with a hydropower potential greater than 1 MW. Table 7-5 shows the hydropower potential from non-powered dams for the states in the contiguous U.S.

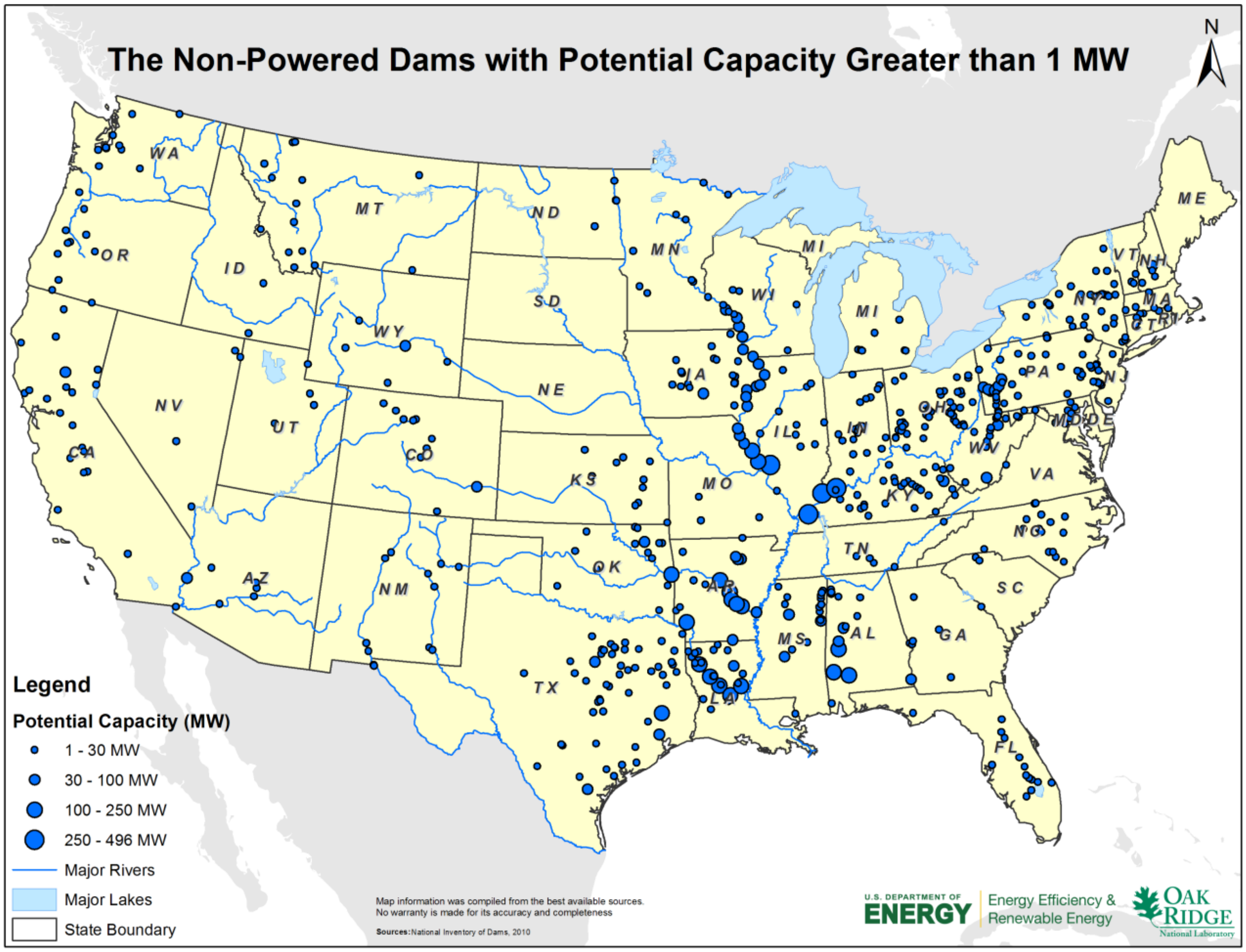

Figure 7-5: Non-powered dams with potential capacity over 1 MW (Source: DOE [19])

State	Potential Capacity (MW)
Illinois	1269
Kentucky	1253
Arkansas	1136
Alabama	922
Louisiana	857
Pennsylvania	679
Texas	658
Missouri	489
Indiana	**454**
Iowa	427
Oklahoma	339
New York	295
Ohio	288
Mississippi	271
Wisconsin	245
West Virginia	210
California	195
Minnesota	186
Florida	173
Colorado	172
North Carolina	167
Georgia	144
Oregon	116
New Mexico	103
Kansas	92
Montana	88
Washington	85
Arizona	80
Connecticut	68
Massachusetts	67
New Hampshire	63
Virginia	50
Maryland	48
Michigan	48
Wyoming	45
Tennessee	40
Utah	40
South Carolina	38
New jersey	33
North Dakota	31
Maine	19
Vermont	17
Nevada	16
Rhode Island	13
Idaho	12
South Dakota	12
Nebraska	7
Delaware	3

Table 7-5: Hydropower potential from non-powered dams by state (Data source: DOE [19])

In April 2014 DOE released another assessment of hydropower potential this time focused on undeveloped stream-reaches: that is, rivers and streams that do not have existing dams of any kind (either hydropower plants or non-powered dams). The total hydropower potential in these rivers and streams is estimated at 84.7 GW capable of producing 460,000 GWh of electrical energy per year [20].

7.4 Hydropower in Indiana

Until the commissioning of the first wind farm in Indiana in 2008, hydroelectricity was the main source of renewable electricity in Indiana as shown in Figure 7-6. With 1,906 MW of installed wind capacity compared to 73 MW of hydroelectricity in Indiana, wind is now the dominant source of renewable electricity. This is a significant change from the situation in 2008 when only 20 kW of grid-connected wind capacity was in operation in Indiana. Furthermore, the photovoltaic capacity has also been climbing rapidly to overtake hydropower with 121 MW installed at the writing of this report.

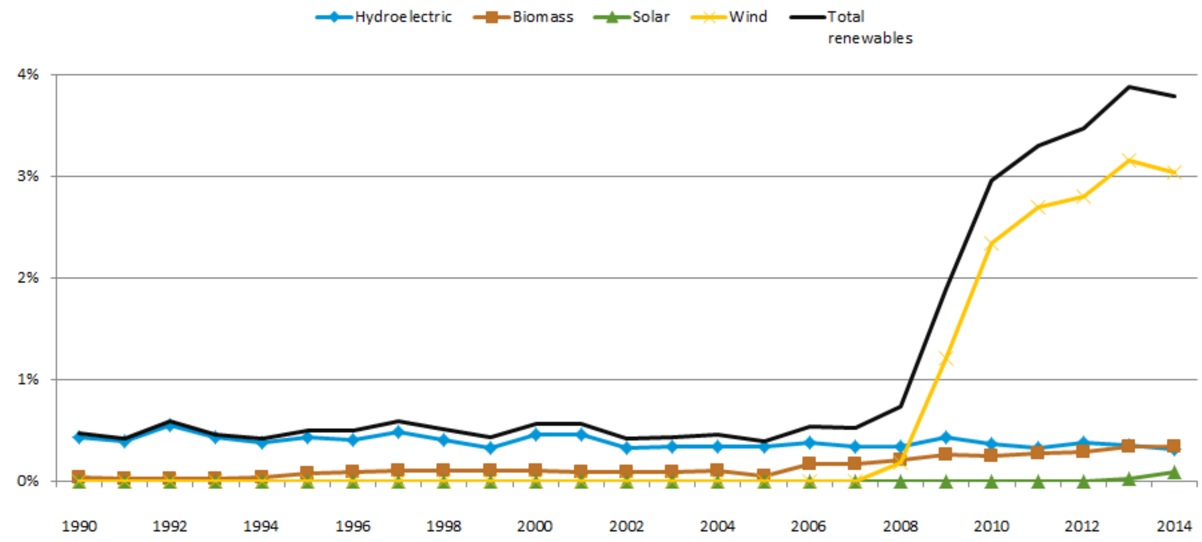

Figure 7-6: Renewables share of Indiana net electricity generation (1990-2014) (Data source: EIA [21])

The 2012 DOE national assessment of hydropower potential from non-powered dams referred to in the preceding section of this report estimated that Indiana had a total potential of 454 MW hydropower capacity from these, already existing, non-powered dams. This assessment is much higher than the 1995 DOE assessment that had estimated Indiana's gross potential at 84 MW [19]. Table 7-6 lists the dams in Indiana with a potential greater than 1 MW. The capacity of the two dams on the Ohio River is assigned in equal proportions between Indiana and Kentucky.

The April 2014 DOE assessment of hydropower potential in rivers and streams that do not have any dams today estimated that Indiana has the potential for 581 MW hydropower capacity capable of generating over 3,000 GWh of electricity per year. This is approximately 7 times the hydroelectricity generated in Indiana in 2012 and 3 percent of the total electricity generated in Indiana from all sources in 2012 [20].

Dam Name	County	City	River	Hydropower Potential (MW)
John T. Myers locks and dams	Posey	Mt. Vernon	Ohio River	395
Newburgh locks and dams	Henderson	Newburgh	Ohio River	319
Mississinewa Lake dam	Miami	Peru	Mississinewa River	14
J. Edward Roush Lake dam	Huntington	Huntington	Wabash River	9
Salamonie Lake dam	Wabash	Lagro	Salamonie River	9
Brookville Lake dam	Franklin	Brookville	White Water River (East fork)	8
Monroe Lake dam	Monroe	Guthrie	Salt Creek	8
White River dam	Marion	Indianapolis	White River	3
Patoka Lake dam	Dubois	Jasper	Patoka River	3
Cagles Mill Lake dam	Putman	Bowling Green	Mill Creek	2
Cecil M. Harden Lake dam	Parke	Mansfield	Raccoon Creek	2
Ball Band dam	St. Joseph	Mishawaka	St. Joseph River	2
Seymour Water Co. dam	Jackson	Seymour	White Water River (East fork)	2
Eagles Creek Reservoir dam	Marion	Clermont	Eagle Creek	2
West fork White River dam	Morgan	Martinsville	White River	2
Harding St. power plant dam	Marion	Indianapolis	White River	2
Versailles State Park dam	Ripley	Versailles	Laughery Creek	1.4
Emerichsville dam	Marion	Indianapolis	White River	1.3
Broad Ripple dam	Marion	Indianapolis	White River	1.3
Geist Reservoir dam	Marion	Indianapolis	Fall Creek	1.3
Cedarville dam	Allen	Cedarville	St. Joseph River	1.3
Hosey (Maumee River) dam	Allen	Fort Wayne	Maumee River	1.2

Table 7-6: Indiana non-powered dams with potential capacity over 1 MW (Data source: DOE [20])

American Municipal Power (AMP), a wholesale electricity supplier to municipal utilities in Ohio, Pennsylvania, Michigan, Virginia, Kentucky and West Virginia is in the process of developing five run-of-the-river hydroelectric projects along the Ohio River. Two of the projects, the 105 MW Melhahl and the 44 MW Willow Island projects, were commissioned earlier in 2016 while two others, the 88 MW Cannelton and the 76 MW Smithland projects, are expected to be fully commissioned before the end of 2016. One project, the 48 MW Robert Byrd, is in the licensing process. The Cannelton project is located on the Indiana/Kentucky section of the river and the adjoining city of Cannelton, Indiana has recently joined as a member of AMP [22-25].

7.5 Incentives for hydropower

Federal Incentives

- Renewable Electricity Production Tax Credit (PTC) provides a 1.2 cents/kWh tax credit for small irrigation hydroelectric facilities for ten years of operation. The PTC was extended to December 2016 by the Consolidated Appropriations Act of 2016 [26].
- U.S. DOE Loan Guarantee Program (Section 1703, Title IV of Energy Policy Act of 2005) provides loan guarantees for large scale innovative, high technology risk renewable energy projects that reduce the emission of pollutants [26].
- USDA Rural Energy for America Program (REAP) promotes energy efficiency and renewable energy for agricultural producers and rural small businesses through the use of grants and loan guarantees for energy efficiency improvements and renewable energy systems. The program covers up to 25 percent of costs [26].
- Clean Renewable Energy Bonds (CREBs) are tax credit bonds designed to offset the tax liability of not-for-profit entities such as public utilities, and local and state governments that, because of their structure, do not benefit from the traditional renewable energy production tax credit (PTC) [26].
- Qualified Energy Conservation Bonds (QECBs) are qualified tax credit bonds that state, local and tribal governments may use to finance renewable energy projects and other energy conservation measures. Unlike the Clean Renewable Energy Bonds (CREBS) QECBs are not subject to U.S. Department of Treasury approval. The volume of the bonds is allocated to states in proportion to the state's percentage of the U.S. population [26].
- High Energy Cost Grant Program administered by 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 [26, 27].
- Green Power Purchasing Goal requires that 30 percent of energy used by federal agencies must be obtained from renewable resources by 2025 [26].

Indiana Incentives

- Net Metering Rule qualifies renewable resource facilities with a maximum capacity of 1 MW for net metering. The net excess generation is credited to the customer in the next billing cycle [26].
- Renewable Energy Property Tax Exemption provides property tax exemptions for solar, wind, hydroelectric and geothermal systems [26].
- Sales and Use Tax Exemption for Electrical Generating Equipment exempts transactions involving manufacturing machinery, tools, and equipment used for the production of tangible personal property, which includes electricity, from state gross retail tax. However, only wind energy has clearly specified rules from the Department of Revenue [26].

- Clean Energy Portfolio Goal sets a voluntary goal of obtaining 4 percent between 2013 and 2018, 7 percent between 2019 and 2024, and 10 percent by 2025, of electricity from clean energy sources based on 2010 retail sales. Participation in the goal makes utilities eligible for incentives that can be used to pay for the compliance projects. The deadline to apply for incentives in the 2013 to 2018 period has expired. The deadline to apply for incentives in the 2013 to 2018 period has expired [26].

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