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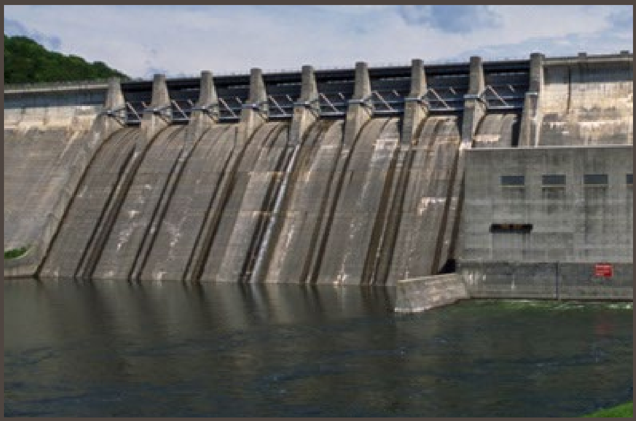
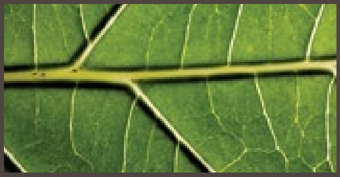
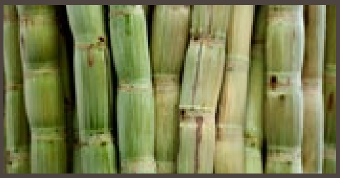
October 2018

2018 INDIANA RENEWABLE ENERGY RESOURCES STUDY







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

PURDUE UNIVERSITY Discovery Park

2018 INDIANA RENEWABLE ENERGY RESOURCES STUDY

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October 2018

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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
CEC	California Energy Commission
CC	Combined cycle power plant (gas turbine-generator combined with a steam turbine-generator powered by the exhaust heat of the gas turbine-generator)
CCS	Carbon capture and sequestration
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
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
LBNL	Lawrence Berkeley National Laboratory, U.S. Department of Energy
LMOP	Landfill Methane Outreach Program, Energy Information Administration, U.S. Department of Energy
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
MW_{AC}	Alternating current 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
NSA	Crane Naval Support Activity
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
yr	year

Foreword

This report represents the sixteenth 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 2018 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 amount of renewable energy in quadrillion British thermal units (Btu) consumed in the U.S. from 1949 to 2017. Until the early 2000s hydroelectricity and woody biomass were the dominant sources of renewable energy consumed in the U.S. Since then biofuels (mainly corn-based ethanol), wind and solar have increased rapidly as sources of renewable energy. In 2017 biofuels, wind and solar combined contributed 49 percent of the 11 quadrillion Btu of renewable energy consumed in the U.S. reducing hydroelectricity's share to 25 percent. The two main factors that have driven the rise in corn-ethanol use as a fuel are its use as a replacement for 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 RPS, 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 for solar energy 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.

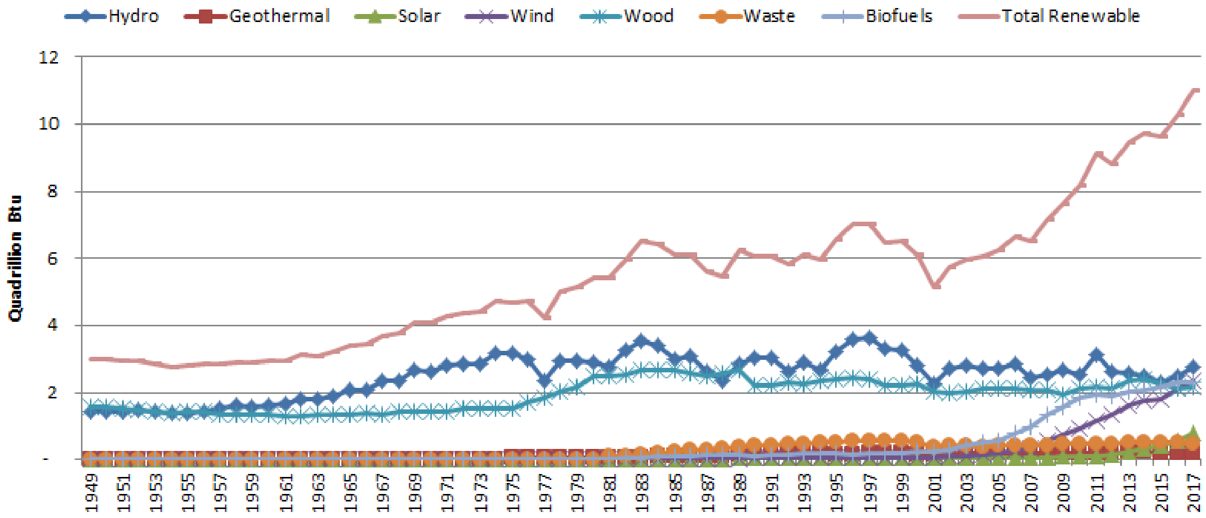

Figure 1-1: Renewable energy consumption in the U.S. (1949-2017) (Data source: EIA [1])

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 11 percent. In 2017 fossil fuels supplied 80 percent of the energy consumed in the U.S.; renewable resources supplied 11 percent while nuclear energy supplied 9 percent. Figure 1-2 shows the sources of total energy consumed in the U.S. from 1949 to 2017.

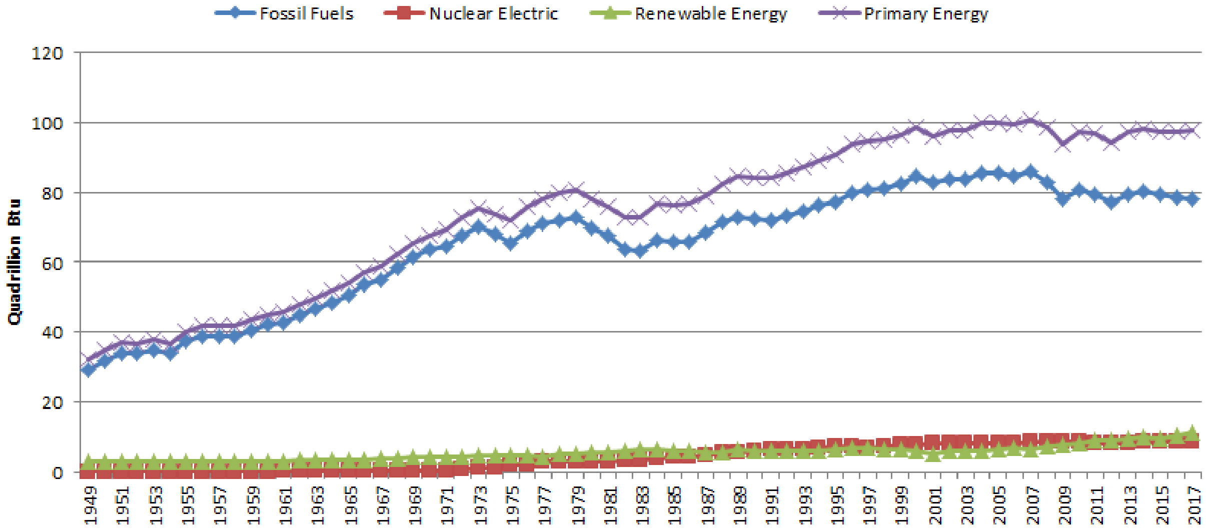

Figure 1-2: U.S. energy consumption by source (1949-2017) (Data source: EIA [2])

Figure 1-3 shows the contribution of the various energy sources to the total energy consumed in the U.S. in 2017. Petroleum continued to be the dominant energy source supplying 37 percent of the energy, followed by natural gas at 29 percent. Coal's share dropped from 15 percent in 2016 to 14 percent, while the total renewable energy's share increased by one percent to 11 percent. Among the renewable resources, biomass (including wood, biofuels, municipal solid waste, landfill gas and others) comprised 45 percent of the total renewable energy, followed by hydroelectricity at 25 percent. Wind's contribution remained at 21 percent, solar energy's share increased by one percent to 7 percent and geothermal energy's share remained at 2 percent.

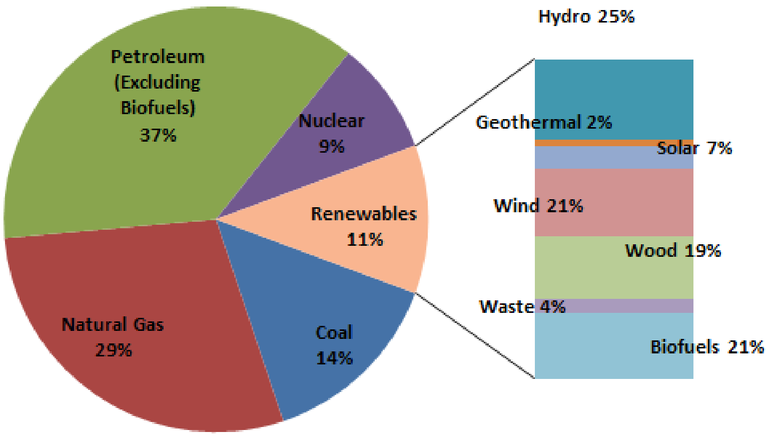

Figure 1-3: U.S. total energy consumption by energy source in 2017 (Data source: EIA [1, 3])

Figure 1-4 shows the growth of renewable resources in electricity generation from 1949 to 2017. Through the late 1980s hydroelectricity was the sole significant source of renewable electricity generated annually at which point wood started gaining prominence, contributing approximately 10 percent of the annual renewable generation in the U.S. In the early 2000s wind energy's share of electricity generation started rising rapidly, reaching to where it now rivals hydroelectricity as a source of renewable electricity generation. Solar electricity generation has risen rapidly in the last ten years to where in 2017 it was a source for 7 percent of the renewable electricity generated in the U.S.

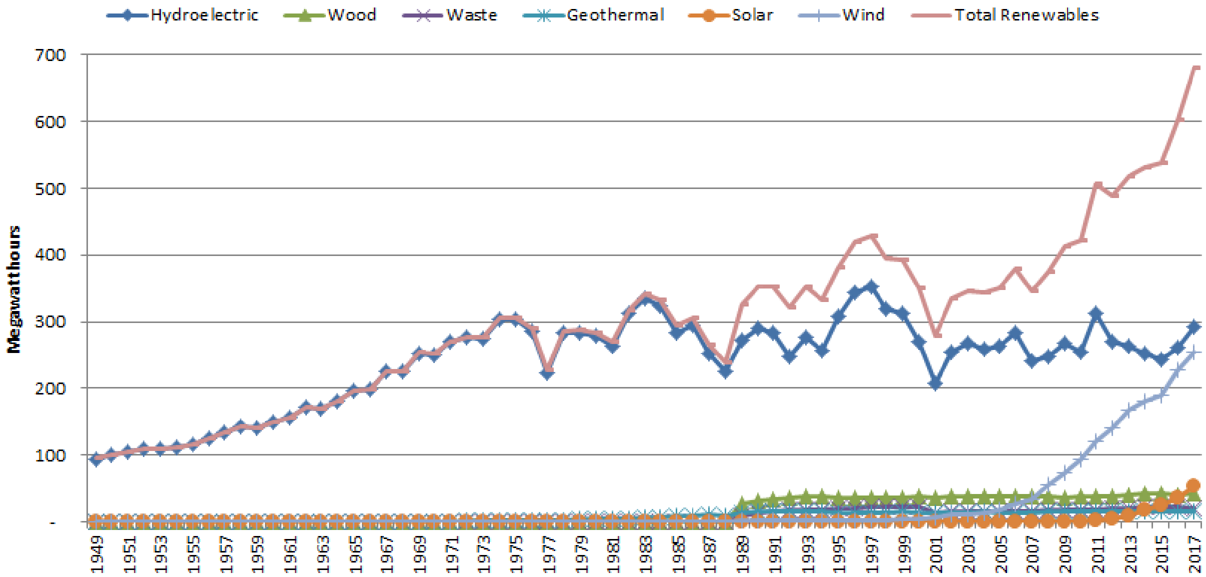

Figure 1-4: Renewable electricity generation in the U.S. (1949-2017) (Data source: EIA [4])

Although the amount of electricity generated from renewable resources has increased rapidly in the last ten years fossil fuels continue to be the main source of energy for electricity generation in the U.S. Figure 1-5 shows the amount of electricity generated from all the sources from 1949 to 2017.

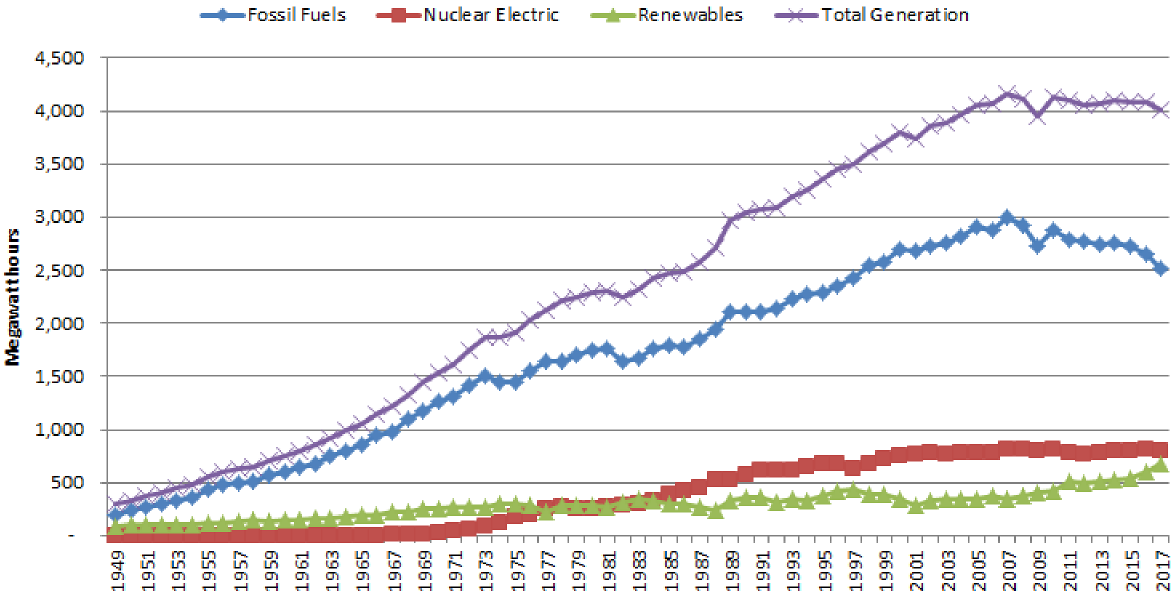

Figure 1-5: U.S. Electricity generation by source (1949-2017) (Data source: EIA [4])

Figure 1-6 shows the share of electricity generated from various energy sources in the U.S. in 2017. Natural gas, coal and nuclear energy dominate electricity generation, jointly accounting for 82 percent of the electricity generated in 2017. Renewable resources contributed 17 percent and petroleum one percent. Among renewable resources hydroelectricity and wind played the dominant role, jointly contributing 81 percent of the total renewable electricity generated (44 percent from hydro and 37 percent from wind). Woody biomass contributed 6 percent, solar 8 percent, waste biomass 3 percent, and geothermal 2 percent. As expected, pumped hydroelectricity's net energy contribution was negative.[1]

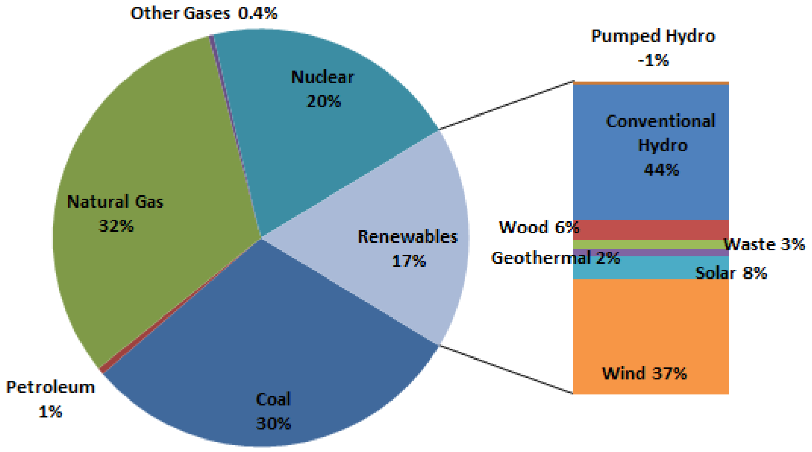

Figure 1-6: Net U.S. electricity generation by energy source in 2017 (Data source: EIA [4])

1.2 Trends in renewable energy consumption in Indiana

Figure 1-7 shows renewable energy consumption in Indiana from 1960 to 2016. 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 6 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 a little over half of the renewable energy consumed in Indiana in 2016, followed by wind energy's 26 percent. Wood and wood waste contributed 18 percent, geothermal 3 percent and solar 1 percent.

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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.

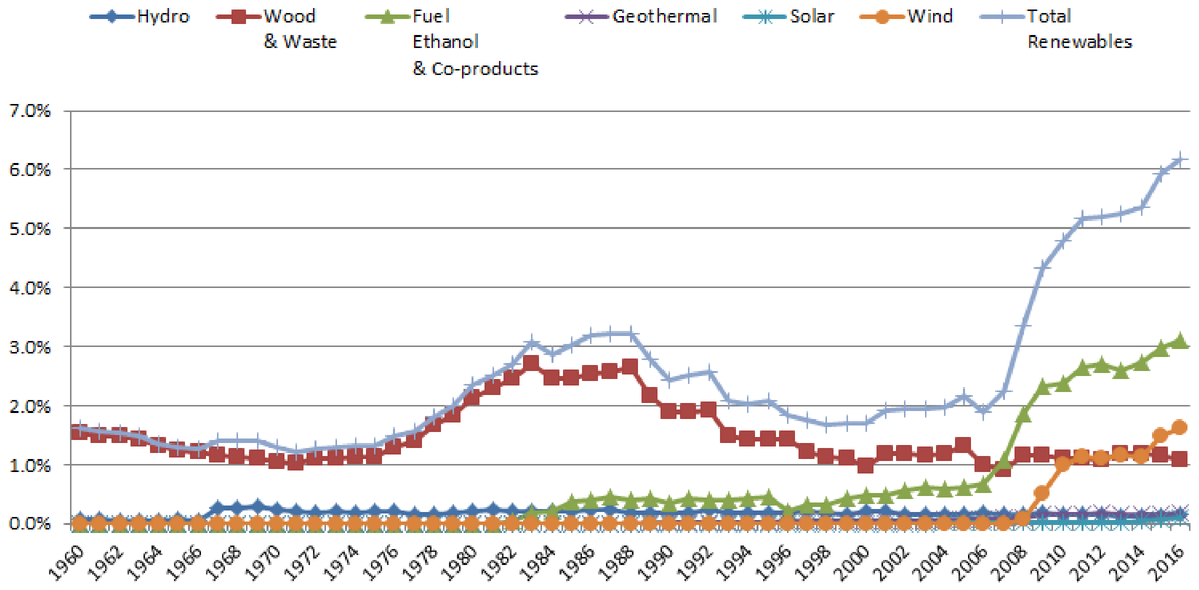

Figure 1-7: Renewables share of Indiana total energy consumption (1960-2016) (Data source: EIA [5])

Figure 1-8 shows the contribution of renewable energy to Indiana's electricity generation from 1990 to 2017. 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 6.2 percent in 2017 most of which (83 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 2015 generation. Solar photovoltaic generation has grown from virtually none in 2011 to 278 GWh in 2017 which was approximately 0.3 percent of Indiana's total generation.

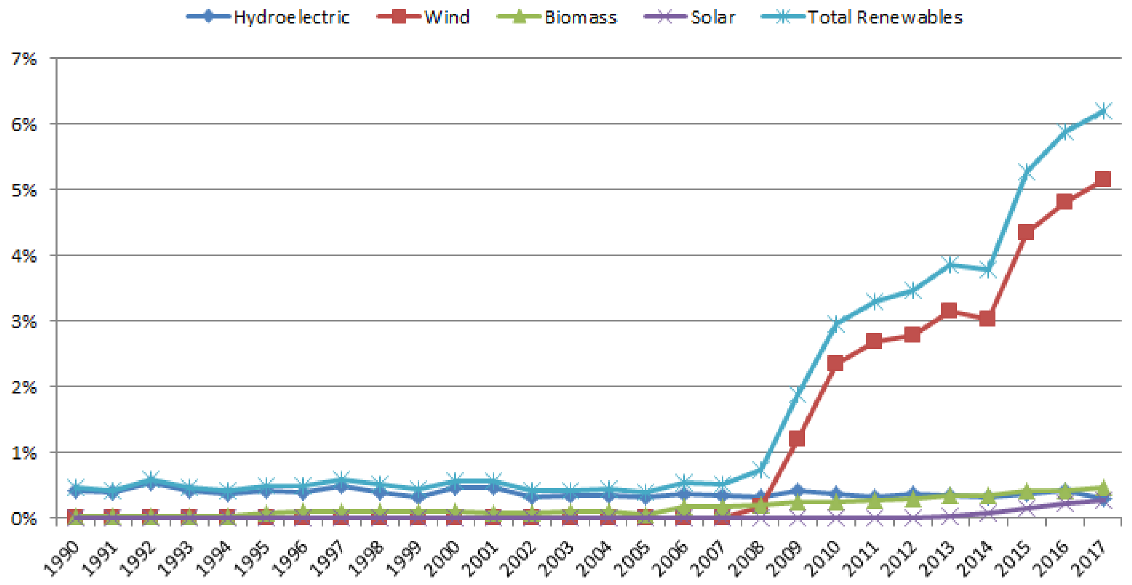

Figure 1-8: Renewables share of Indiana electricity generation (1990-2017) (Data source: EIA [6])

As can be seen in Figure 1-9 there was a rapid growth in installed wind capacity in Indiana in the three years from 2008 to 2010 when nine utility scale wind farms with a combined capacity of 1,344 MW were commissioned. Although that rapid pace of expansion slowed down somewhat after 2010, wind energy capacity in Indiana has continued to grow at a steady pace with two wind farms with a combined capacity of 220 MW being completed in 2017 and two wind farms with a combined capacity of 600 MW currently under construction. In addition Indiana utilities have a total 1,404 MW contracted through power purchase agreements, with 966 MW from wind farms in Indiana and 438 MW from out of state wind farms [7].

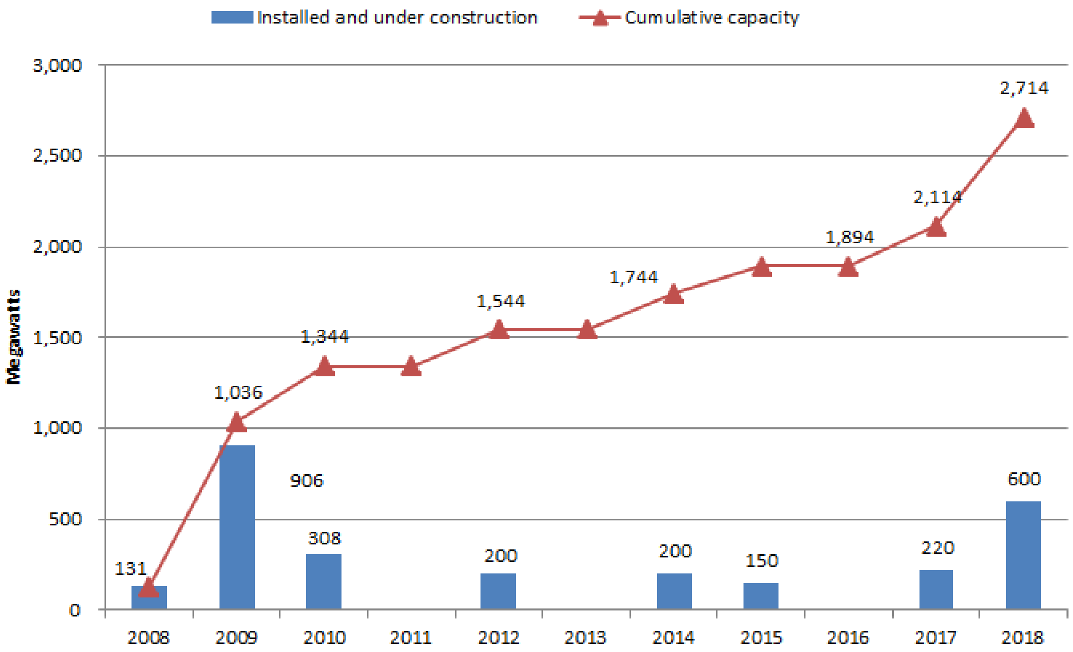

Figure 1-9: Wind energy capacity in Indiana (Data sources: IURC [7]).

Another renewable resource, solar photovoltaic, has been experiencing rapid growth with the installed capacity increasing from virtually none in 2008 to nearly 254 MW at the time this report was written. As can be seen in Table 1-1 the PV capacity is connected to the grid as follows: 44 percent (113 MW) through the feed-in-tariffs, 20 percent (77 MW) through net metering tariffs, 14 percent owned by utilities and 7 percent through power purchase agreements.[2]

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 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 PTC, 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 from one-tenth of a percent to one percent of its most recent summer peak [8].

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[2] For the sake of brevity, the following designations are used in this report to indicate each utility: Duke – Duke Energy Indiana, Hoosier – Hoosier Energy Rural electric Cooperative, IPL – Indianapolis Power & Light Company, IMPA – Indiana Municipal Power Agency, I&M – Indiana Michigan Power, NIPSCO – Northern Indiana Public Service Company, Vectren – Vectren Corporation, and WVPA – Wabash Valley Power Association.

[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.

The net metering rule has since been modified by Indiana Senate Bill 309 to change the compensation after June 30, 2022 to 1.25 times the utility's average wholesale cost for the most recent year. Generators installed before the end of 2017 shall continue to receive full retail credit until July 1, 2047 and those installed in the years 2018 to 2022 shall receive full retail credit for their generation until July 1, 2032 [8, 9].

	Feed-in-Tariff (MW_{AC})	Net Metered (MW_{AC})	Utility Owned (MW_{AC})	Utility Purchase Agreement (MW_{AC})	Total (MW_{AC})
IPL	94.4	-	2.3	-	97
Duke	-	17.3	15.7	19.4	52
IMPA	-	36.7	-	-	37
NIPSCO	18.5	-	8.6	-	27
I&M	-	12.7	9.9	-	23
Hoosier	-	10.0	-	-	10
Vectren	-	-	7.8	-	8
WVPA	-	0.5	-	-	0.5
Total	**113**	**77**	**44**	**19**	**254**

Table 1-1: Total Installed Indiana PV capacity (Data source: IURC [7]

Another major factor has been the feed-in tariffs [4] offered by two of Indiana's utilities: IPL and NIPSCO. The IPL feed-in-tariff ended in 2013. Table 1-2 shows the 49 MW of renewable capacity contracted via net metering in the respective territories of Indiana utilities, while Table 1-3 shows the 127 MW of renewable capacity contracted to two Indiana utilities under their feed-in tariffs.

	Wind (kW)	Solar (kW)	Biomass (kW)	Total (kW)
Duke	2,220	15,659		17,879
I&M	256	9,909	240	10,405
IPL	50	2,319		2,369
NIPSCO	2,048	8,641		10,689
Vectren	16	7,782		7,798
Total	**4,590**	**44,310**	**240**	**49,140**

Table 1-2: Renewable generation capacity contracted under net metering (Data source: IURC [7])

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[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)	Biomass (kW)	Total (kW)
IPL	-	94,384	-	94,384
NIPSCO	180	18,482	14,348	33,010
Total	**180**	**112,866**	**14,348**	**127,394**

Table 1-3: Renewable generation capacity contracted under feed-in tariffs (Data source: IURC [7])

A significant development that has the potential to dampen the rapid growth in the PV industry is the tariffs on imported PV cells and modules announced on January 22, 2018. The tariffs, taking effect immediately last for four years starting at 30 percent and reducing annually by 5 percent until they expire in 2021. According to the Solar Energy Industry Association the estimated effect of the tariffs is a $0.1/W increase in the price of solar modules in year one (2018) [10].

1.3 Cost of renewable resources

One of the main barriers to widespread use of renewable resources for electricity generation is the cost. Figure 1-10 shows the average cost of the generating plant installed in 2016 released by the Energy Information Agency (EIA) in August 2018. As can be seen in Figure 1-10 the average capital cost of the wind turbines installed in 2016, the least cost of the renewable technologies, is 61 percent higher than the average cost of the natural gas-fired combined cycle plants installed in 2016 and 127 percent higher than simple-cycle combustion turbines installed in 2016.

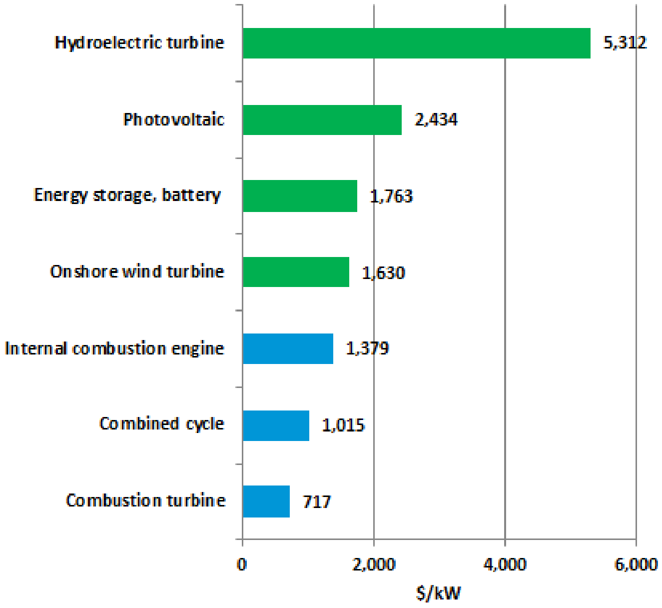

Figure 1-10: Average construction cost of generation installed in 2016 (Data source EIA [11])

Figure 1-11 the estimated cost of generating plants modeled in the 2018 EIA Annual Energy Outlook. As can be seen in Figure 1-11, EIA estimates that both wind and photovoltaic generating capacity are more expensive to build than natural-gas fired generators on a per kW basis.

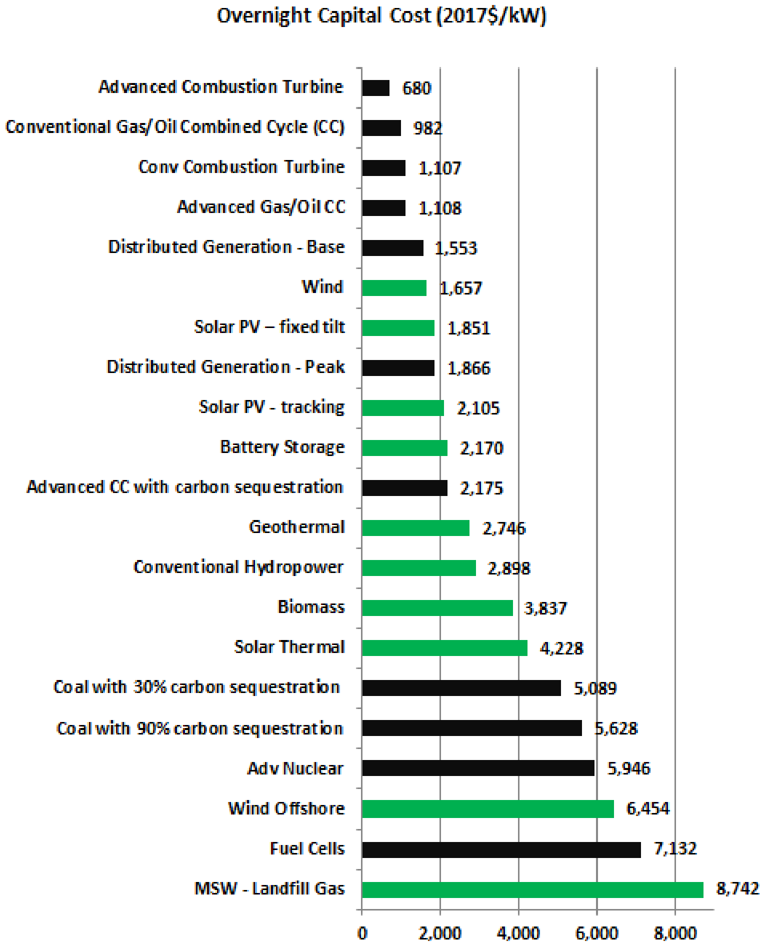

Figure 1-11: Estimated generating technologies capital cost (Data source EIA [12])

Figure 1-12 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).

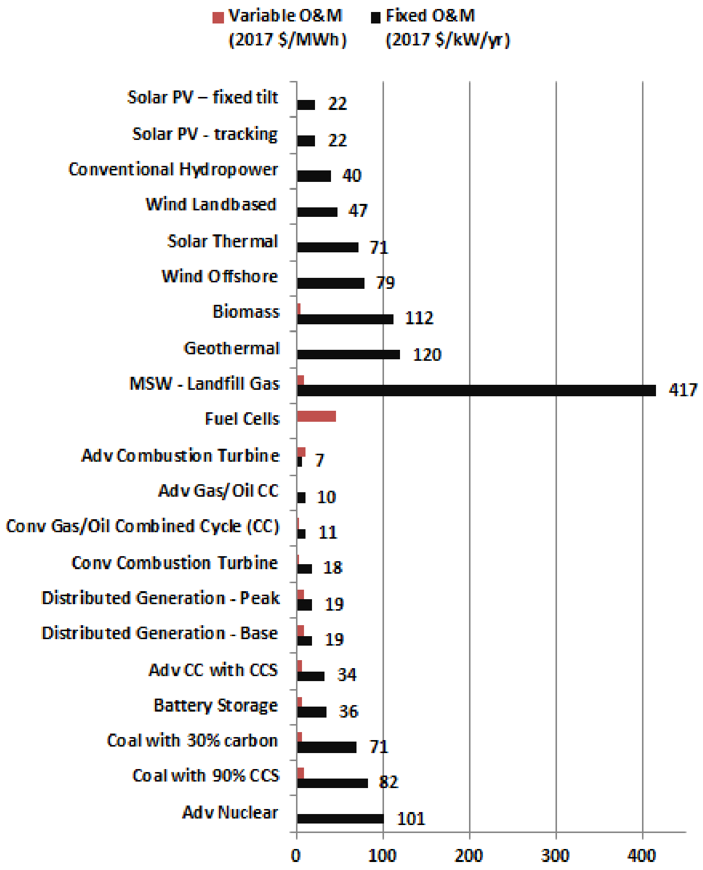

Figure 1-12: Estimated generating technologies fixed and variable O&M cost (Data source EIA [12])

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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.

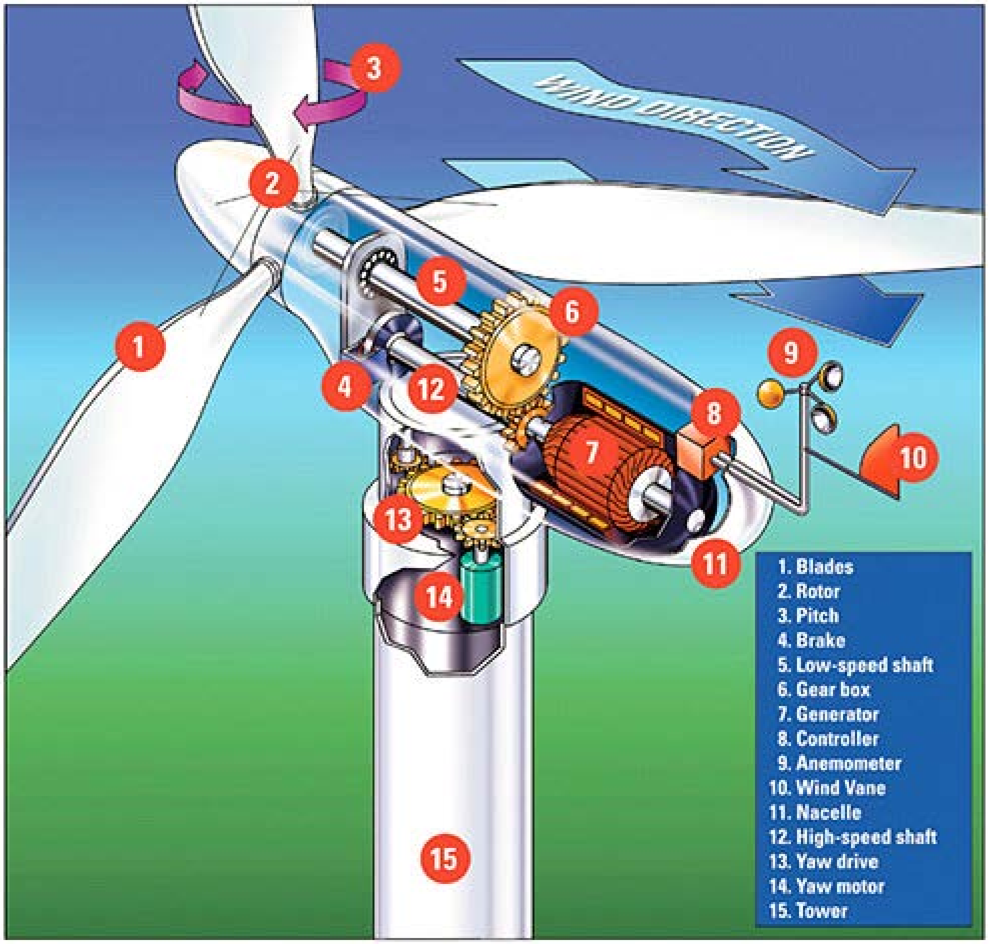

Figure 2-1: Horizontal wind turbine configuration (Source: Alternative Energy News [1])

Although utility-scale wind farms were not installed in the U.S. until the 1980s, windmills had been a vital source of energy for pumping water on farms and ranches in the 19th century and into parts of the 20th century. Until the rural electrification efforts of the federal government through the Rural Electrification Administration delivered reliable grid-connected electricity to rural areas, wind-powered generators were a major source of electricity for farms and ranches far removed from the grid [2]. 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 [3, 4].

Although wind farms' capacities have grown to be comparable to fossil fuel-fired 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 fuel-fired 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 [5].

Wind speeds are important in determining a turbine's performance. Generally, annual average wind speeds of greater than 9 miles per hour (mph), or 4 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 10 mph (4.5 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" [6]. 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.

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

	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 [7])

In addition to being a plentiful 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 disadvantage of wind is that the amount of energy available from the generator 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 plants modeled by the EIA in the 2018 Annual Energy Outlook. According to these estimates, onshore utility scale wind power plants have the lowest capital cost among the renewable options at $1,657/kW. In

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

addition, onshore wind has a capital cost lower than three of the baseload plants modeled, i.e. nuclear, coal and gas with 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.

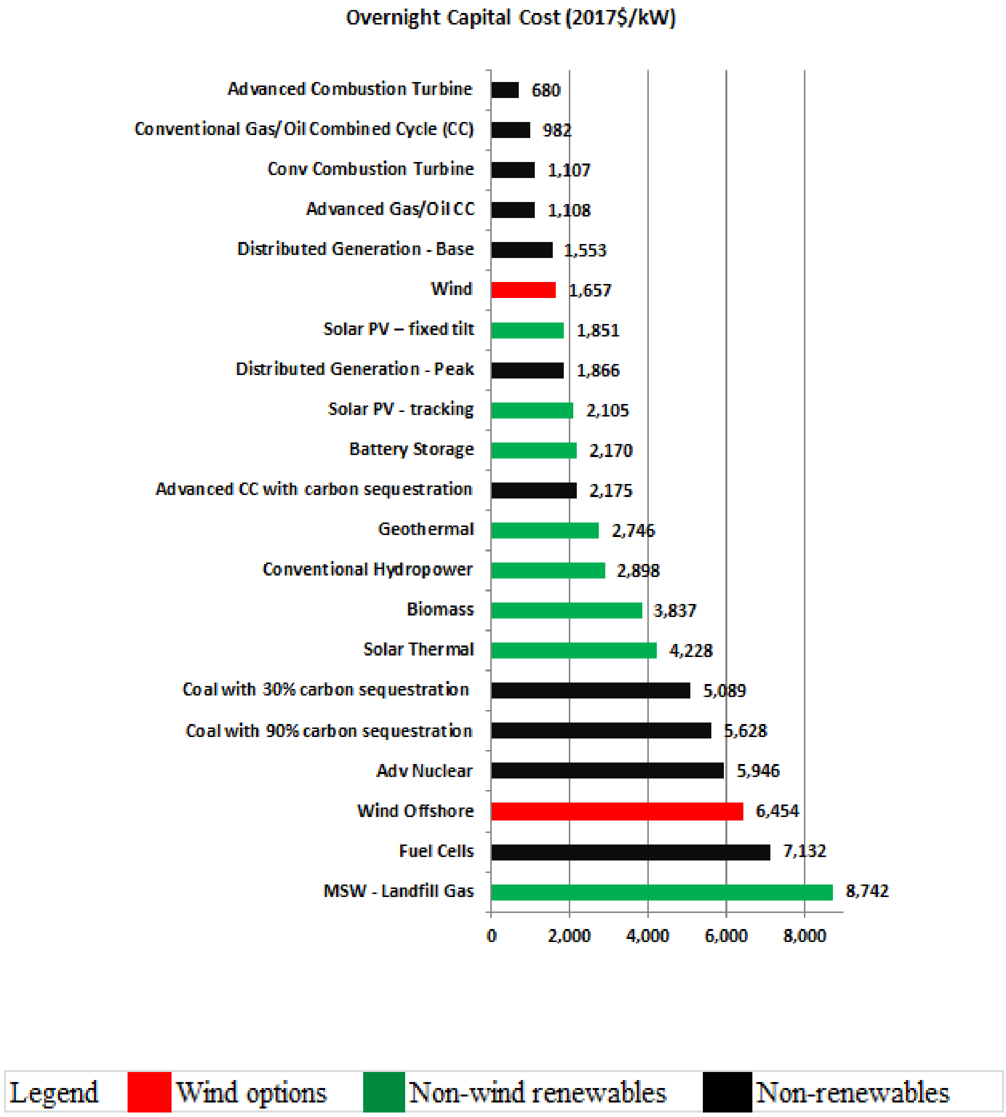

Figure 2-2: Estimated capital costs of various electric generation options (Source: EIA [8])

Figure 2-3 shows the trend in installed wind power plant costs for the projects from 1982 to 2017 contained in the 2017 *Wind Technologies Market Report* [9] 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 2017 capacity-weighted average installed project cost of $1,611/kW was 33 percent lower than the peak $2,407/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.

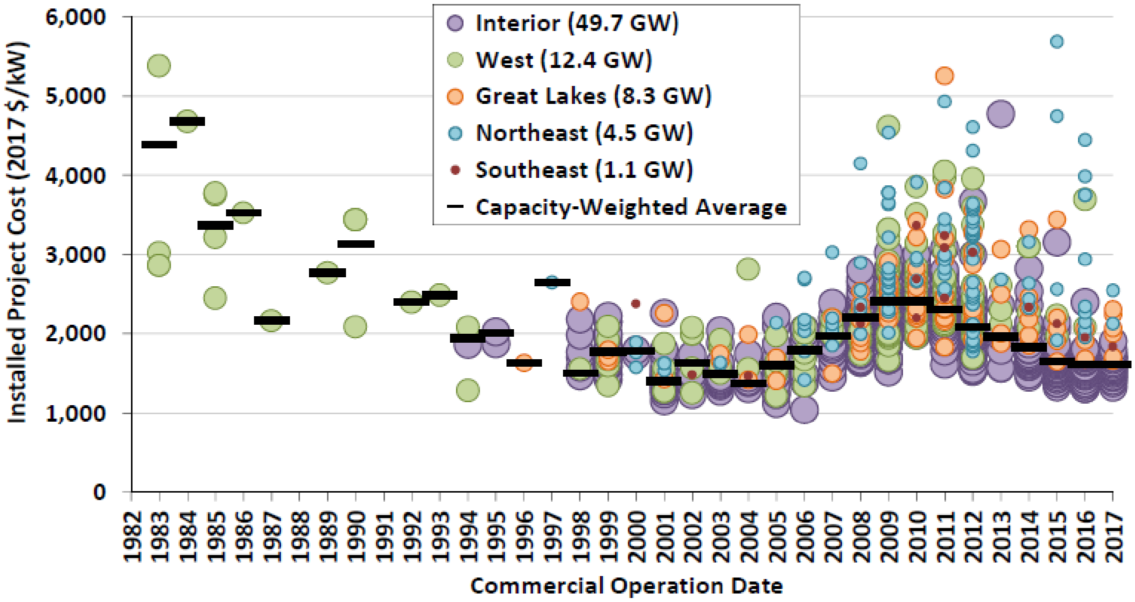

Figure 2-3: Installed wind power project costs over time (Source: LBNL [9])

According to the *2017 Wind Technologies Market Report*, operation and maintenance (O&M) costs are a significant part of the overall cost of wind power plants and can vary widely between projects. Figure 2-4 shows the O&M costs of electricity generating plants according to the EIA January 2017 estimates. EIA estimates the variable O&M to be zero for both onshore and offshore wind farms while the fixed O&M cost is $77/kW/yr for offshore wind and $47/kW/yr for onshore wind farms.

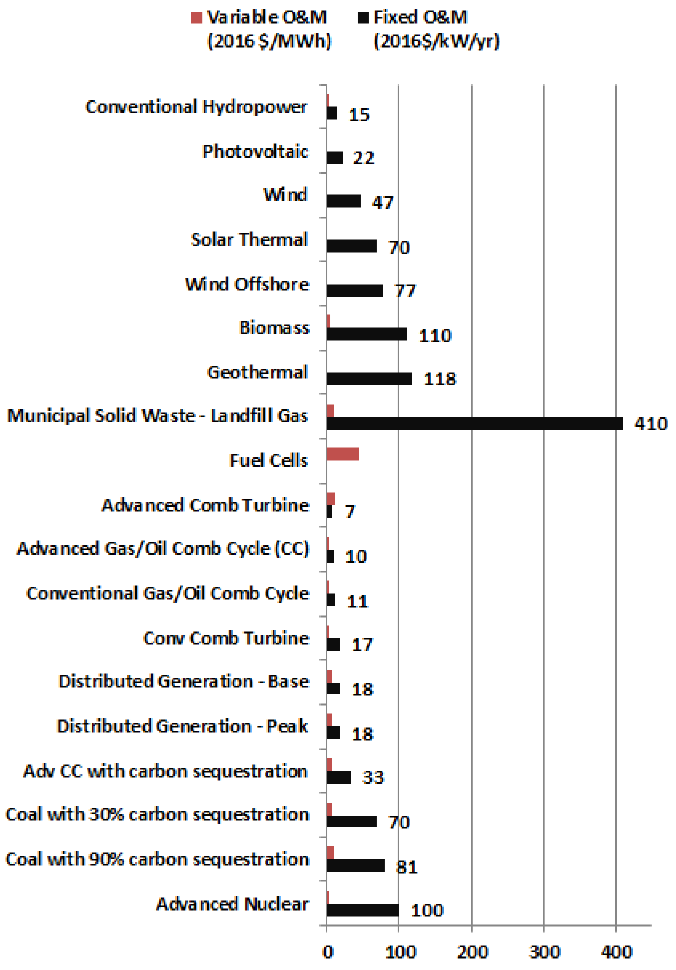

Figure 2-4: Generating technologies O&M cost (Data Source: EIA [8])

Figure 2-5 shows the project-level O&M costs by commercial operation date in the *2017 Wind Technologies Market Report.* It represents the O&M costs in $/kW/yr for the 80 installed wind power projects totaling 10,506 MW with commercial operation dates between 1982 and 2016 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 2017, using however many years of available data for that period. According to the Lawrence Berkeley National Laboratory the figure suggests that projects installed within the past decade have incurred lower O&M costs on average. And that specifically, the average O&M costs for the 24 projects installed in the 1980s was $70/kW/yr, which dropped to $58/kW/yr for the 37 projects installed in the 1990s, to $28/kW/yr for the 65 projects installed in the 2000s, and stayed at $28/kW/yr for the 38 projects installed since 2010.

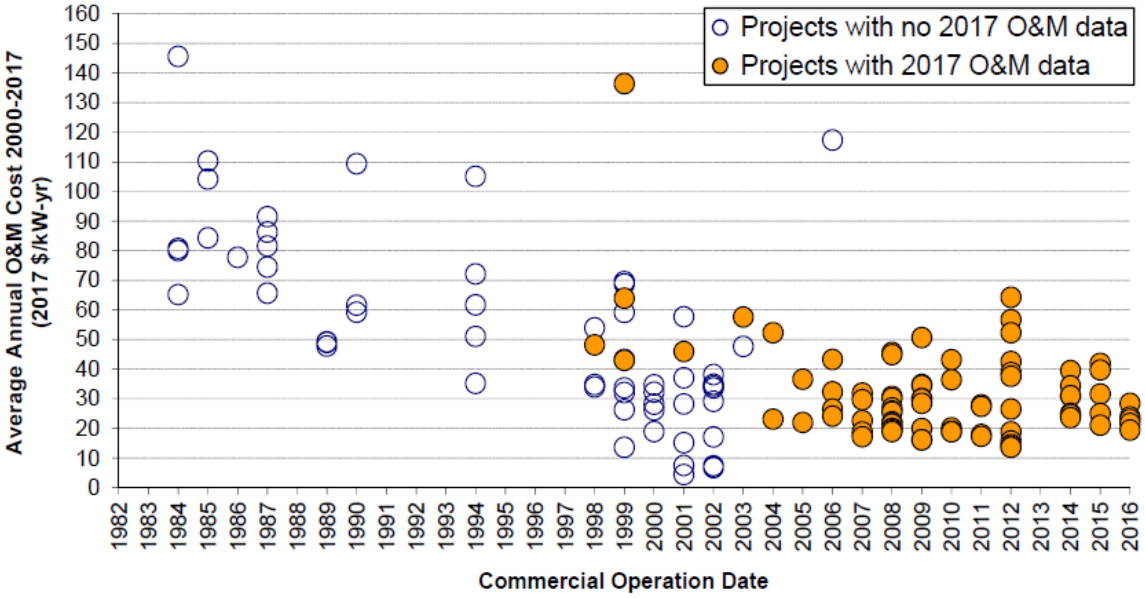

Figure 2-5: Average O&M costs for available data years (Source: LBNL [9])

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 wind 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. A drop in wholesale prices combined with a sharp rise in wind PPA prices in 2015 reduced wind's competitiveness, especially in the interior of the country (shaded brown in Figure 2-6). The competitiveness of wind was improved somewhat in 2016 with a drop in PPA prices putting wind at the lower end of the range of wholesale electricity prices. Wind project owners are able to make a profit with a price lower than the wholesale market price because they have access to the federal PTC.

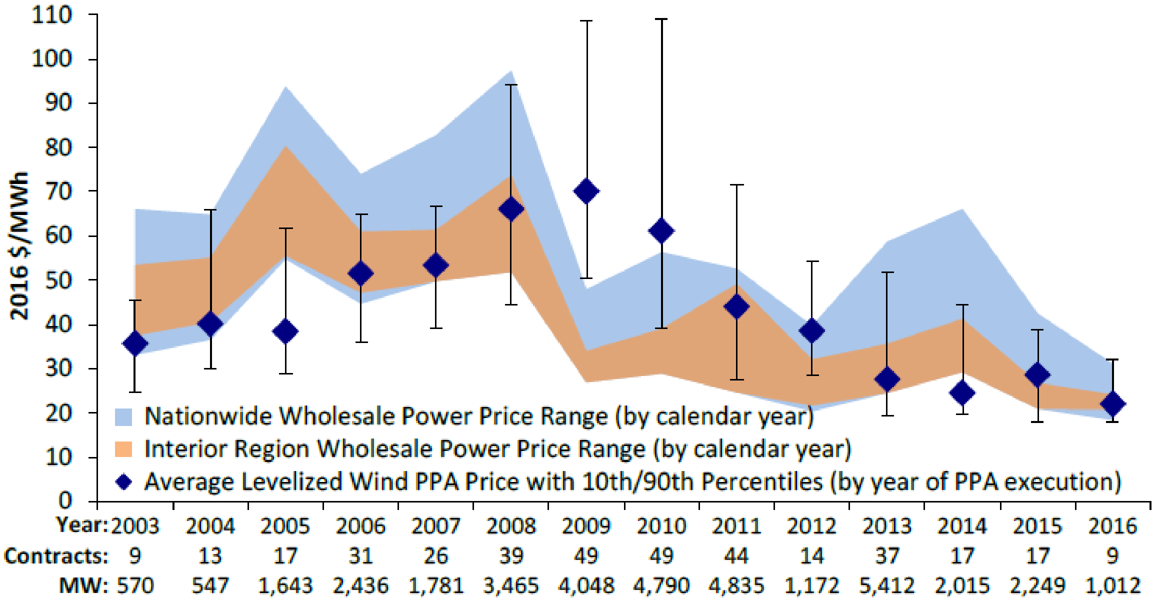

Figure 2-6: Average wind and wholesale electricity prices (Source: LBNL [10])

Figure 2-7 shows the estimated wholesale energy market value of wind across different regions of the country mapped along with the nation-wide generation-weighted average wind PPA prices from 2008 to 2017. Unlike Figure 2-6, which maps the whole price range for all the generation, Figure 2-7 maps the value of wind energy obtained using the regional hourly wind output profiles and the real-time hourly wholesale energy prices at the nearest pricing point. According to the *2017 Wind Technologies Market Report* the market value of wind has been declining and has been somewhat lower than the market value of other generation sources. The tendency for wind energy's value to be lower than that of other generation is because wind generation tends to be concentrated in areas with limited transmission capacity which tends to suppress the energy price at those nodes. In addition wind production does not always align well with the system's energy needs, which also has the tendency to suppress the energy prices at the wind production node when wind production is high. As can be seen in Figure 2-7 the cost of wind, as represented by the PPAs, has also been declining and at such a rate that wind has been competitive since 2013. During those years when the value of wind energy was below the PPA prices, wind energy's competitiveness was aided by the federal production tax credit.

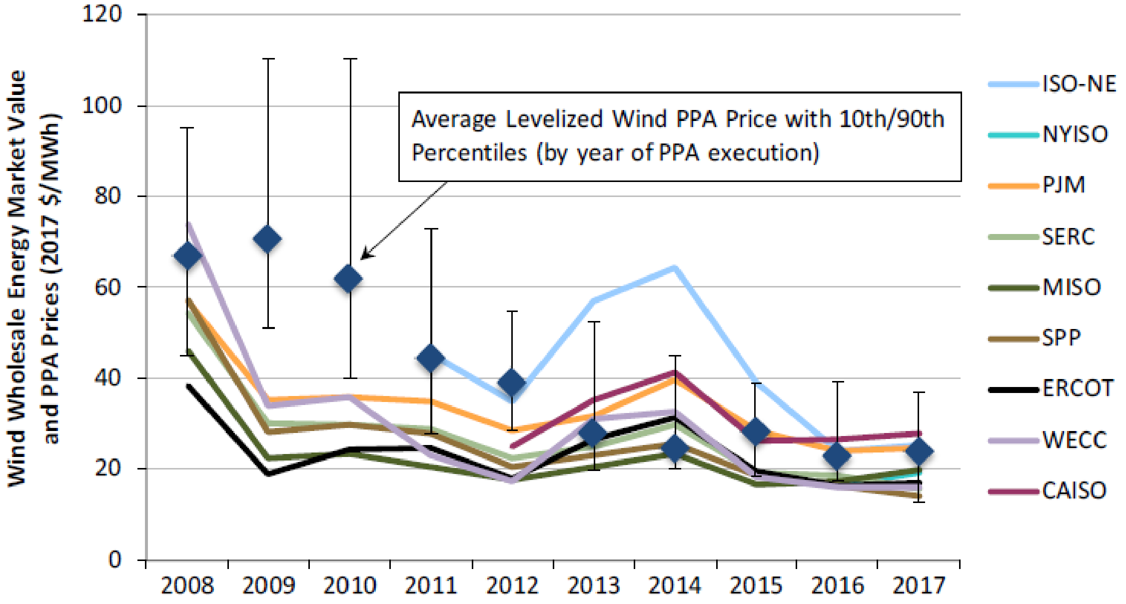

Figure 2-7: Wholesale energy value of wind (Source: LBNL [9])

2.3 State of wind energy nationally

As can be seen in Figure 2-8 U.S. installed wind energy capacity has increased steadily, from 2,456 MW installed at the end of 2005 to 89,379 MW at the end of March 2018. In that period wind energy has grown to become the second largest source of renewable electricity contributing 37 percent of the renewable electricity generated in 2017 as compared to hydroelectricity's 44 percent and solar energy's 8 percent.

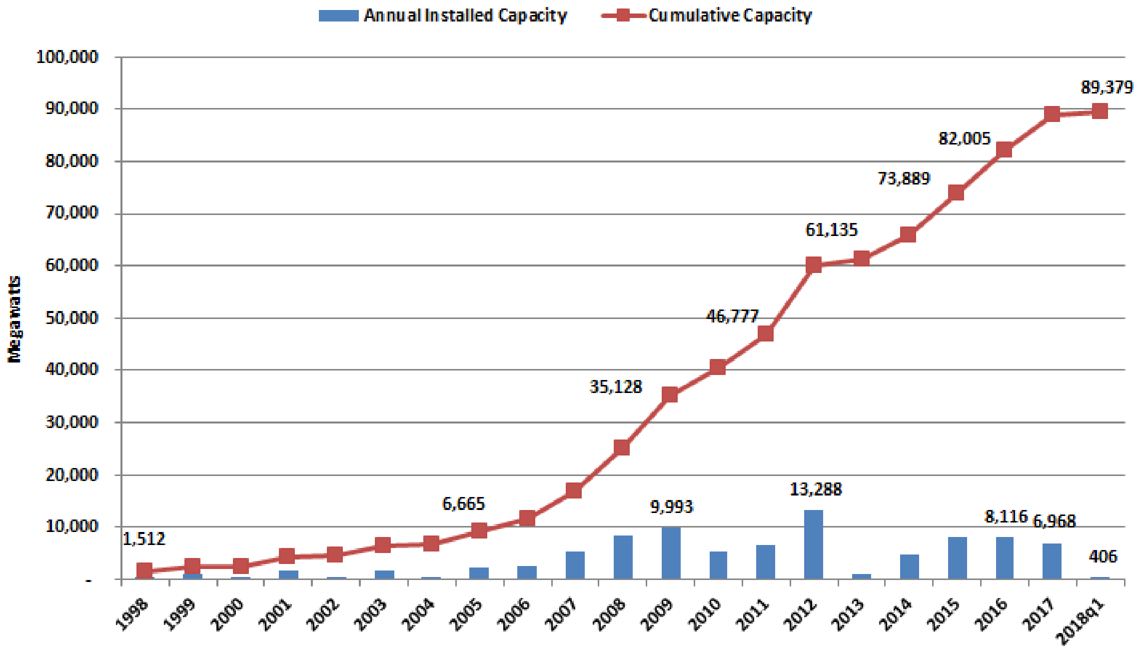

Figure 2-8: U.S. wind capacity growth (Data source LBNL [9], AWEA [11])

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, allowing 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 federal renewable PTC. The PTC has subsequently been extended, most recently to December 2019 by the Consolidated Appropriations Act of 2016. This extension however included a phasing down of the credit by 20 percent for projects commencing construction in 2017, 40 percent for projects commencing construction in 2018 and by 60 percent for projects commencing construction in 2019.

Figure 2-9 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.

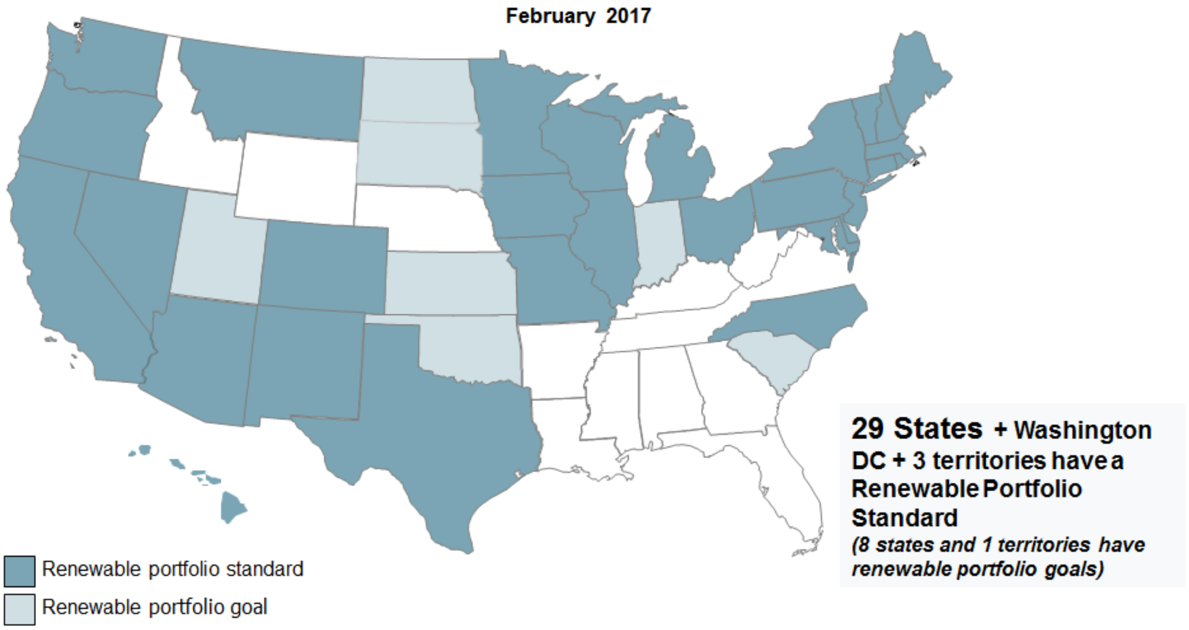

Figure 2-9: Renewable portfolio standards across the U.S. (Source: DSIRE [12])

Figure 2-10 shows the cumulative capacity of utility-scale wind energy installed by state as of the end of the first quarter of 2018. Texas continued to lead with a total capacity of 22,799 MW installed, more than three times its closest follower Oklahoma which had 7,495 installed. Iowa followed closely with 7,312 MW cumulative capacity at the end of June 2017. Indiana ranked 12th overall with 2,117 MW of utility-scale wind capacity. In terms of wind capacity added in 2017 and first quarter of 2018, Texas again led with 2,478 MW followed by Oklahoma with 850 MW.

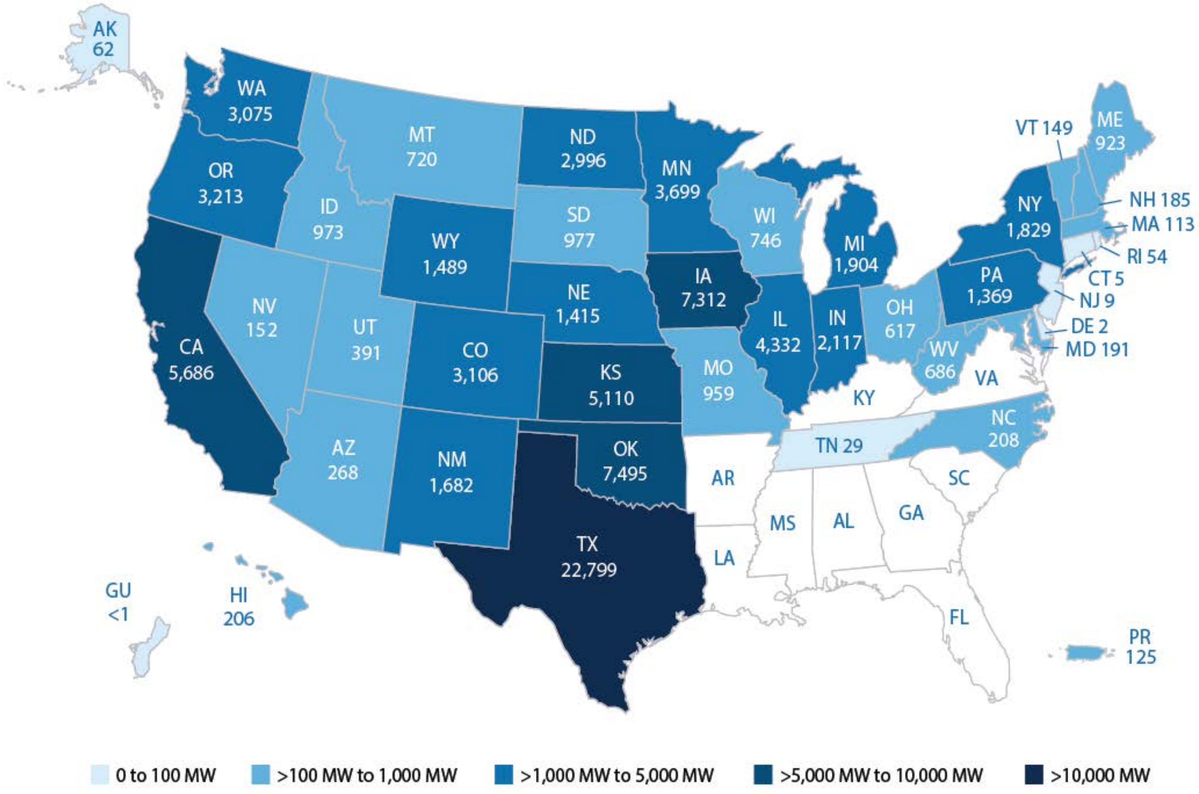

Figure 2-10: Wind power capacity by state at the end of March 2018 (MW) (Source: AWEA [11])

While Texas and California produced the most wind energy in 2017, as a percent of total energy produced, Iowa, Kansas, Oklahoma, South Dakota, and North Dakota had a higher percentage of wind production. Their wind energy production as percentage of total energy produced in 2017 was Iowa – 36.9 percent; Kansas – 36.0 percent; Oklahoma – 31.9 percent; South Dakota – 30.1 percent and North Dakota –26.8 percent. Indiana’s penetration was 4.7 percent and the U.S. total 6.3 percent [13]. Table 2-2 shows the penetration of wind energy in each of the fifty states in 2016.

State	Wind share of electricity generation in 2017 (%)		State	Wind share of electricity generation in 2017 (%)
Iowa	36.9		Utah	2.5
Kansas	36.0		New Hampshire	2.4
Oklahoma	31.9		Missouri	2.3
South Dakota	30.1		Wisconsin	2.3
North Dakota	26.8		West Virginia	2.2
Maine	19.9		Pennsylvania	1.7
Minnesota	18.2		Maryland	1.5
Colorado	17.6		Ohio	1.3
Idaho	15.4		Nevada	1.0
Texas	14.8		Massachusetts	0.7
Nebraska	14.6		Arizona	0.6
New Mexico	13.5		North Carolina	0.4
Vermont	13.4		Delaware	0.1
Oregon	11.1		Alabama	0
Wyoming	9.4		Arkansas	0
Montana	7.6		Florida	0
California	6.8		Georgia	0
Washington	6.5		Kentucky	0
Hawaii	6.5		Louisiana	0
Illinois	6.2		Mississippi	0
Indiana	**4.7**		South Carolina	0
Michigan	4.5		Tennessee	0
New York	3.1		Connecticut	0
Rhode Island	2.9		New Jersey	0
Alaska	2.7		Virginia	0
U.S.				6.3

Table 2-2: Wind share of electricity generation in 2017 by state (Data source: AWEA [13])

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 nearly ten times the electricity generated from all sources in the U.S. in 2017 [14, 15]. Figure 2-11 shows the distribution of the wind resource.

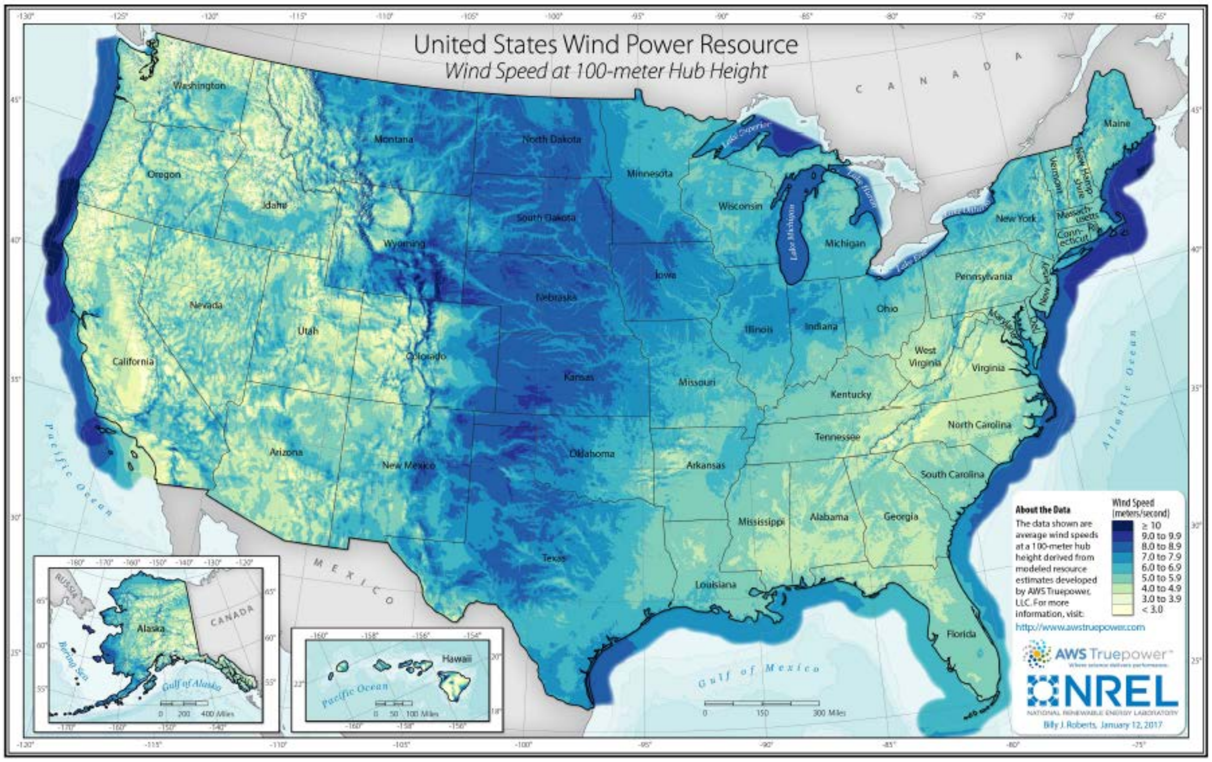

Figure 2-11: 100-meter U.S. wind resource map (Source: DOE [16])

As can be seen in Figure 2-11 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 U.S. offshore wind farm, the 30 MW Block Island Wind farm off of the coast of Rhode Island, was commissioned by the wind developer Deepwater Wind in 2016. According to the DOE 2016 *Offshore Wind Technologies Market Report* the prospects for offshore wind farm development in the U.S. have been improved by the plummeting market prices for offshore wind energy in European wholesale markets and more favorable state policy commitments. A 21 MW demonstration project, the Icebreaker, is being developed jointly by DOE and Fred Olsen Corporation in Lake Erie off of Cleveland, Ohio. The project will study the challenges unique to offshore wind projects in fresh water bodies such as fresh water ice [17].

2.4 Wind energy in Indiana

Like a number of other states, Indiana experienced a rapid growth of wind generation capacity in the 2008 to 2010 time period. Although this rapid expansion has slowed down, wind generation has continued to grow at a steady pace with two wind farms with a combined capacity of 220 MW being completed in 2017 and two wind farms with combined capacity of 600 MW currently under construction. Figure 2-12 shows the utility scale wind installed capacity and the capacity currently under construction. In addition to the utility scale wind farms there is approximately 4.77 MW of small wind projects connected through net metering and feed-in-tariffs offered by Indiana utilities.

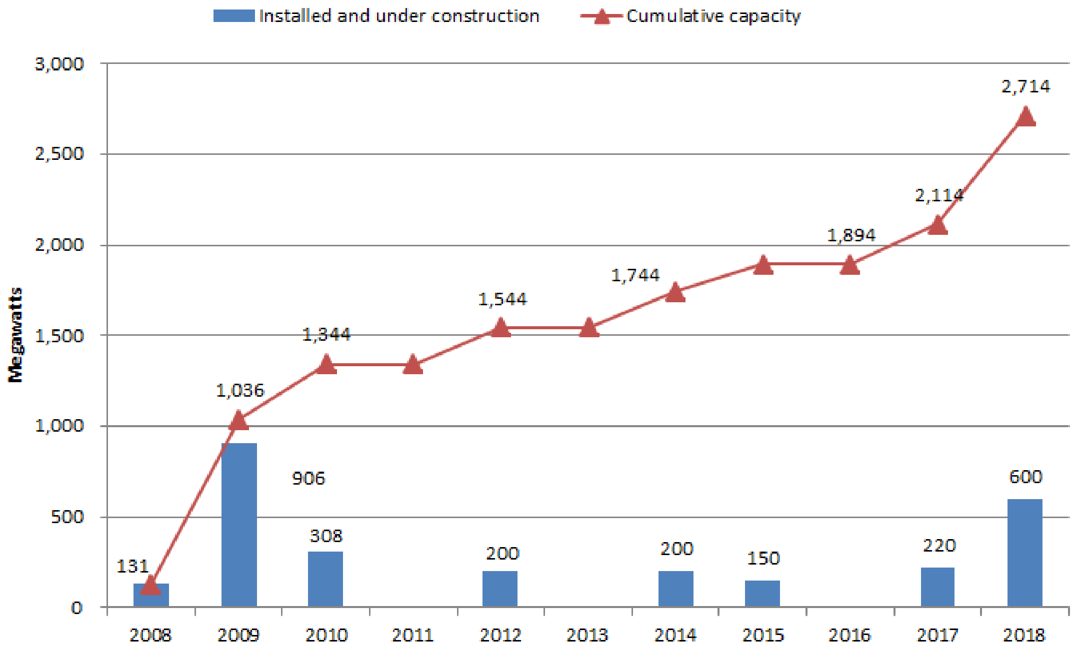

Figure 2-12: Wind energy capacity in Indiana (Data source: IURC [18]).

Table 2-3 is a list of utility scale wind farms installed, under construction or proposed in Indiana. Fourteen of the wind farms, with a combined capacity of 2,114 MW, are installed and operational. Two wind farms with a combined capacity of 600 MW are currently under construction. One of them, the 200 MW Meadow Lake Wind Farm VI, is expected to be completed in 2018 and the second, the 400 MW Jordan Creek Wind Farm in Warren County, is expected to be completed in 2019. The construction of a 102 MW wind farm proposed for Fayette County had not started as of the writing of this report.

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
Fowler Ridge IV Wind Farm (Amazon)	Benton	150	2015
Meadow Lake Wind Farm V	White	100.8	2017
Bluff Point	Jay/Randolph	119	2017

Project under construction

Meadow Lake Wind Farm VI	White	200.4
Jordan Creek Wind Farm	Warren	400

Proposed project

West Fork Wind Farm	Fayette	102

Table 2-3: Utility Scale Wind Farms in Indiana (Data source: IURC [18])

Indiana utilities have a total 1,404 MW of wind power contracted on power purchase agreements, with 966 MW from wind farms in Indiana and 438 MW from out of state wind farms. Table 2-4 shows the wind power capacity contracted to Indiana utilities.

Utility	Project	State	Power Purchase Agreement (MW)
Duke	Benton County	Indiana	110.7
Vectren	Benton County	Indiana	30
Vectren	Fowler Ridge II	Indiana	50
I&M	Fowler Ridge I	Indiana	100.4
I&M	Fowler Ridge II	Indiana	50
I&M	Headwaters	Indiana	200
I&M	Wildcat I	Indiana	100
I&M	Bluff Point	Indiana	119
IPL	Hoosier	Indiana	106
Hoosier	Meadow Lake V	Indiana	75
WVPA	Meadow Lake V	Indiana	25
IPL	Lakefield	Minnesota	201
NIPSCO	Barton	Iowa	50
NIPSCO	Buffalo Ridge	South Dakota	50.4
Hoosier	Story County	Iowa	25
WVPA	Various sources	Various	64
IMPA	Crystal Lake	Iowa	48*

*IMPA power purchase agreement expires at end of 2018

Table 2-4: Wind energy purchase agreements by Indiana utilities (Data sources: IURC, Hoosier [19], WVPA [20], IMPA [21])

Figure 2-13 shows the distribution of Indiana 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 2-14 shows the distribution of the wind resource at 50m, a height at which smaller scale community wind projects operate.

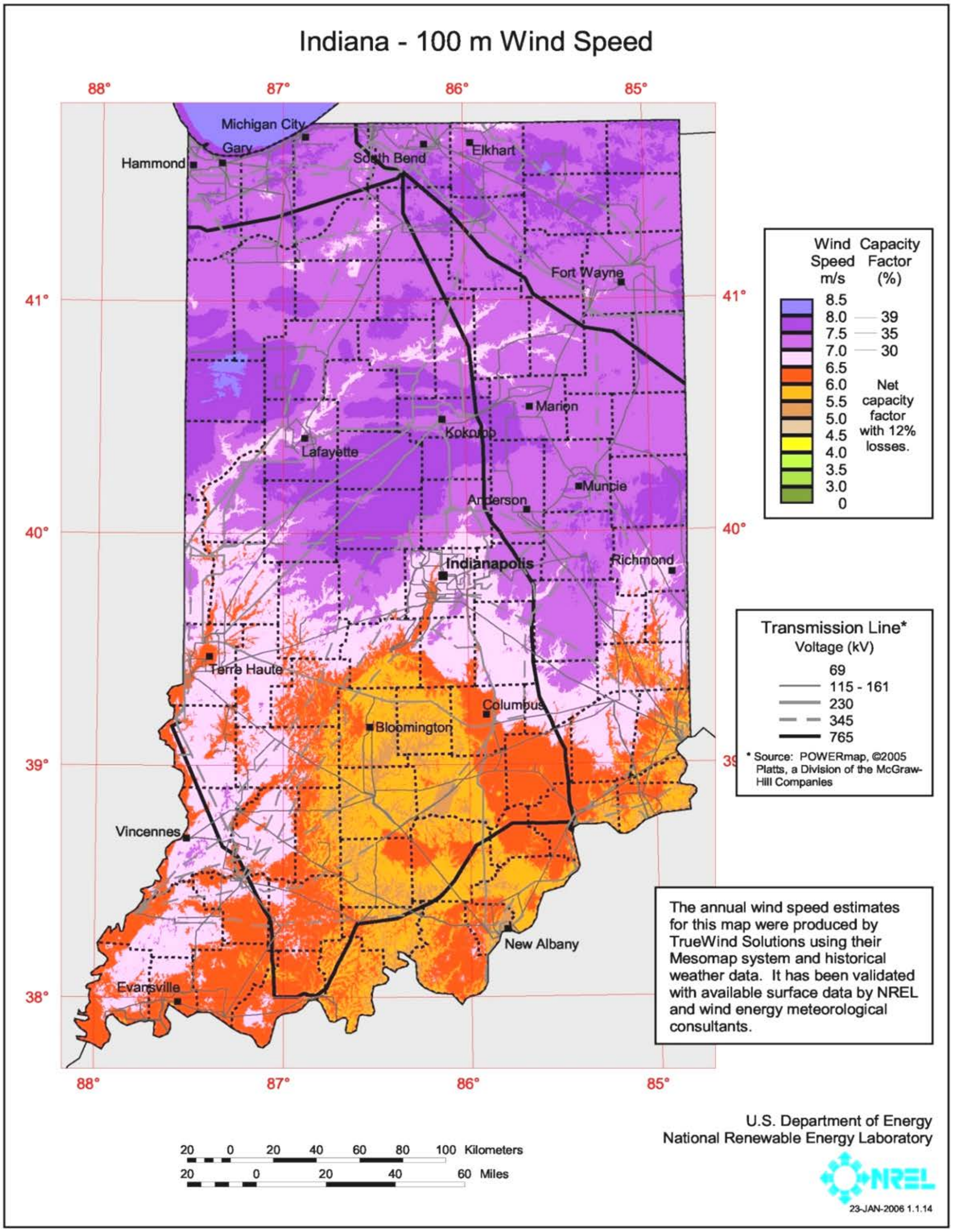

Figure 2-13: Indiana wind speed at 100 meters height (Source: OED/NREL [22])

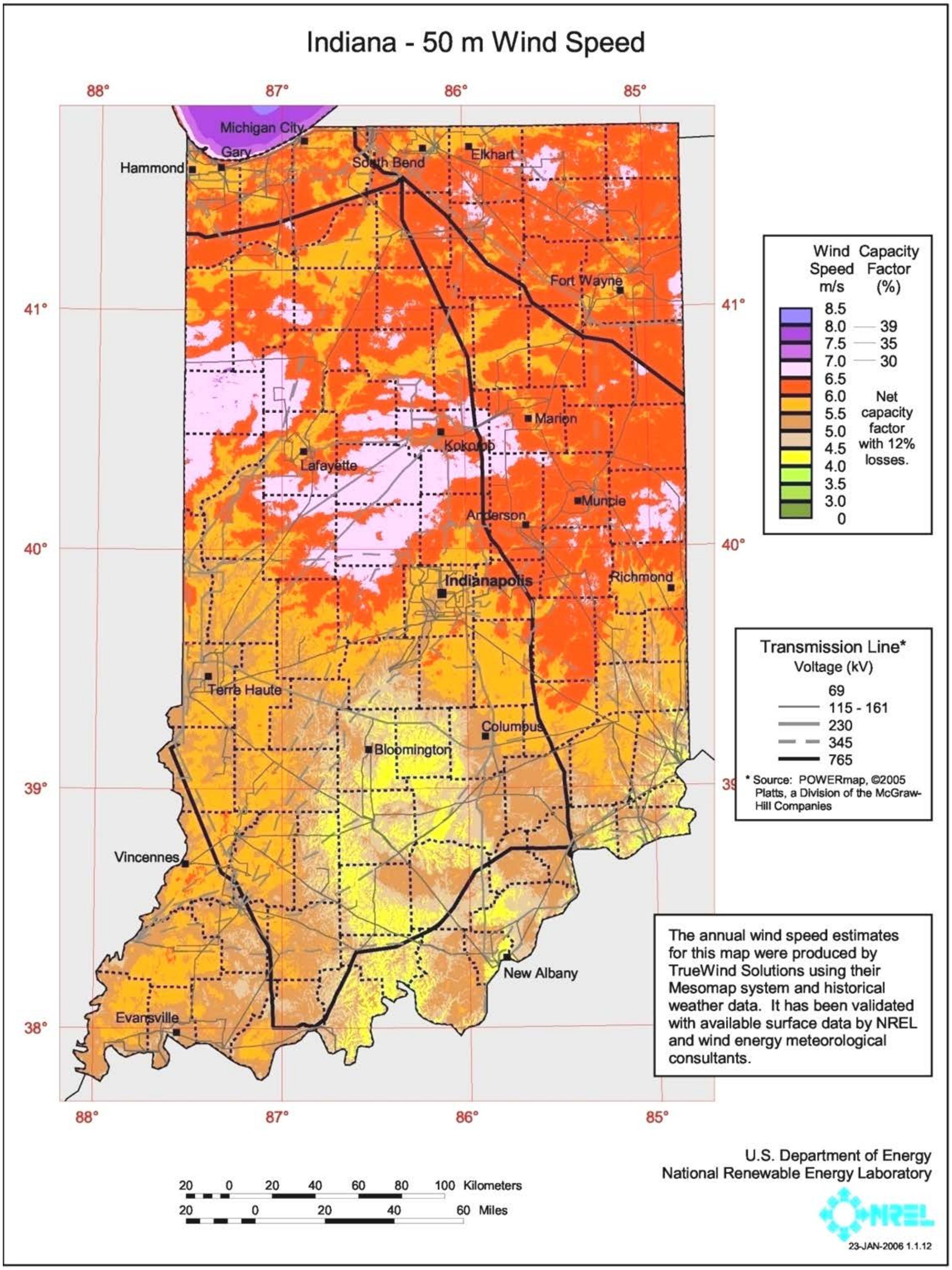

Figure 2-14: Indiana wind speed at 50 meters height (Source: OED/NREL [22])

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 1.5 cents/kWh in 1993 dollars adjusted by an inflation adjusted factor for the calendar year supplied by the IRS. When the credit was extended in 2015 a provision was included to phase it down by reducing the credit 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. Applying the inflation factor and the 20 percent reduction resulted in a credit for projects that commenced construction in 2017 at 1.9 cents/kWh. The credit expires on December 31, 2019 for wind projects [12].
- 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 expired in December 2016 [12].
- 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 [12].
- 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 [12].
- 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 [12].
- 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) [12].
- 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 [12].

- 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 [12, 23].
- 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 [12].
- Green Power Purchasing Goal requires that 30 percent of energy used by federal agencies must be obtained from renewable resources by 2025 [12].

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 [12]. Indiana Senate Bill 309 signed into law in May 2017 made changes to the net metering rule to modify the compensation after June 30, 2022 to 1.25 times the utility's average wholesale cost for the most recent year. Generators installed before the end of 2017 shall continue to receive full retail credit until July 1, 2047 and those installed in the years 2018 to 2022 shall receive full retail credit for their generation until June 30, 2032 [12, 24].
- Renewable Energy Property Tax Exemption provides property tax exemptions for solar thermal, PV, wind, hydroelectric and geothermal systems [12].
- Community Conservation Challenge Grant provides $20,000-$80,000 in grants for community energy conservation projects that reduce energy consumption or displace the use of traditional energy sources [25].
- 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 [12].
- 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 [12].
- 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* [12, 26, 27].

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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. This is distinct from the use of organic waste and residues discussed in the section that follows (Section 4) and also from bioenergy from dual use crops such as corn and soybeans to make transportation fuels such as ethanol and biodiesel. Although biomass is already the largest source of renewable energy in the U.S., the energy crops industry is still in its infancy. In 2012 an estimated 11,264 dry tons of switchgrass and miscanthus were grown and harvested for energy conversion as compared to the 170 million dry tons of forestry byproducts (wood and wood waste) used for energy conversion in 2014 [1].

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 [2]. This research effort is detailed in the DOE report titled *2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy* [1] 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.

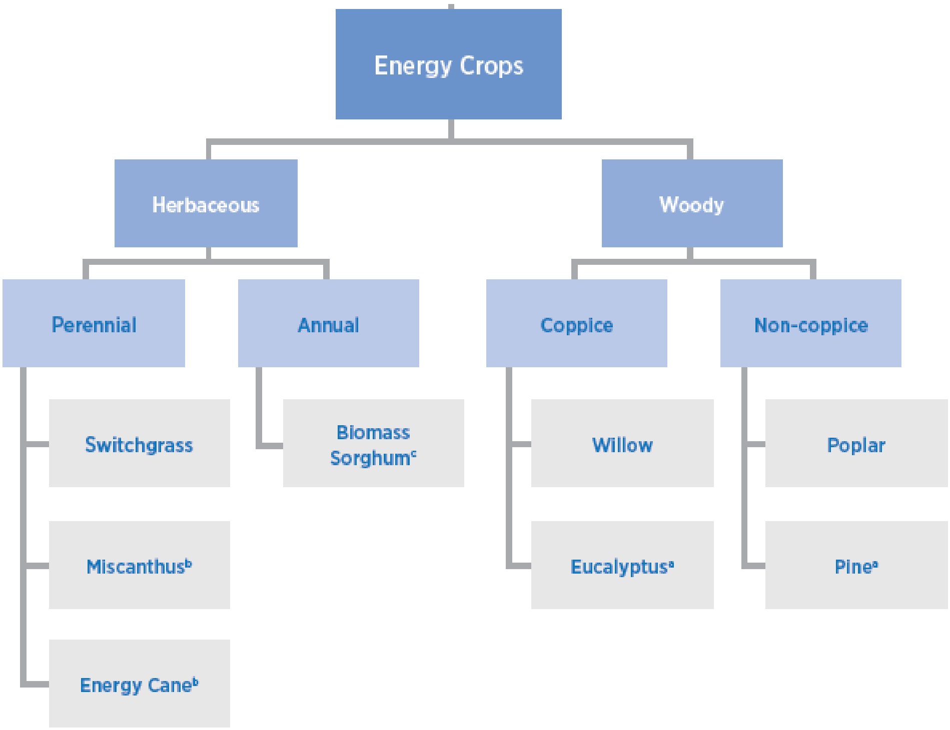
The Giant Miscanthus hybrid was developed in Japan and introduced to the U.S. as a landscape plant. The main attraction of Giant Miscanthus as an energy crop is its high level of biomass production. While a great deal of research has been done establishing its potential as an energy crop, there are still 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.

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 [4]. Figure 3-1 shows the energy crops considered under the *2016 Billion-Ton Report*.



[a, b, c] These energy crops are studied in more detail in the *2016 Billion-Ton Report* than in previous versions of the *Billion-Ton Study*.

Figure 3-1: Energy crops included in the *2016 Billion-Ton Report* (Source: DOE [1])

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 [5].
- 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 [6].

- 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 [7].

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 31 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 fourteen 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 [8].

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
ADM	Decatur, IL	Pilot	Biochemical
BioProcess Algae	Shenandoah, IA	Pilot	Algae*
Frontline	Ames, IA	Pilot	Thermo-Gasification
ICM	St. Joseph, MO	Pilot	Biochemical
Logos 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 this report

Table 3-1: DOE funded integrated biorefinery projects (Data source: DOE [8])

3.2 Economics of energy crops

The DOE vision of a large scale bioenergy economy supported by large scale farming of energy crops and collection of agricultural and forest residues is not yet realized. The economics of large scale farming of energy crops are still unfavorable. For such a large scale production of dedicated energy crops to occur, the price of the energy crops will have to be high enough to compete with the current cropland uses, while on the energy industry side be low enough to compete with traditional fuels (e.g. petroleum and natural gas) currently in use. In the *2016 DOE Billion-Ton Report* the U.S. agricultural sector simulation model (POLYSYS) was used 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 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.

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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.

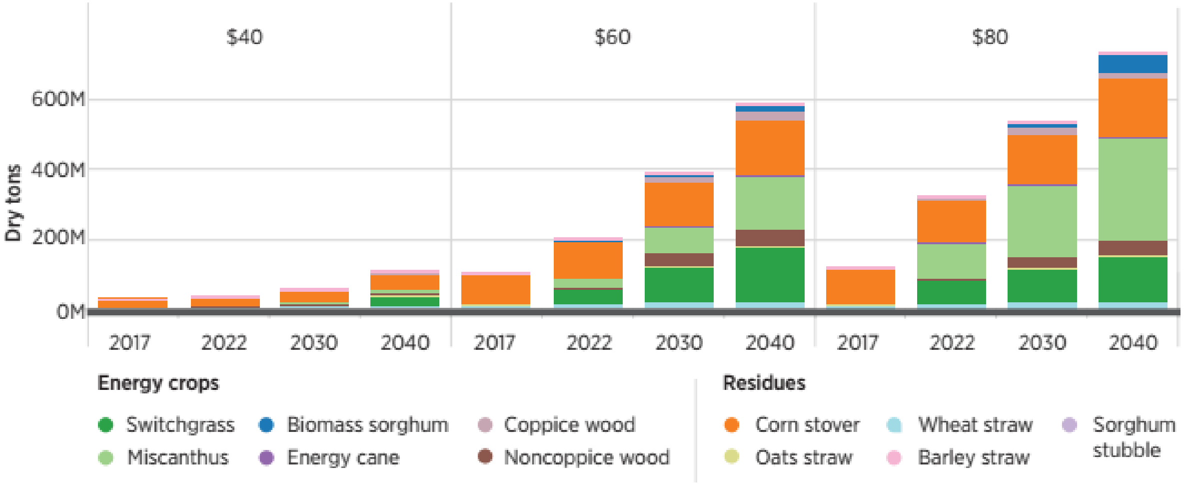

Figure 3-2: Production of energy crops at various farm-gate prices for select years (Source: DOE [1])

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.

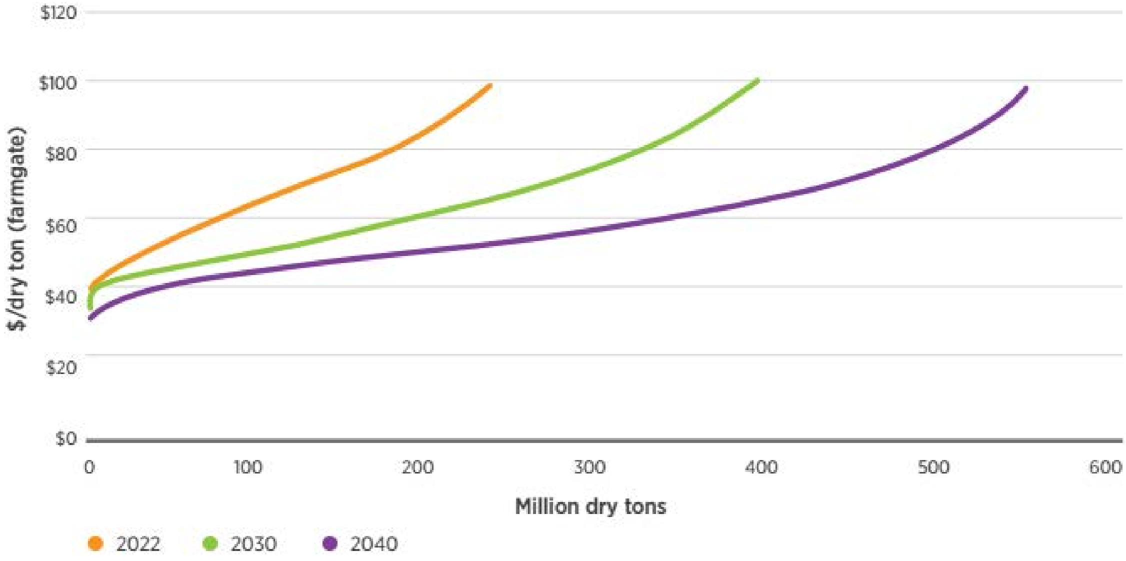

Figure 3-3: Supply curves of potential herbaceous energy crop production for select years under base-case assumptions (Source: DOE [1])

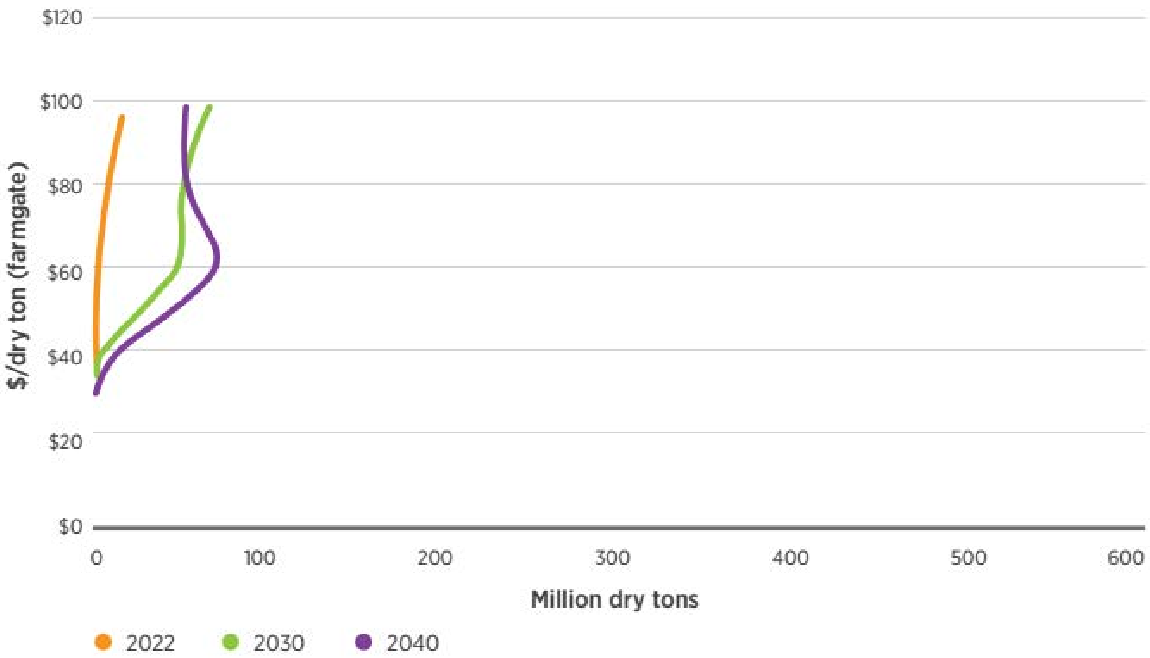

Figure 3-4: Supply curves of potential woody energy crop production for select years under base-case assumptions[9] (Source: DOE [1])

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. [9]. 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., and
- 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 eleven corn-ethanol plants with a combined capacity of 1,140 MGY have been constructed, bringing the total corn-ethanol capacity to 1,230 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, which brought an end to the expansion of the ethanol production industry. Table 3-2 shows the location and capacities of ethanol plants in Indiana.

Company	Location	Capacity (MGY*)
Green Plains Corp	Mt. Vernon	90
Cardinal Ethanol	Union City	100
Central Indiana Ethanol	Marion	60
Grain Processing Corp.	Washington	20
Green Plains	Bluffton	120
Iroquois Bio-Energy Company LLC	Rensselaer	50
MGPI of Indiana	Lawrenceburg	35
Noble Americas South Bend Ethanol LLC	South Bend Ethanol	102
Poet Biorefining	Alexandria	75
Poet Biorefining	Cloverdale	90
Poet Biorefining	North Manchester	70
Poet Biorefining	Portland	70
The Andersons Clymers Ethanol	Clymers	110
Valero Renewable Fuels	Linden	130
Valero Renewable Fuels	Mount Vernon	110

*MGY denotes million gallons per year.

Table 3-2: Ethanol plants in Indiana (Data source: Ethanol Producers Magazine [10])

There are two operating biodiesel plants with a combined capacity of 93 million gallons per year operating in Indiana. They are the 5 MGY Integrity Biofuels plant in Morristown and the 88 MGY Louis Dreyfus plant in Claypool [11, 12].

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 methyl tertiary-butyl ether (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 [13].
- The renewable fuel standard first enacted in 2005 and then expanded in 2007 required 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. Starting in 2014, EPA began revising the annual volume requirements downwards in recognition of the fact that the demand for gasoline was lower than had been anticipated when the blending volumes were set in 2007 [14, 15].
- 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 entities who produce the mixture of gasoline and ethanol. This tax credit expired at the end of 2011 [16].

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*.

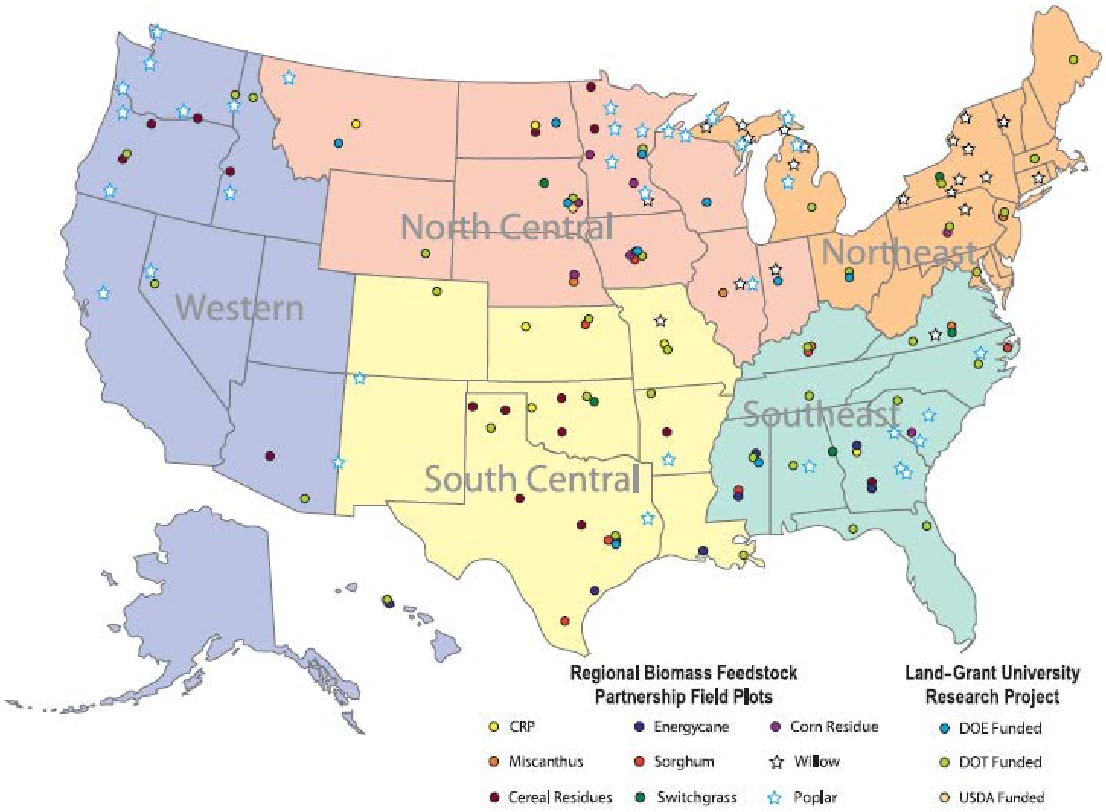

Figure 3-5: Bioenergy crop trial stations (Source DOE [17])

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 [18]. At the March 2015 project peer review conference the following progress was reported on the feedstock research [19]:

- 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, and
- 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 that in the national bioenergy economy, Indiana and other corn-belt stated like Iowa and Illinois would mainly be suppliers of biomass in the form agricultural residues such as corn stover and only a limited amount of dedicated energy crops. This is because the price that energy crops would have to offer farmers to displace the food crops would be too high for the resulting biofuels to be competitive with petroleum in the transportation sector and traditional fuels such as natural gas in the electricity sector. 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.

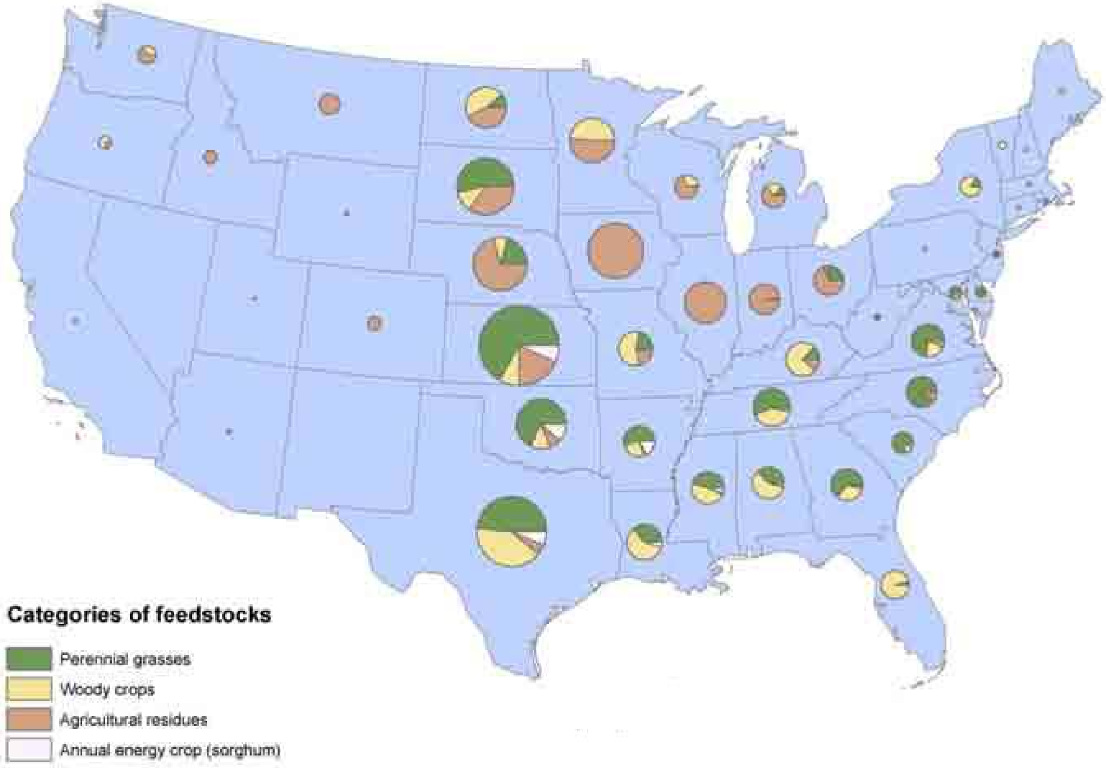

Figure 3-6: Estimated shares of energy crops and agricultural residues supplied at $60 per dry ton in 2030 (Source: DOE [4])

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.

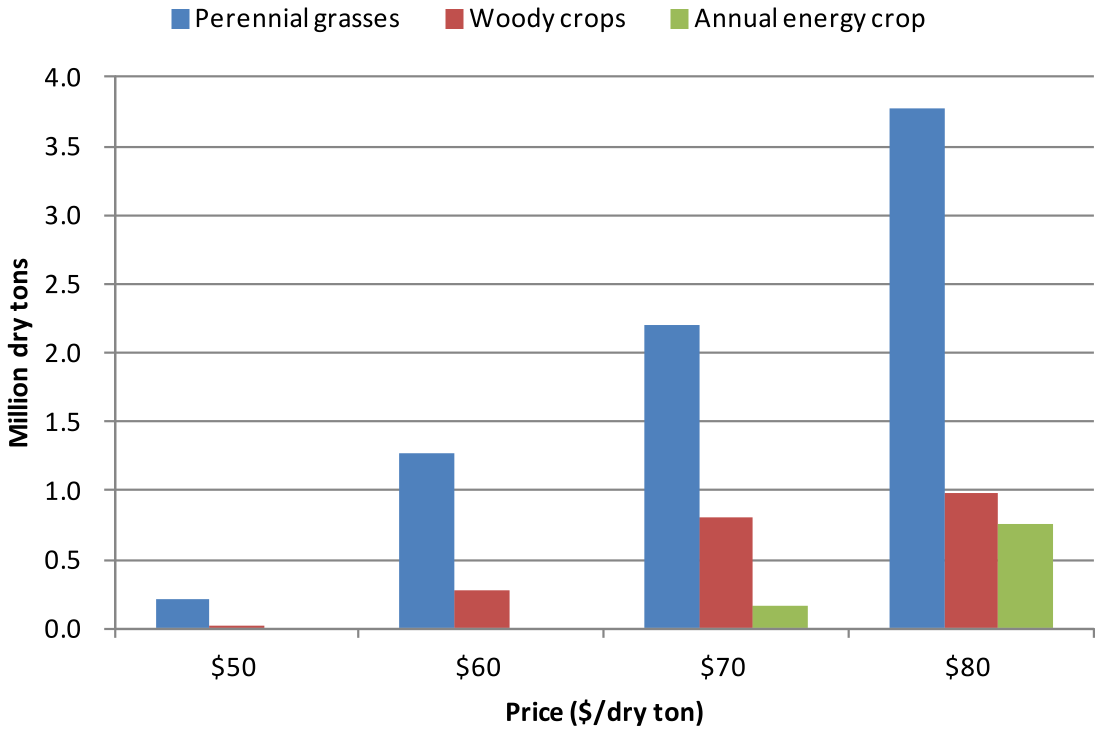

Figure 3-7: Projected production of energy crops in Indiana in 2030 (Data source: DOE [20])

In a 2008 paper, Brechbill and Tyner of Purdue's Agricultural Economics Department did a study of the estimated cost of producing switchgrass and harvesting corn stover for the energy industry in Indiana. Table 3-3 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.

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 [22].

In her 2013 Master's thesis, Song performed an integrated economic and environmental assessment of cellulosic biofuel production focusing on the Wildcat Creek Watershed. 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 3-4. The opportunity cost of growing perennial grasses instead of the cash crops common to the area, corn and soybean, is considered ($180/acre, based on the 2015 Purdue Crop Cost & Return Guide [23]). 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 3-4 are considered in order to compare candidate feedstocks and corn stover removal rates [24, 25].

	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 3-3: Average cost ($/ton) for producing switchgrass in Indiana (Data source: Brechbill & Tyner [21])

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 3-4: Cost by category for producing corn stover, switchgrass, and miscanthus in Wildcat Creek Watershed (Data source: Song et al. [25])

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) for dedicated energy crops, which falls under the category closed-loop biomass, expired at the end of 2017. It is however still available for projects that started construction in 2017 at the rate of 2.3 cents/kWh [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].
- 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 [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].
- 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 [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].
- 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 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 [26]. Indiana Senate Bill 309 signed into law in May 2017 made changes to the net metering rule to modify the compensation after June 30, 2022 to 1.25 times the utility's average wholesale cost for the most recent year. Generators installed before the end of 2017 shall continue to receive full retail credit until July 1, 2047 and those installed in the years 2018 to 2022 shall receive full retail credit for their generation until July 1, 2032 [26, 27].
- Community Conservation Challenge Grant provides $20,000-$80,000 in grants for community energy conservation projects that reduce energy consumption or displace the use of traditional energy sources [28].
- 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 for applying for the 2013 to 2018 incentive has expired [26].
- 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 [26, 29, 30].

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4. Organic Waste Biomass

4.1 Introduction

This section presents the use of biomass in the form of organic waste and residues as a source of renewable energy, as opposed to the previous section (Section 3) that presented biomass in the form of dedicated energy cops. Unlike the dedicated energy crops industry, organic waste biomass is already in widespread use as a source of renewable energy, historically being second only to hydroelectricity as the source of renewable energy consumed in the U.S. 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, like the DOE funded *Billion-Ton Study* referred to in Section 3 [2], have shown that substantial energy resources in the form of biomass from crop residues could be harvested under appropriate economic conditions. Agricultural residues have the added advantage that they do not require any further cultivation or the use of additional cropland, and they therefore present a potential near-term feedstock into the bioenergy industry. According to the DOE in the *2016 Billion-Ton Report* most of the cellulosic plants completed to date have focused on agricultural residues, primarily corn stover for feedstock. They include the POET-DSM plant in Emmetsburg, Iowa, the Abengoa plant in Hugoston, Kansas and the Dupont plant in Nevada, Iowa [2].

Large scale farming of algae is another area being considered as a potential source of bioenergy. Algae encompass a wide range of organisms; from microscopic unicellular bacteria, through the common blue-green algae to sea weeds such as giant kelp that can grow to over 150 feet long. They are fast growing organisms which require some form of energy (e.g. sunlight or sugars), water, carbon dioxide and a few other nutrients to produce biomass usable for energy production. Several characteristics have made algae a favorable feedstock for biofuels. They include [3].

- Algae’s high biomass yields per acre, as much as 50 times more than soy beans
- Algae can be grown in otherwise non-arable lands, reducing competition with conventional agricultural crops
- Algae can be grown using wastewater, saline water, or water that is produced as a byproduct of oil and gas extraction.
- Algae have the potential for recycling of carbon dioxide from fossil fueled power plants and other industrial carbon dioxide emitters.
- Algae is compatible with the concept of using integrated biorefineries that produce a variety of fuels and co-products to maximize the value extracted out of a biomass feedstock.

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 [4].

The production of algae for energy is still in the development stage. The federal government through the DOE biotechnologies 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 [3].

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 January 2017 Energy Information Administration (EIA) plant cost estimates, the MSW power plant was listed as having the highest capital cost ($8,623/kW) among the technologies considered and the highest fixed O&M cost ($410/kW/yr) [5].

Another waste stream that is currently a major source of renewable energy, especially in Indiana, is landfill gas. That is, tapping the methane-rich gas in already established landfills. Unlike the MSW energy conversion facilities that rely on burning solid waste in a boiler to extract the energy, landfill gas projects on existing landfills do not need a boiler. As a result their capital cost is much lower than that of MSW energy conversion facilities. The capital cost of recently installed landfill gas energy projects in Indiana is estimated at $1,350/kW, about 15 percent of the EIA estimate of the capital cost of MSW energy conversion facilities.

Like MSW and landfill gas other organic waste streams such as animal waste and municipal wastewater treatment plants 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 that carry out the decomposition/digestion of the biomass.

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. As was mentioned in Section 3, a substantial research and development effort, led by the DOE Bioenergy Technology has been under way since the early 2000s to build a national bioenergy industry. As a part of this effort in 2005 the U.S. Department of Agriculture (USDA) and 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* [6], 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 [7]. 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 [2].

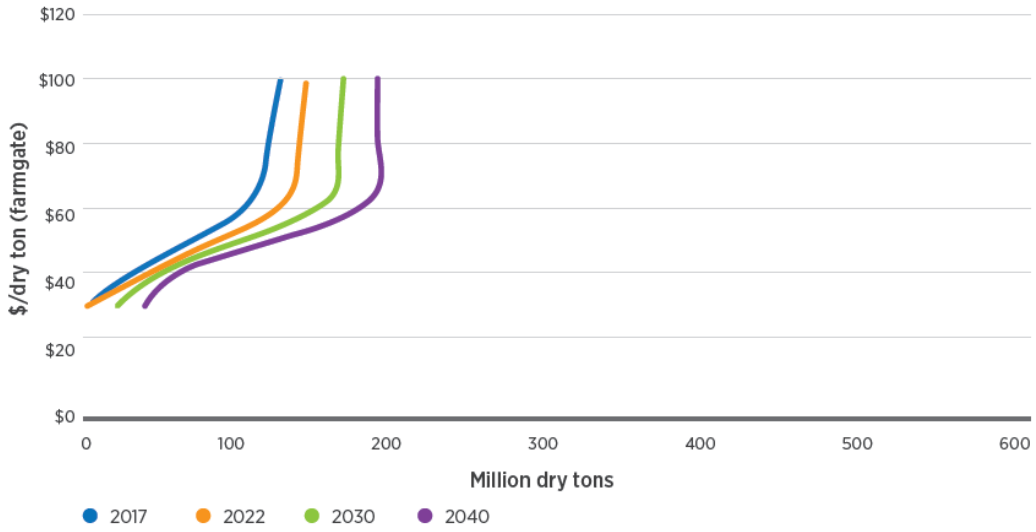
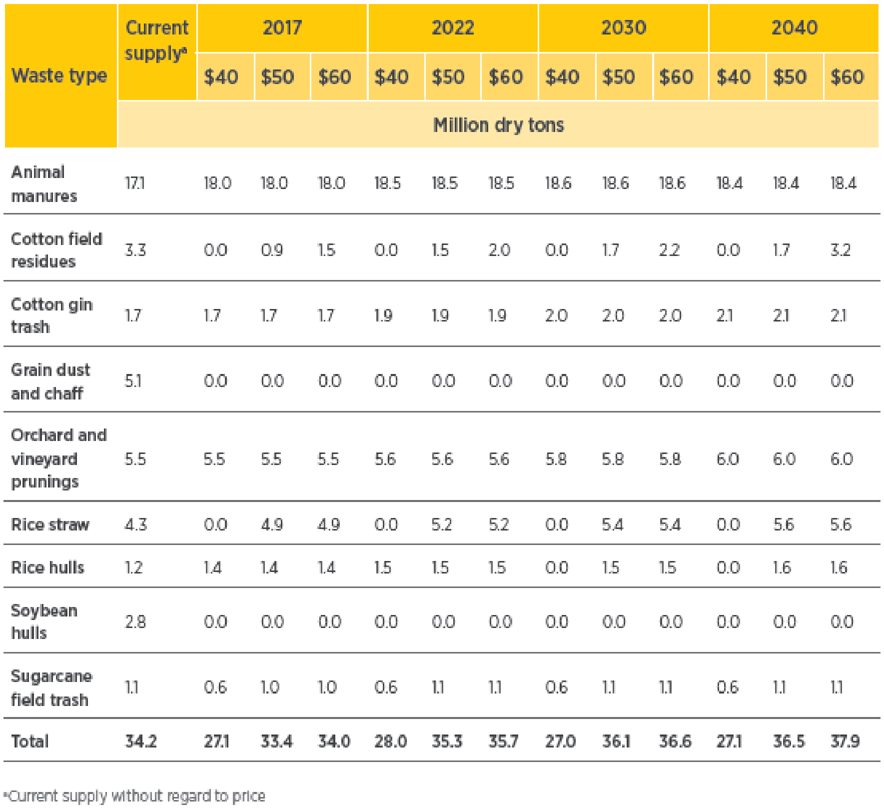


Figure 4-1 Supply curves of potential production from primary crop residues for select years under *2016 Billion-ton* study base-case assumptions[10] (Source: DOE [2])



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**

^aCurrent 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 [2])

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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 [8], 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 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.

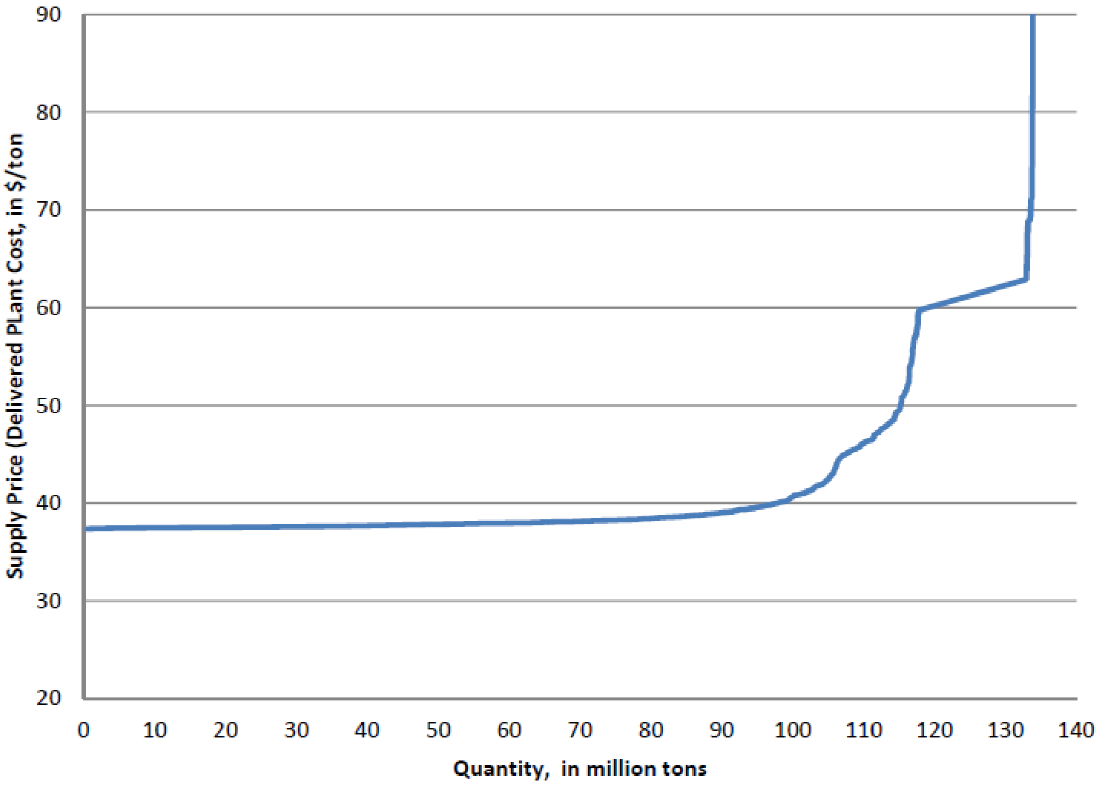


Figure 4-2: U.S. corn stover supply curve (Source: USDA [8])

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. 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 [9].

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. Recently wood was relegated to fourth place as the source of renewable energy consumed in the U.S. Wood contributed 19 percent of the renewable energy consumed in 2017, behind hydro’s 25 percent, biofuel’s and wind energy’s 21 percent each.

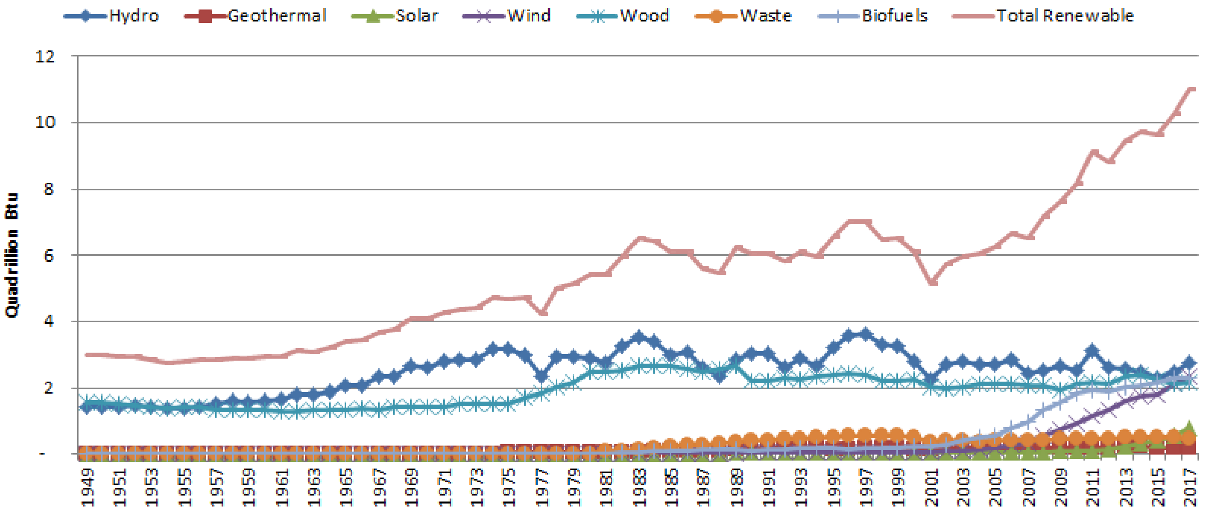


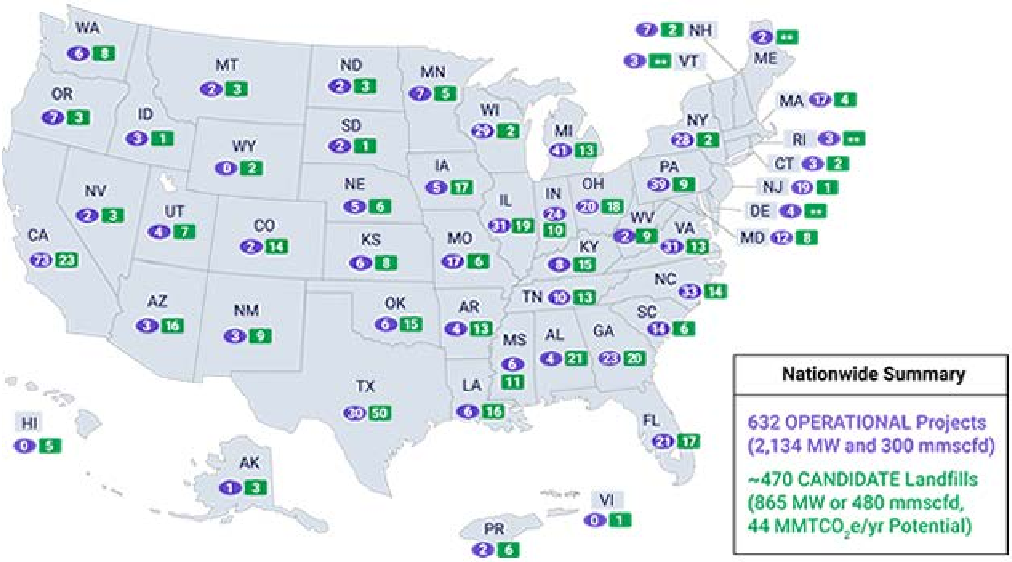
Figure 4-3: U.S. renewable energy consumption 1949-2017 (Source: EIA [10])

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 [11])

Another organic waste stream in use as a source of energy is landfill gas. According to the EPA there were 632 landfills with operational energy conversion projects with a combined capacity of 2,134 MW electricity generation and 300 million standard cubic feet per day (mmscfd) of gas for thermal energy production. In addition, there were 470 'candidate' landfills that have the size and capacity necessary to support energy projects. These candidate landfills have the potential for 865 MW of electricity generation or 480 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 [12].



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 [12])

Livestock manure is in use currently as an energy source with 253 anaerobic digester biogas recovery systems in operation on livestock farms in the U.S. as of May 2018. The majority of these digesters (199) were on dairy farms, but there were also 36 on swine farms, 7 on mixed cattle/swine farms, 6 on poultry farms, 4 on beef farms and one on a mixed cattle/swine/poultry farm [13]. 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 [14]. 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 [14])

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 [15].   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 [15])

Although crop residues are not in use today as a source of energy, they are the most readily available biomass feedstock. 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 tons of other types of grain crop residues [16].

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 from 1960 to 2015. 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. In 2015 waste biomass' contribution to Indiana's renewable energy mix (18 percent) fell to third place behind ethanol's 51 percent and wind's 25 percent.

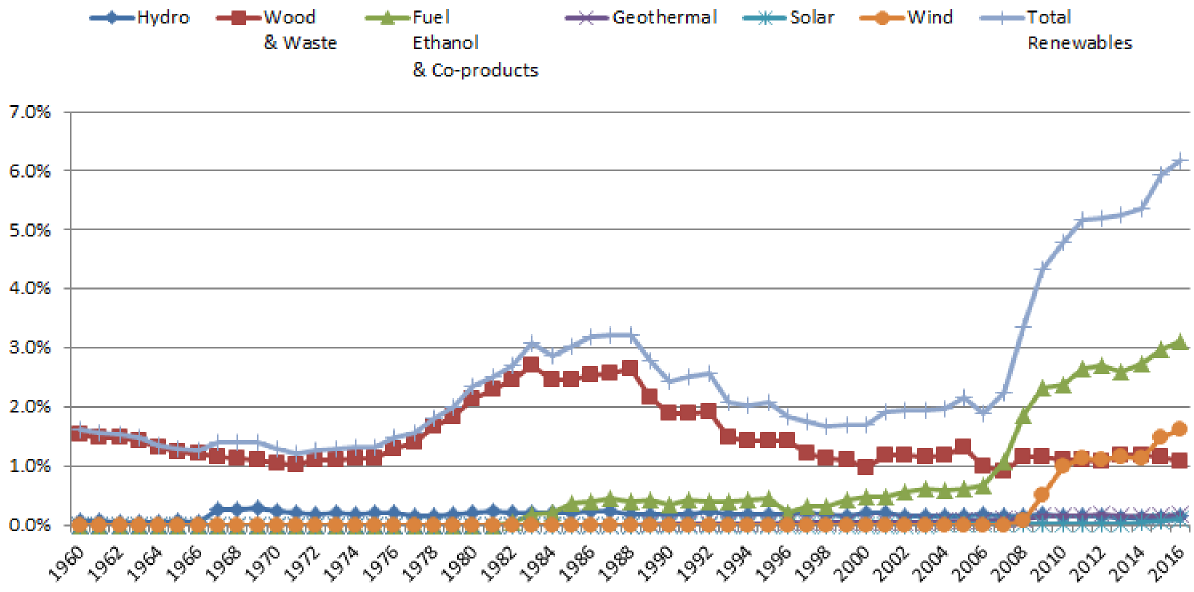


Figure 4-5: Renewables share of Indiana total energy consumption (1960-2016) (Source EIA [17])

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 day [18].

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 operational landfill gas electricity generating projects in Indiana with a combined 71.4 MW installed generating capacity. Table 4-5 provides a list of operational landfill gas electricity generating plants in Indiana in the

EPA database. WVPA, with 47.2 MW listed in the EPA database, is the most active user of landfill gas for electricity generation. According to the WVPA website WVPA has 16 landfill power plants with a combined capacity of 53 MW [19].

Project Developer	Landfill Name	County	Generating Capacity (MW)	End User
	National Serv-All LF	Allen	6.4	General Motors
Aria Energy; Republic Services	County Line LF	Fulton	6	NIPSCO; WVPA
Energy Systems Group	Blackfoot Landfill	Pike	3.2	Vectren
Energy Systems Group	Munster LF	Lake	1.1	NIPSCO
Granger Energy	South Side Landfill Inc.	Marion	4	Rolls-Royce
Hoosier	Clark-Floyd LF	Clark	2.14	Hoosier
Hoosier	Clark-Floyd LF	Clark	1.4	Hoosier
WVPA	Deercroft RDF	LaPorte	4	WVPA
WVPA	Earthmovers LF	Elkhart	4.8	WVPA
WVPA	Jay County LF	Jay	2.4	WVPA
WVPA	Liberty Landfill	White	6.4	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

Table 4-5: Electricity generating plants in Indiana landfills (Data source: EPA [20])

Giraldo in his 2013 Master's thesis [21] 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 [21])

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 20.4 MW. In addition, the Fair Oaks Dairy Farm has installed purification and compression equipment to produce biogas to run milk delivery trucks [22]. 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 [14].

Project Name	County	Year Operational	Animal Type	Population Feeding Digester	Installed Generating Capacity (kW)*	Electricity Generated (MWh/yr)
Bio Town Ag, Inc. Digester	White	2011	Cattle; Swine	4,500 cattle 1,600 swine other feedstock	9,450	70,365
Waste No Energy Digester	White	2013	Cattle; Swine	300 cattle 8,000 swine	1,059	7,885
Bos Dairy Digester	Jasper	2005	Dairy	3,600	1,050	7,818
Fair Oaks Dairy - Digester 2	Jasper	2008	Dairy	9,000	1,050	7,818
Homestead Dairy Digester	Marshall	2013	Dairy	2,100 Fats, oils, greases	1,000	7,446
Hidden View Digester	Jasper	2007	Dairy	3,500	950	7,074
Herrema Dairy Digester	Jasper	2002	Dairy	3,750	800	5,957
Fair Oaks Dairy - Digester 1	Jasper	2004	Dairy	3,000	700	5,212
Green Cow Power LLC Digester	Elkhart	2015	Dairy	1,500 Food processing wastes	3,150[#]	0
Windy Ridge Dairy Digester	Jasper	2006	Dairy	7,000	0	Flared Full-time
Culver Duck Farm (processing plant) [@]	Elkhart	2013	Ducks	105,000 gallons processing byproducts per week	1,200	

*Data from June 2017 AgStar digester database [23]

[#]Data from Waste Today magazine website [24];

[@]Data from 2G Energy Corporation [25]

Table 4-7: Operational Anaerobic Digesters in Indiana (Data source EPA [13])

It is estimated that 144 concentrated animal feeding operations (CAFOs) 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 [21])

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 [26]. 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 [21])

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-Ton* 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.

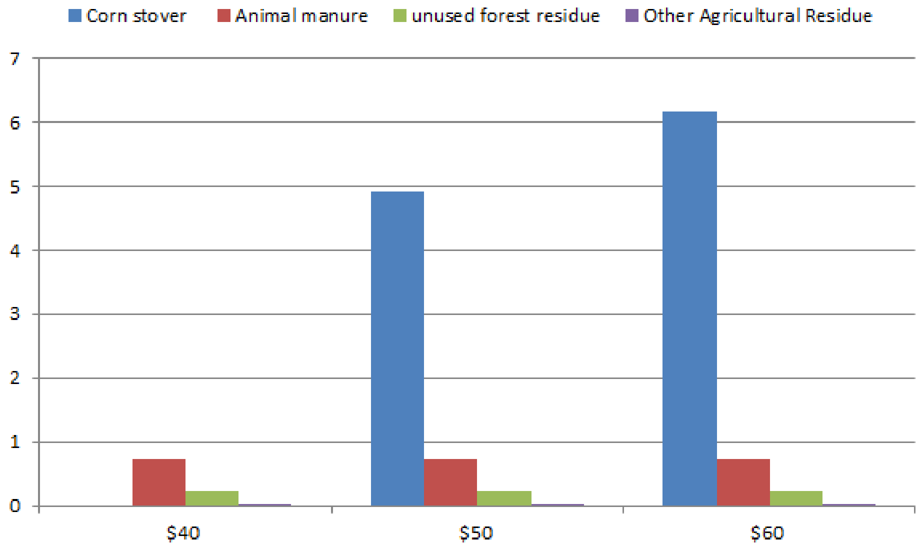


Figure 4-6: Estimated biomass production potential in Indiana (Data source: DOE [16])

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 convert 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 [27]. Stellarwind, on the other hand, is focused on producing oil from algae that has the potential for use in producing transportation fuels [28].

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 expired on January 1, 2018 but is still available for projects whose construction was started before the end of 2017 [29].
- 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 [29].
- 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 [29].
- 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 [29].
- 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 [29].
- USDA Biorefinery Assistance Program offers loan guarantees for the 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 [29].
- 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) [29].
- 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 [29].

- 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 [29].
- Green Power Purchasing Goal requires that 30 percent of energy used by federal agencies must be obtained from renewable resources by 2025 [29].

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. Indiana Senate Bill 309 signed into law in May 2017 made changes to the net metering rule to modify the compensation after June 30, 2022 to 1.25 times the utility's average wholesale cost for the most recent year. Generators installed before the end of 2017 shall continue to receive full retail credit until July 1, 2047 and those installed in the years 2018 to 2022 shall receive full retail credit for their generation until July 1, 2032 [29, 30].
- Community Conservation Challenge Grant provides $20,000-$80,000 in grants for community energy conservation projects that reduce energy consumption or displace the use of traditional energy sources [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 [29].
- 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 [29].
- 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 [29, 32, 33].

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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.

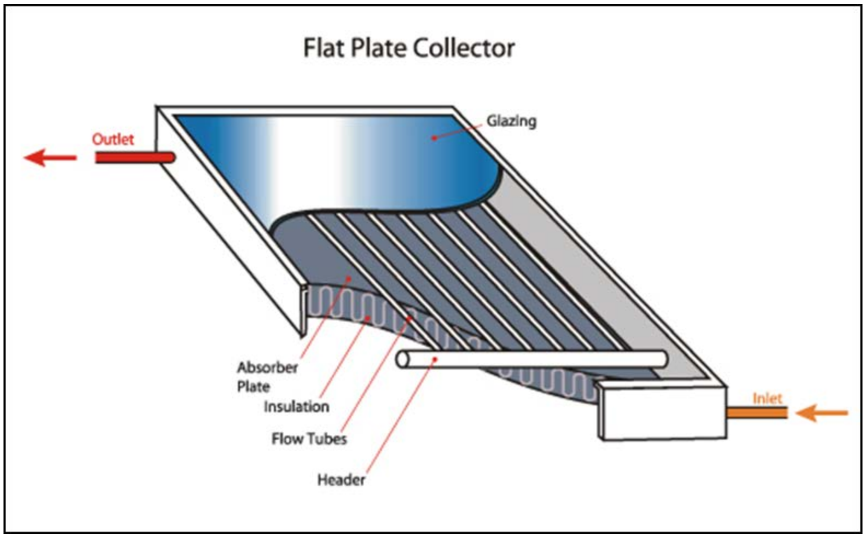

Figure 5-1: The layout of a flat-plate collector (Source: GoGreen heat solutions [1])

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.

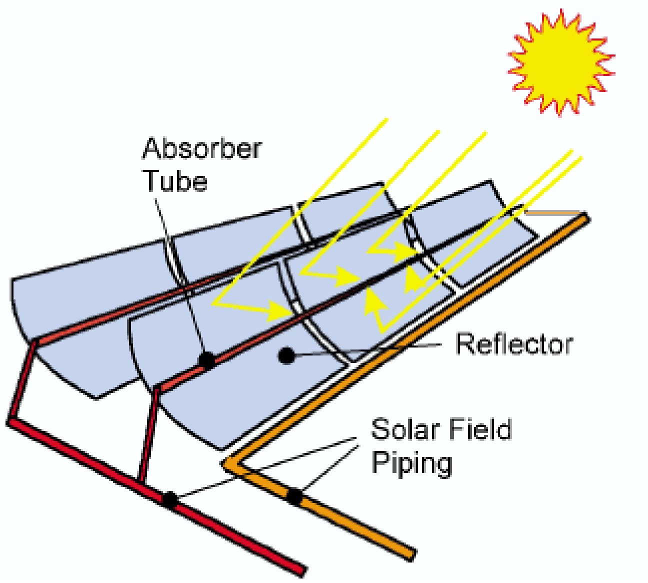

Figure 5-2: A parabolic trough CSP system (Source: NREL [2, 3])

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].

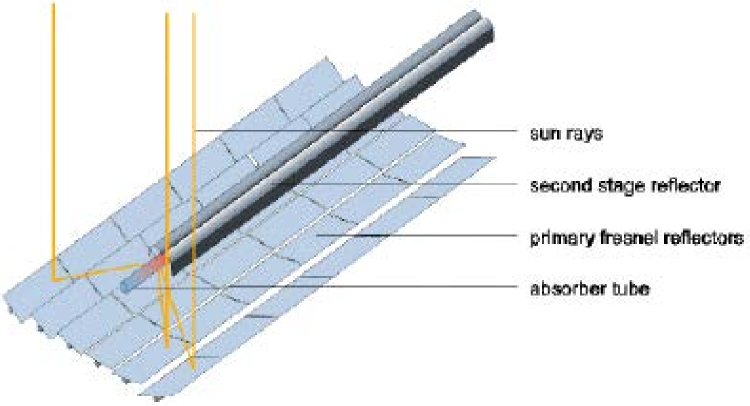

Figure 5-3: A linear Fresnel CSP system (Source: IEA [2, 3])

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 two operational power tower projects in the U.S.: the 377 MW Ivanpah project in the Mojave Desert in California and the 110 MW Crescent Dunes project in Tonopah, Nevada [6].

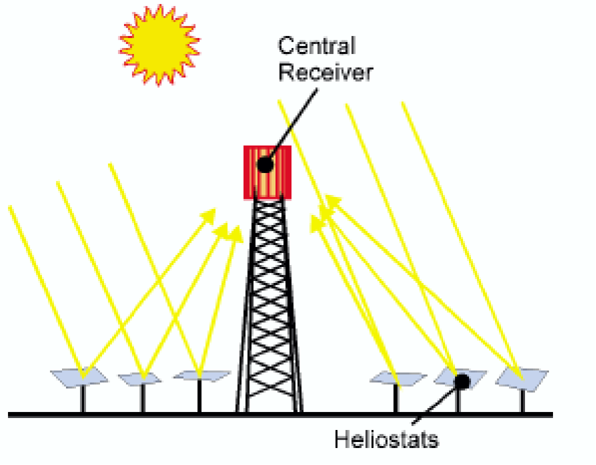

Figure 5-4: A power tower CSP system (Source: NREL [2, 3])

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 two dish/engine CSP plants in the U.S. are no longer operational. They are the 1.5MW Maricopa project in Arizona and the 1.5 MW project at the Tooele Army Depot in Utah [6].

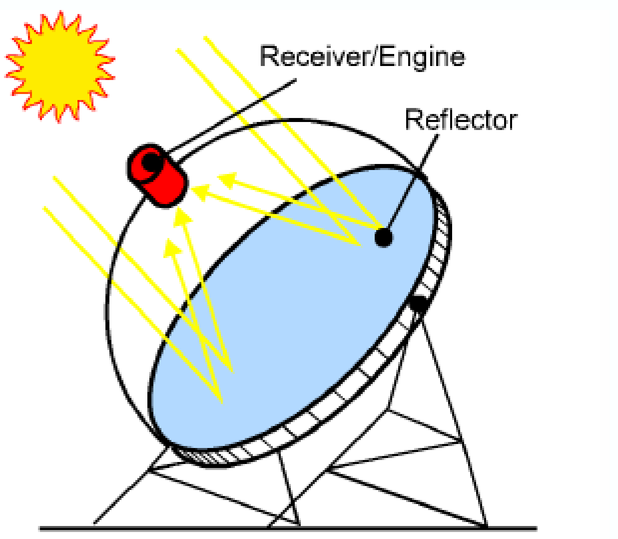

Figure 5-5: A dish/engine CSP system (Source: NREL [2, 3])

5.2 Economics of solar technologies

Table 5-1 shows the overnight capital cost[11] estimates from the National Renewable Energy Laboratory (NREL) for CSP power plants currently in operation in the U.S. 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
Mojave Solar Project	Abengoa	Harper Dry Lake, California	250	Parabolic Trough	2014	6,400	None
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
Saguaro Power Plant	Arizona Public Service	Red Rock, AZ	1.16	Parabolic Trough	2006	5,172	None
Nevada Solar One	Acciona	Boulder City, Nevada	72	Parabolic Trough	2007	3,694	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 February 2016 EIA update of generating plant costs sorted in order of increasing capital cost. The solar thermal technology's capital cost of approximately $4,228 /kW is in the mid-range among the renewable technologies between the low end of wind generation at $1,657/kW and the high end $8,742 /kW for municipal solid waste based generation technology.

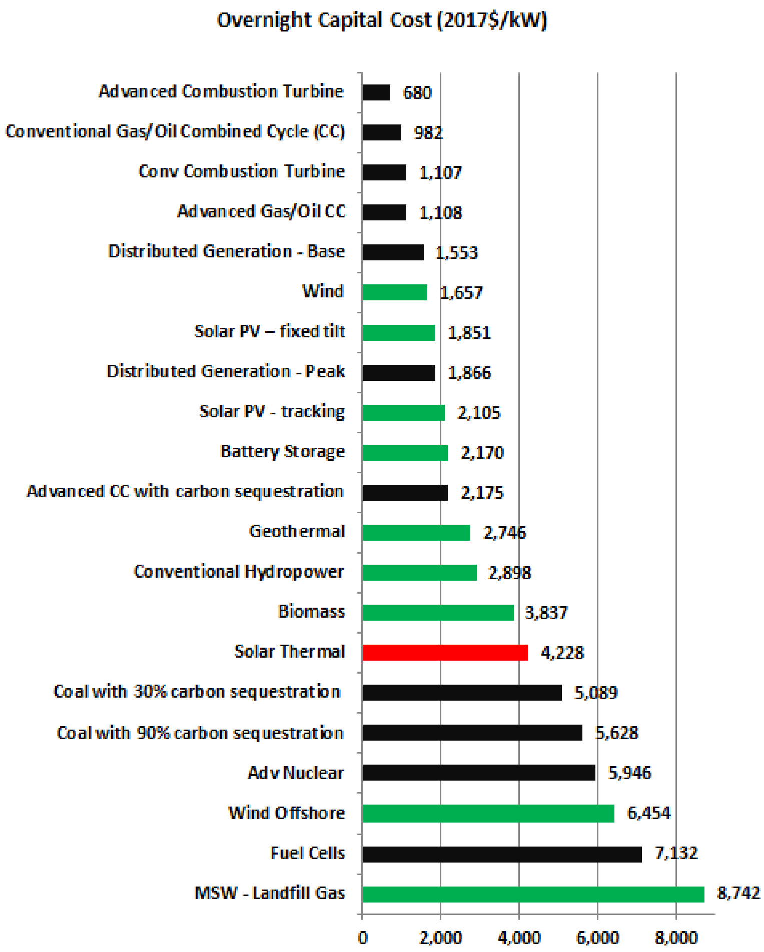


Figure 5-6: Estimated capital cost of generating technologies (Data source: EIA [7])

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 $71/kW. The fixed O&M cost is higher than that of PV ($22/kW) and land-based wind ($47/kW) but lower than offshore wind, biomass, geothermal and landfill gas based generators.

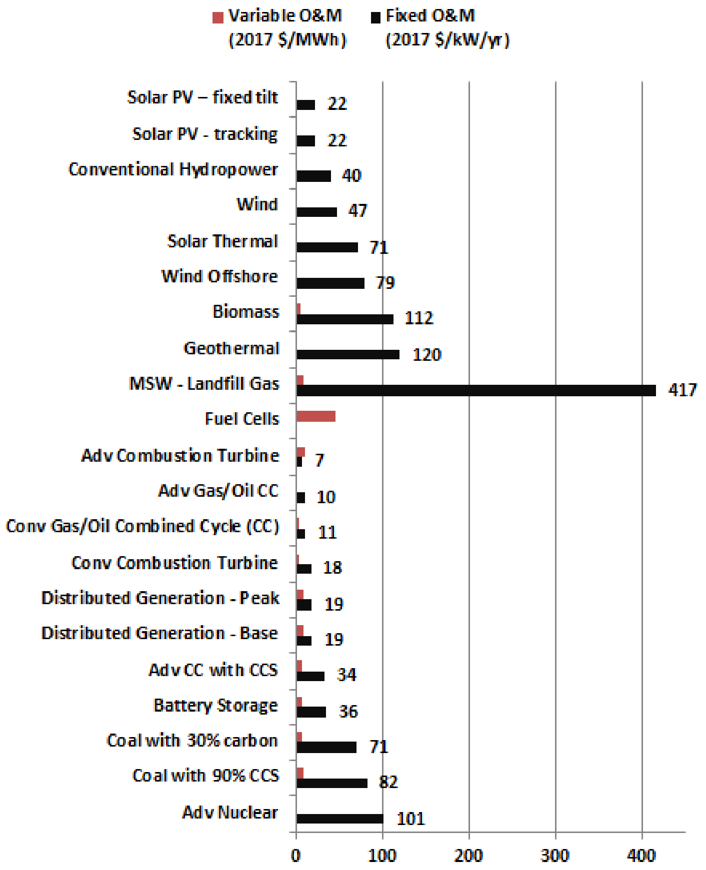


Figure 5-7: Operating and maintenance cost of generating technologies (Data source: EIA [7])

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.

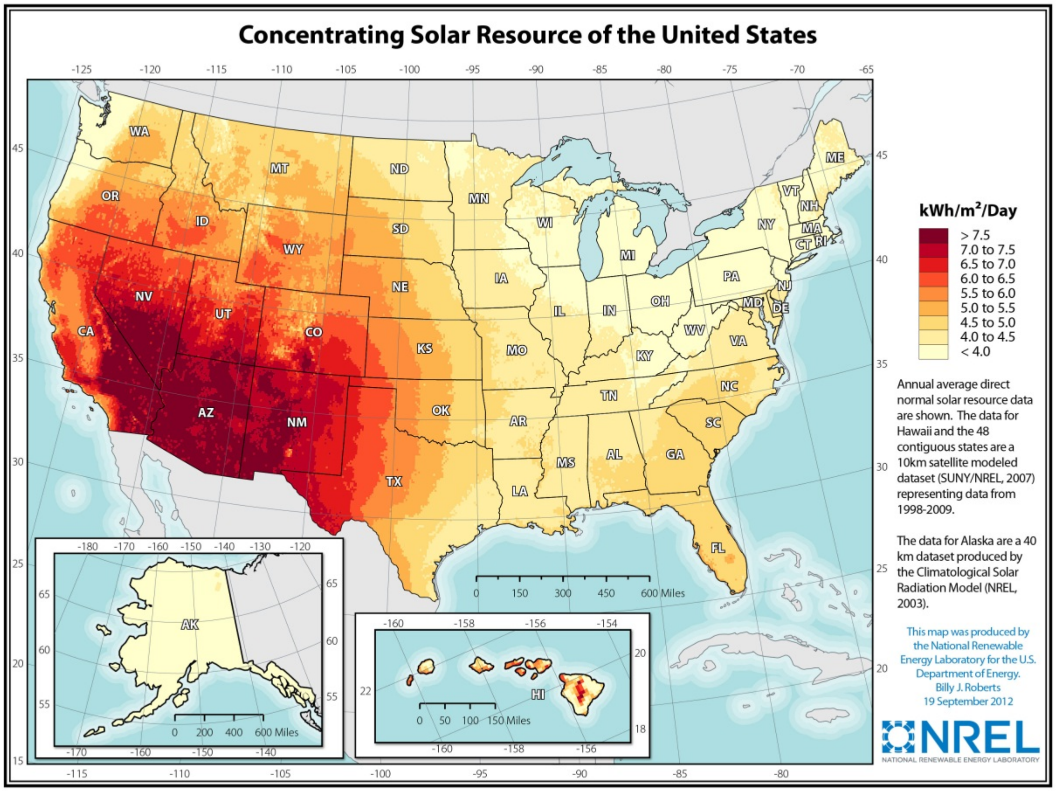


Figure 5-8: Concentrating solar power resource in the U.S. (Source: NREL [8])

Like the PV systems presented in Section 6, there has been a surge in the installation of CSP capacity in the U.S. in since 2007. 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.

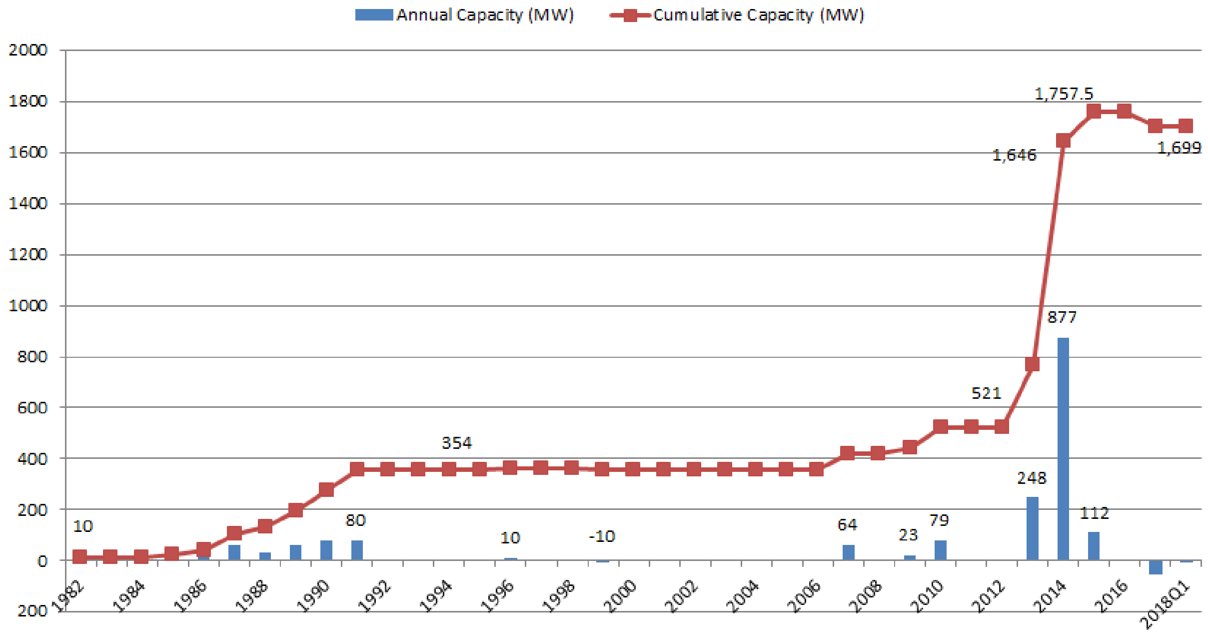


Figure 5-9: Solar thermal power capacity installed in the U.S. (Data sources: NREL [6], SEIA [9], IREC [10], Go Solar [11])

Since 2005 a total of thirteen CSP projects with a combined installed capacity of 1,407 MW have been added, bringing the total CSP installed capacity in the U.S. to 1,699 MW. The high total operating capacity of 1,757.5 MW in 2016 has been reduced by the capacity of 7 plants with a combined capacity of 58.3 MW which are no longer operational. Five of the largest operating projects, with a combined capacity of 1,282 MW, were completed in 2013 - 2015. The largest of these is the 377 MW Ivanpah power tower in the Mojave Desert in California. The other four are the 250 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 while Table 5-3 is a list of installed CSP projects that are no longer operational.

Project Name	**State**	**Generating Capacity (MW)**	**Technology**	**Production Start Year**
Solar Electric Generating Station (SEGS) III	CA	30	Parabolic trough	1985
SEGS IV	CA	30	Parabolic trough	1989
SEGS V	CA	30	Parabolic trough	1989
SEGS VI	CA	30	Parabolic trough	1989
SEGS VII	CA	30	Parabolic trough	1989
SEGS VIII	CA	80	Parabolic trough	1989
SEGS IX	CA	80	Parabolic trough	1990
Nevada Solar One	NV	72	Parabolic trough	2007
Martin Next Generation Solar	FL	75	Parabolic trough	2010
Solana Generating Station	AZ	250	Parabolic trough	2013
Genesis Solar Energy Project	CA	250	Parabolic trough	2014
Mojave Solar Project	CA	250	Parabolic trough	2014
Ivanpah Solar Electric Generating System	CA	377	Power tower	2014
Crescent Dunes Solar Energy Project	NV	110	Power tower	2015
Stillwater GeoSolar Hybrid Plant	NV	2	Parabolic trough	2015

Table 5-2: Operating concentrating solar power plants in the U.S. (Data source: NREL [6])

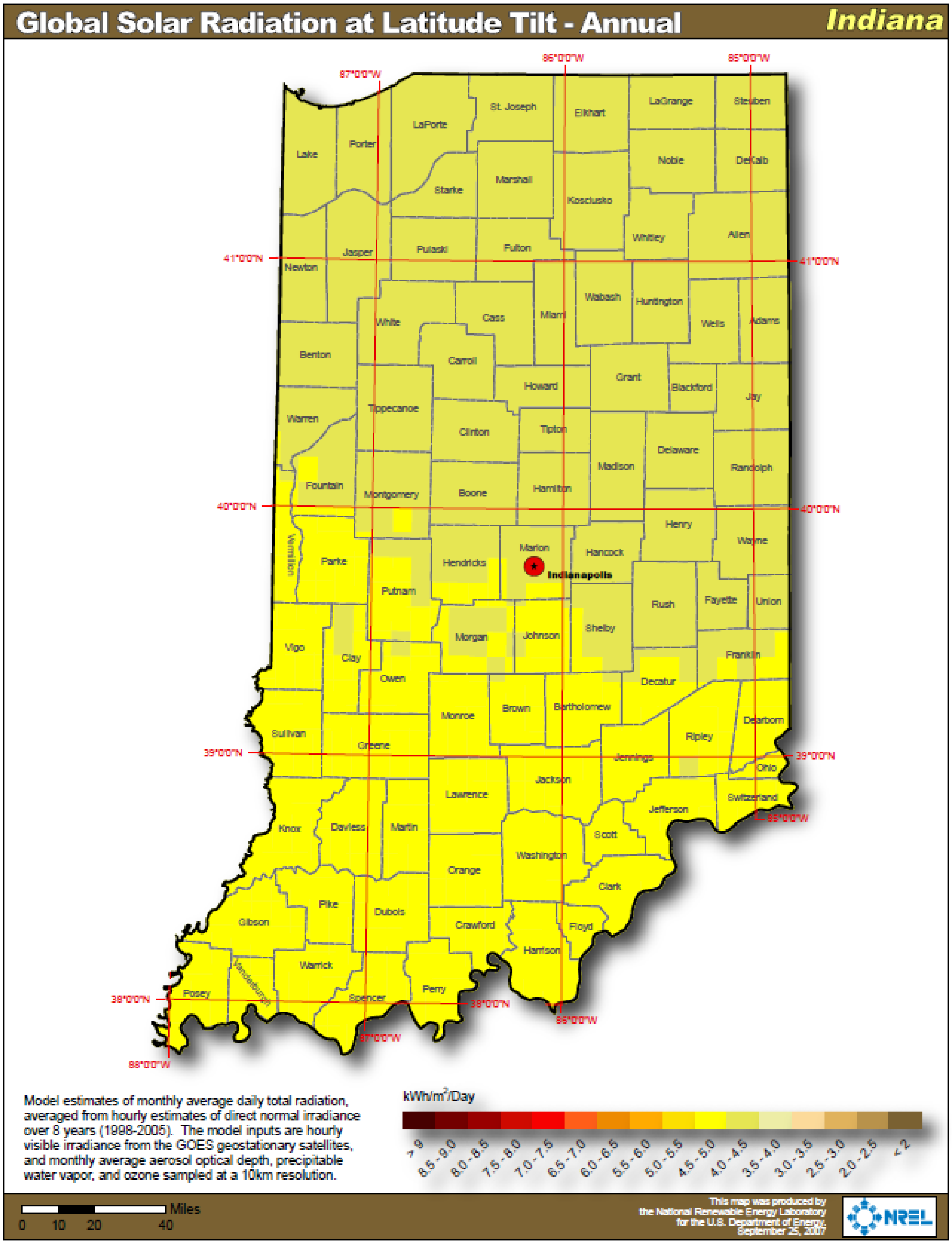
Project Name	**State**	**Generating Capacity (MW)**	**Technology**	**Production Start Year**
SEGS I	CA	13.8	Parabolic trough	1984
SEGS II	CA	30	Parabolic trough	1985
Saguaro Power Plant	AZ	1	Parabolic trough	2006
Kimberlina Solar Thermal	CA	5	Linear Fresnel reflector	2008
Sierra SunTower	CA	5	Power tower	2009
Holaniku at Keahole Point	HI	2	Parabolic trough	2009
Maricopa Solar Project	AZ	1.5	Dish/Engine	2010
Colorado Integrated Solar	CO	2	Parabolic trough	2010
Tooele Army Depot	UT	1.5	Dish/Engine	2013

Table 5-3: Concentrating solar power plants in the U.S. that are no longer operating (Data source: NREL [6])

5.4 Solar energy in Indiana

As can be seen in the U.S. solar radiation map (Figure 5-8), Indiana is in a region of the country that has comparatively 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 1,799 MW of solar thermal power plants in the U.S. are located in four states as follows: California – 1,256 MW, Arizona – 281 MW, Nevada – 187 and Florida – 75 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

Figure 5-10: Direct normal solar radiation (flat-plate collector) in Indiana (Source: NREL [12])

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 [13].
- 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 [13].
- 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 [13].
- 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 [13].
- 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) [13].
- 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 [13].
- 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 [13, 14].
- 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 [13].
- Green Power Purchasing Goal requires that 30 percent of energy used by federal agencies must be obtained from renewable resources by 2025 [13].

- 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 [13].

Indiana Incentives

- 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. Indiana Senate Bill 309 signed into law in May 2017 made changes to the net metering rule to modify the compensation after June 30, 2022 to 1.25 times the utility's average wholesale cost for the most recent year. Generators installed before the end of 2017 shall continue to receive full retail credit until July 1, 2047 and those installed in the years 2018 to 2022 shall receive full retail credit for their generation until July 1, 2032 [13, 15].
- 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 [13].
- Renewable Energy Property Tax Exemption provides property tax exemptions for solar thermal, PV, wind, hydroelectric and geothermal systems [13].
- Community Conservation Challenge Grant provides $20,000-$80,000 in grants for community energy conservation projects that reduce energy consumption or displace the use of traditional energy sources [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 [13].
- 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*. [13, 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].

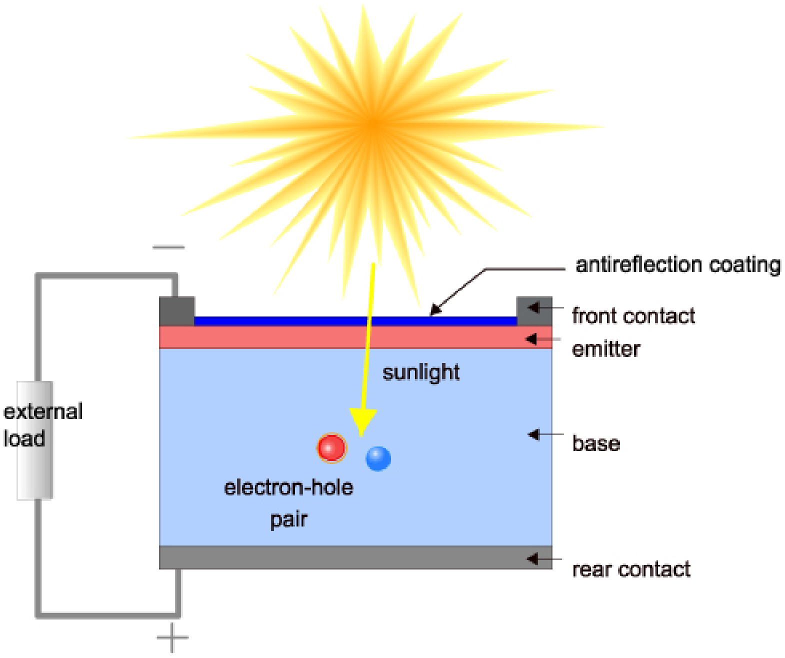

Figure 6-1: Photovoltaic cell operation (Source: EIA [2])

The photovoltaic cell is the basic building block of a PV system. Individual cells range in surface area from 0.25 to 16 square 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].

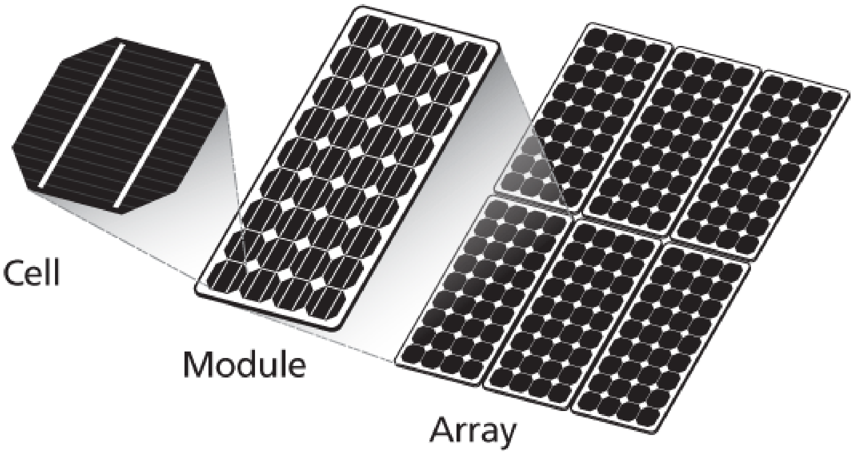

Figure 6-2: Illustration of a cell, module and array of a PV system (Source: SamLexSolar [3])

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 54 gigawatts (GW) of grid-connected PV systems installed in the U.S. since 2000 [4].

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

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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.

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 44 MW [5]. The largest of these is the 35 MW Alamosa Solar Generating Station installed in Alamosa, Colorado in 2012. Figure 6-3 shows the layout of a CPV cell.

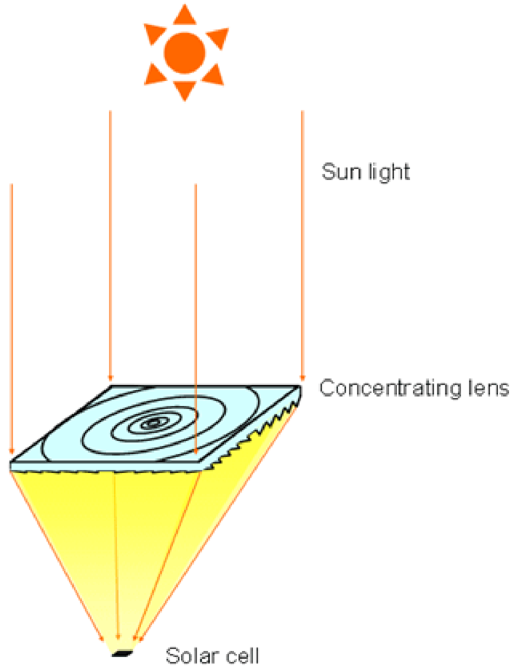

Figure 6-3: Illustration of concentrating photovoltaic cell (Source: Kuraray [6])

According to the International Energy Agency (IEA) 2014 Technology Road Map Crystalline Silicon modules constituted approximately ninety percent of the global installed PV capacity, thin-film modules approximately 10 percent and concentrated photovoltaics less than one percent. The DOE Solar Technology Office is investing in the development of organic photovoltaic cells. Their attractive characteristics include low manufacturing cost, the abundance of organic materials, and the flexibility of the material that make them ideal for building-integrated PV applications. According to DOE limitations in their efficiency and long-term reliability remain significant barriers to their commercial deployment [7, 8].

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 report dedicated to utility-scale systems (ground-mounted with capacity greater than 5 MW) and the other focused on distributed PV systems, which includes all roof-mounted systems and all ground mounted systems with an installed capacity up to 5 MW.

Figure 6-4 shows the trends in median installed prices for distributed PV systems in the Berkeley lab database divided into three sub-categories; all residential PV systems, small non-residential systems (up to 500kW) and large non-residential systems (between 0.5 MW and 5 MW). The shaded areas around the solid median price line are the 20th and 80th percentile ranges. As can be seen in Figure 6-4 the installed prices for all three groups of distributed PV systems have fallen rapidly since 2000 with an interruption between 2005 and 2009 and a slowing down of the rate of decline starting in 2014. The median prices for residential systems have fallen from nearly $12/W in 2002 to $3.7/W in 2017, from over $10/W to $3.1/W for small non-residential systems and from approximately $8/W to $2.2/W for larger non-residential systems (0.5 MW to 5 MW). The installed prices in Figure 6-4 is the upfront cost and does not include any financial incentives.

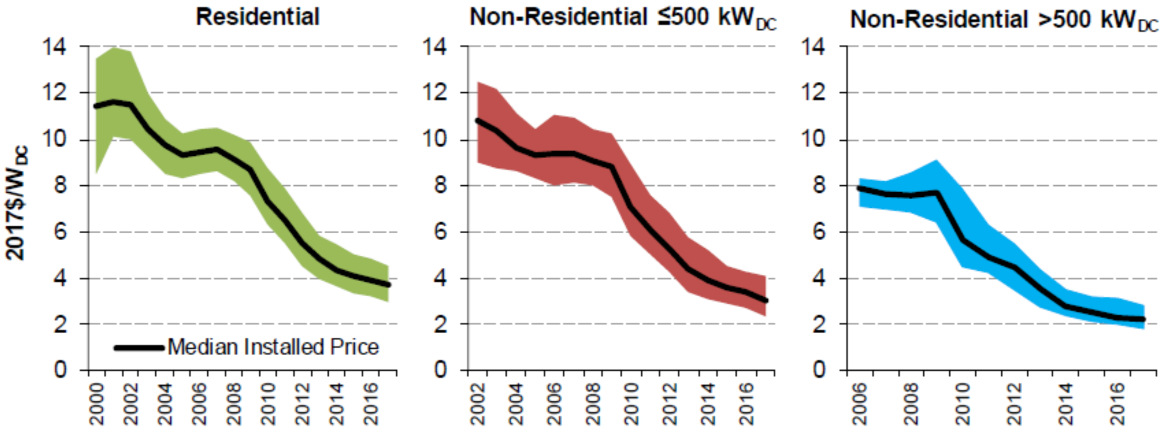

Figure 6-4: Installed price trends ($/W$_{DC}$) for residential and commercial PV systems (Source: LBNL [9])

Figure 6-5 shows the installed price in $/W for the utility-scale PV projects in the Berkeley Labs database based on the year of the projects' commissioning. Utility-scale in the Berkeley Labs report includes ground-mounted PV projects larger than 5 MW in capacity.

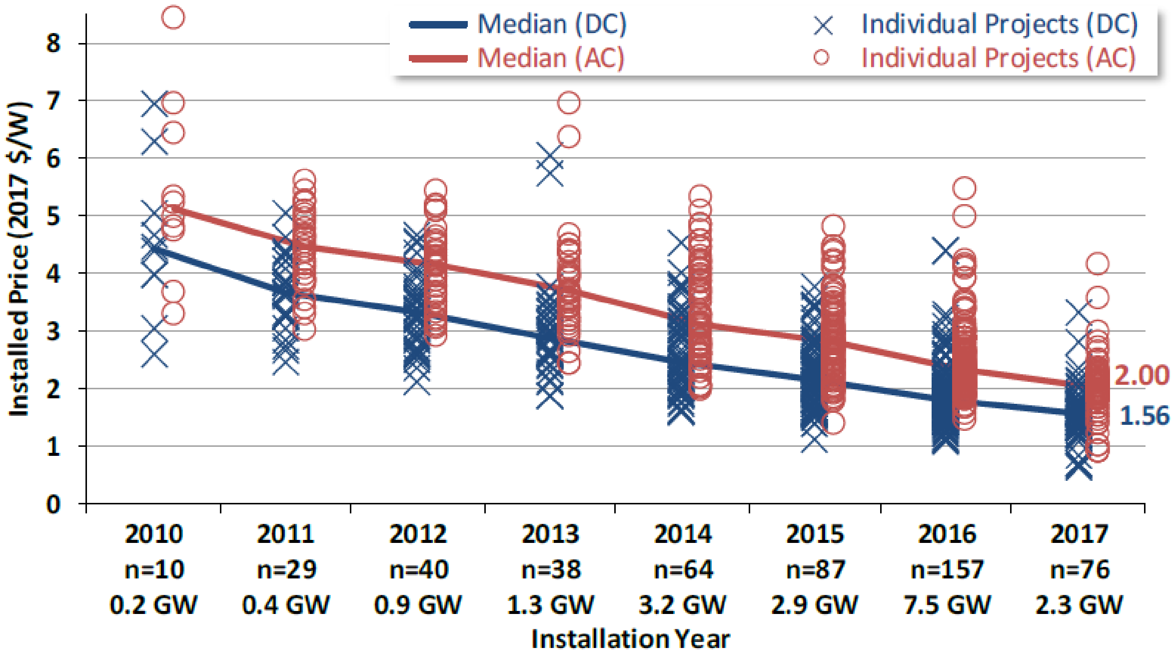

Figure 6-5: Installed price of utility-scale PV systems over time (Source: LBNL [10])

As can be seen in Figure 6-5 the median price for utility-scale PV projects in the Berkeley Lab database has dropped from $5.1/W for the projects commissioned in 2010 to $2/W for the projects commissioned in 2017. Although there was an overall decline in installed prices, there is a wide spread in prices between individual projects, ranging from less than $1/W to over $4/W for projects commissioned in 2017.

Figure 6-6 shows the construction cost in $/kW for PV systems installed in the U.S. in 2016 according to a report released by EIA in August 2018 [11]. The data included in the EIA report is for PV systems 1 MW or more installed on the utility side of the meter. The capacity-weighted average cost for the projects installed in 2016 included in the EIA report is $2,434/kW. This is 1 percent higher than the $2.416/W capacity-weighted average cost of the projects installed in 2016 included in the Berkeley Labs report shown in Figure 6-5.

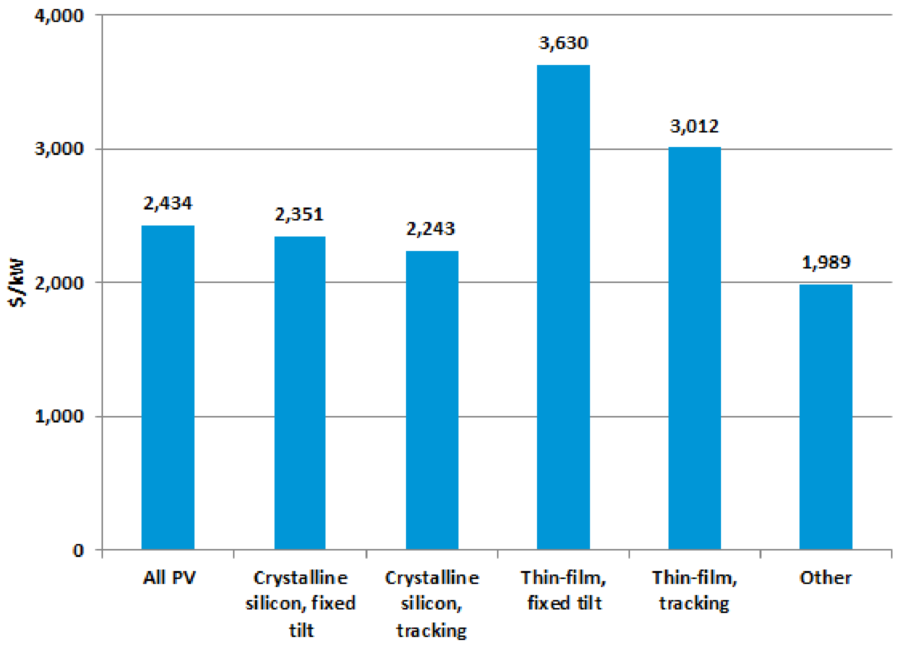

Figure 6-6: Average cost of PV systems of at least 1 MW installed in the U.S. in 2016 (Data Source: EIA [11])

Figure 6-7 shows EIA's estimates of the capital cost of utility scale photovoltaic electricity generating plants alongside other utility scale electricity generating technologies. The capital costs for utility-scale photovoltaic power plants, $1,851/kW for fixed tilt and $2,105/kW for sun-tracking ones, are the second lowest among the renewable resources after land-based wind power plants.

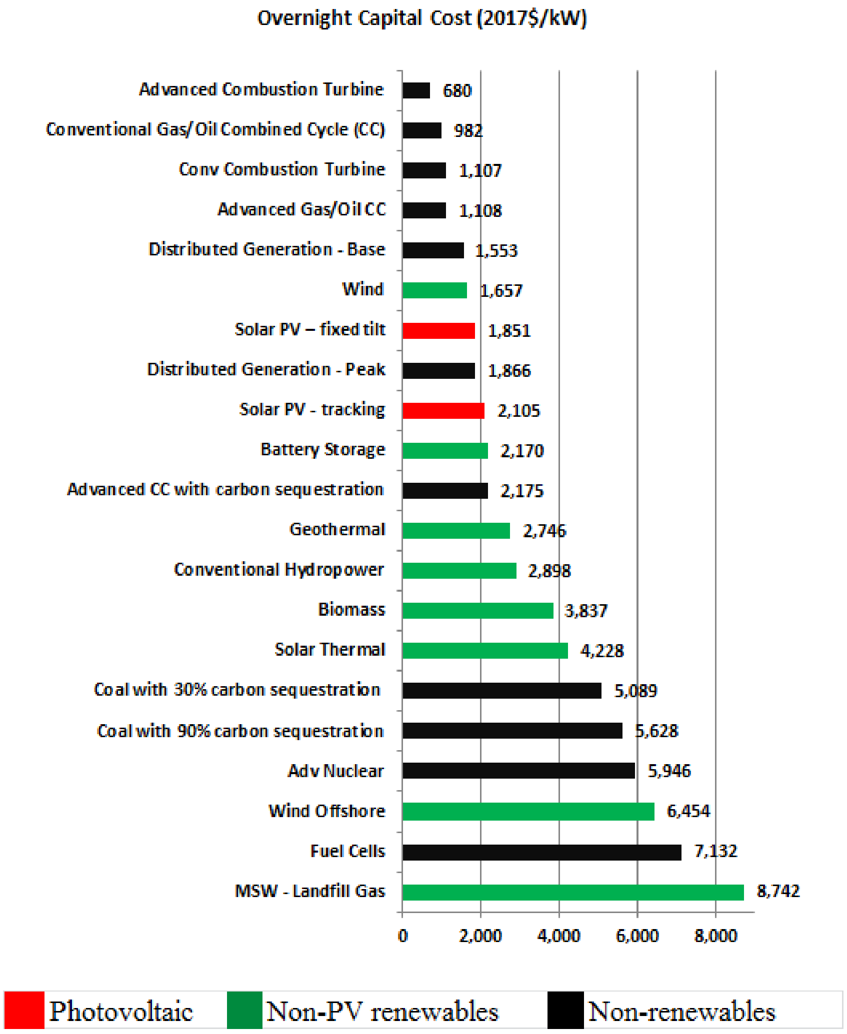

Figure 6-7: Estimated capital cost of generating technologies (Data source: EIA [12])

Figure 6-8 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 fixed O&M costs of photovoltaics are among the lowest of the renewable energy technologies at $22/kW/yr and there is virtually no variable O&M cost.

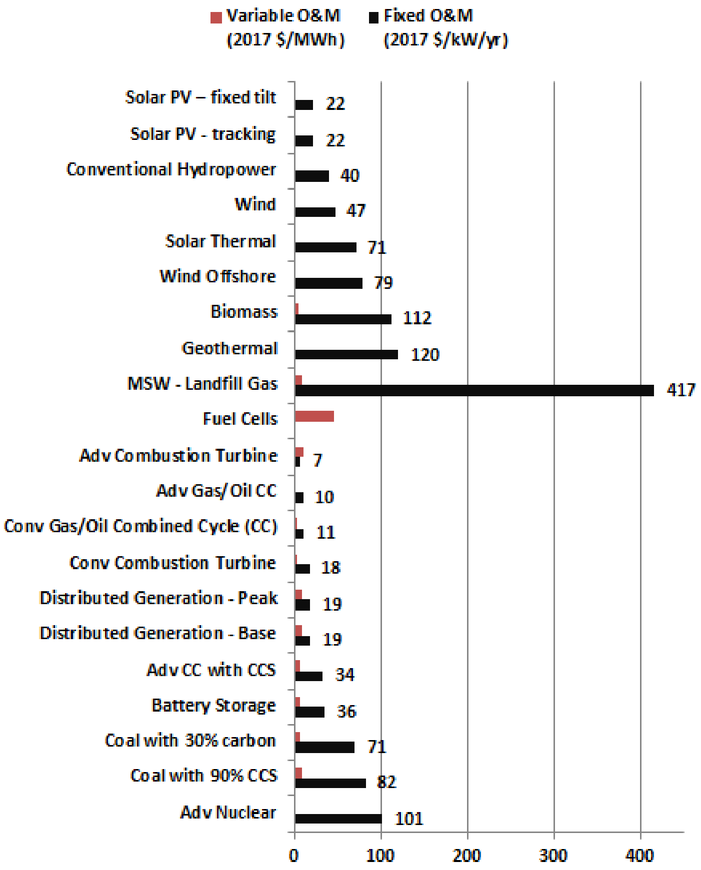

Figure 6-8: Estimated fixed and variable O&M cost of generating technologies (Data source: EIA [12])

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 54,064 MW at the end March 2018. Figure 6-9 shows the annual and the cumulative installed capacity of grid-connected PV systems in the U.S.

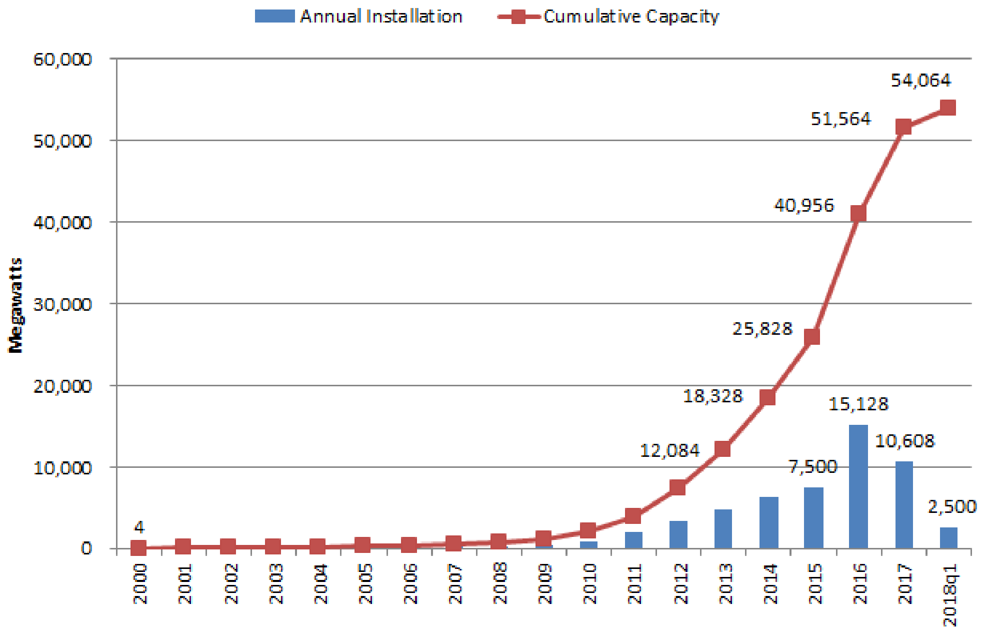

Figure 6-9: Grid-connected U.S. PV installed 2000 to 2017 (Data source: SEIA [4, 13, 14])

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. The thirty percent federal investment tax credit (ITC) is generally recognized as one the most important drivers of the rapid expansion in installed PV capacity in the U.S. The ITC was first enacted into law in the 2005 Energy Policy Act. In 2008 the federal government eliminated the $2,000 cap on residential installations and permitted utilities and companies the alternative minimum tax to access the credit. As currently authorized the credit for solar systems scales down to 26 percent in 2020, 22 percent in 2021 and 10 percent in subsequent years.

At the state level, 22 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 6-10 shows the various forms of solar provisions in state RPS.

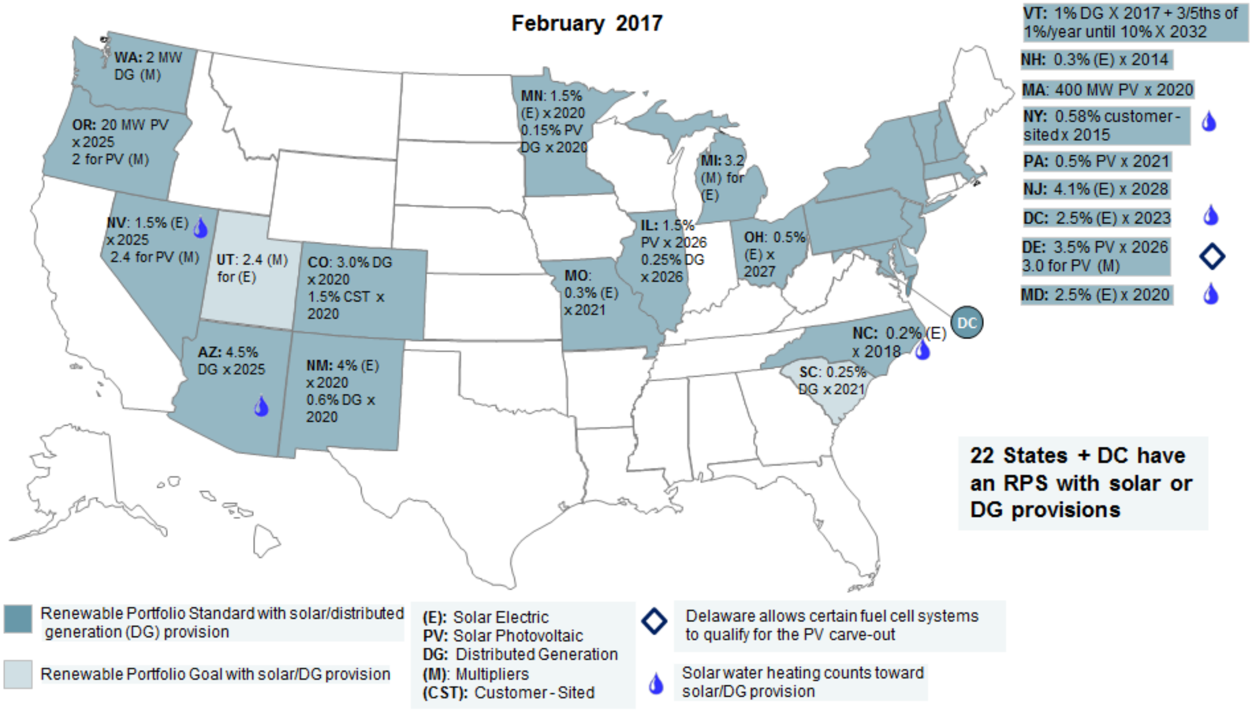

Figure 6-10: Renewable portfolio standards with solar carve-outs (Source: DSIRE [15])

A significant development that has the potential to dampen the rapid growth in the PV industry is the tariffs on imported PV cells and modules announced on January 22, 2018. The tariffs, taking effect immediately last for four years starting at 30 percent and reducing annually by 5 percent until they expire in 2021. Estimates of the impact on costs of new installation vary. According to the Solar Energy Industry Association the estimated effect of the tariffs is a $0.1/W increase in the price of solar modules [4] in year one (2018). Assuming a $4/W price for residential solar PV installations, this amounts to a 2.5% increase in project price, and assuming a $2/W price for utility scale solar installations this amounts to a 5% impact on project price. According to the EIA the tariffs are expected to increase the cost of utility-scale PV plants by approximately 10 percent. EIA estimates that the impact on residential PV systems will be approximately 4 percent and approximately 6 percent for customer-side non-residential installations [16].

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	CA
Solar Star	SunPower	575	2015	Rosamond	CA
Desert Sunlight	First Solar /Nextra	550	2015	Riverside	CA
Topaz Solar Farm	First Solar	550	2014	Santa Mar	CA
Copper Mountain Solar	Sempra	458	2010 - 2015	Boulder City	NV
Springbok 1&2	8minutenergy	328	2016	Kern	CA
Agua Caliente	First Solar	290	2013	Dateland	AZ
Garland Solar	Recurrent Energy	272	2016	Kern	CA
Tranquility Solar	Recurrent Energy	258	2016	Fresno	CA
Moapa Southern Paiute	First Solar	250		Moapa River	NV
Silver State South Solar	First Solar	250	2016	Primm	NV
California Valley Solar Ranch	SunEdison	250	2013	San Luis Obispo	CA
Antelope Valley Solar Ranch One	First Solar	242	2013	Lancaster	CA
Astoria I, II	Recurrent Energy	231	2016	Kern	CA
Mount Signal Solar Farm	8minutenergy	206	2014	Imperial	CA
Imperial Valley Solar	AES Solar	200	2013	Imperial	CA
Centinela Solar Energy	LS Power	175	2014	Calexico	CA
Mesquite Solar	Sempra	170	2012	Tonopah	AZ
Comanche Solar	Community Energy	156	2017	Pueblo	CO
Solar Gen 2	First Solar	150	2014	Brawley	CA
Catalina Solar	EDF Renewables	143	2013	Kern	CA
Campo Verde	First Solar	139	2013	Imperial	CA
Mustang LLC	Recurrent Energy	134	2016	Imperial	CA
Imperial Solar Energy South	First Solar	130	2013	Calexico	CA
Arlington Valley Solar Project II	LS Power	125	2013	Arlington	AZ
Blythe Solar Energy	NextEra	115	2016	Blythe	CA
Quinto Solar PV Project	SunPower	110	2016	Los Banos	CA
Solverde 1	Solverde LLC	107	2016	Lancaster	CA
Utah Redhills Renewable Energy	Scatec Solar	104	2015	Iron Count	UT
White Pine Solar	Geronimo Energy	101	2016	Taylor	CA

Table 6-1: PV systems with capacity above 100 MW installed in the U.S. (Data source: PVresources [17], SEIA [18], CEC [19], NextEra[20])

6.4 PV systems in Indiana

Similar to the rest of the U.S., Indiana has seen a rapid growth in the amount of PV capacity installed in the last five years. As of June 2018 Indiana's installed PV capacity was 253.8 MW. The capacity was distributed among Indiana utility service territories as shown in Table 6-2.

	Feed-in-Tariff (MW_{AC})	Net Metered (MW_{AC})	Utility Owned (MW_{AC})	Utility Purchase Agreement (MW_{AC})	Total (MW_{AC})	Percentage
IPL	94.4	-	2.3	-	97	38%
Duke	-	17.3	15.7	19.4	52	21%
IMPA	-	36.7	-	-	37	14%
NIPSCO	18.5	-	8.6	-	27	11%
I&M	-	12.7	9.9	-	23	9%
Hoosier	-	10.0	-	-	10	4%
Vectren	-	-	7.8	-	8	3%
WVPA	-	0.5	-	-	0.5	0.2%
Total kW	**113**	**77**	**44**	**19**	**254**	

Table 6-2: Total installed Indiana PV capacity (Data source: IURC [21]

The PV capacity is connected to the grid as follows: 44 percent (113 MW) through the feed-in-tariffs, 20 percent (77 MW) through net metering tariffs, 14 percent owned by utilities and 7 percent through power purchase agreements.

Table 6-3 lists the PV installations in Indiana with a capacity of 1.5 MW or more. Three of the largest projects account for almost 30 percent of the installed capacity in Indiana. They are the 20 MW Indy Solar I and II projects in Franklin Township in Marion County, the 19.8 MW project at the Indianapolis International Airport, and the newly installed 17.25 MW Duke Energy Solar project at the Crane Naval Support Activity (NSA) facility in Martin County.

Project	**Utility Interconnected**	**Location (County)**	**Capacity (MW_{AC})**
Indy Solar No. I&II (Franklin Township)	IPL	Marion	20
Indianapolis Airport (I, IIA, IIB)	IPL	Marion	19.8
Crane Solar	Duke	Martin	17.25
Indianapolis Motor Speedway	IPL	Marion	9
Indy Solar No. 3 (Decatur Township)	IPL	Marion	8.64
Anderson II Solar Park	IMPA	Madison	8
Vertellus	IPL	Marion	8
McDonald Solar	Duke	Vigo	5
Pastime Farm	Duke	Clay	5
Geres Energy	Duke	Howard	5
Sullivan Solar	Duke	Sullivan	5
Anderson I Solar Park	IMPA	Madison	5
Olive	I&M	St. Joseph	5
Lifeline Data Centers	IPL	Marion	4
Washington Solar Park	IMPA	Daviess	4
CWA Authority	IPL	Marion	3.83
Duke Realty #129	IPL	Marion	3.4
Crawfordsville Solar Park	IMPA	Montgomery	3
Peru Solar Park	IMPA	Miami	3
Greenfield Solar Park	IMPA	Hancock	2.84
Rexnord Industries	IPL	Marion	2.8
Equity Industrial	IPL	Marion	2.73
Duke Realty #98	IPL	Marion	2.72
Duke Realty #87	IPL	Marion	2.72
Twin Branch	I&M	St. Joseph	2.6
Deer Creek	I&M	St. Joseph	2.5
Lake County Solar, LLC - East Chicago	NIPSCO	Lake	2
Lake County Solar, LLC - Griffith	NIPSCO	Lake	2
Pendleton Solar Park	IMPA	Madison	2
GSA Bean Finance Center	IPL	Marion	1.8
Huntingburg Solar Park	IMPA	Dubois	1.8
Citizens Energy (LNG North)	IPL	Marion	1.5
Middlebury Solar, LLC	NIPSCO	Elkhart	1.5
Portage Solar, LLC	NIPSCO	Porter	1.5
Lincoln Solar, LLC	NIPSCO	Cass	1.5

Table 6-3: PV systems in Indiana with capacity 1.5 MW and above (Data source: IURC [21])

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 Indiana net metering rule was modified by the May 2017 Senate Enrolled Act to reduce the compensation from net retail rate to 1.25 times the utility's average wholesale rate beginning on July 1, 2022. Generators installed before the end of 2017 would continue to receive the full retail rate compensation until July 1, 2047 while those installed in the years 2018 through 2022 would compensated at the full retail rate until July 1, 2032 [15, 22].

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 (Allocation 1)**	**Purchase Rate per kWh (Allocation 2)**	**Total system capacity available (MW)**
Micro Solar	5 – 10	$0.17	$0.1564	2
Intermediate Solar	> 10 – 200	$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 [23, 24])

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 was 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 ran from March 4, 2015 to March 4, 2017. The remaining 4 MW capacity was made available under the *allocation 2* rate beginning March 4, 2017.
- For biomass projects, half the system wide capacity limit for the technology had been made available for the *allocation 1* category from March 4, 2015 to March 4, 2017. The other half is available in a reverse auction under the *allocation 2*.

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 [15].
- 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 [15].
- 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 [15].
- 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 [15].
- 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) [15].

- 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 [15].
- 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 [15, 25].
- 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 [15].
- Green Power Purchasing Goal requires that 30 percent of energy used by federal agencies must be obtained from renewable resources by 2025 [15].
- 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 [15].

Indiana Incentives

- 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. Indiana Senate Bill 309 signed into law in May 2017 made changes to the net metering rule to modify the compensation after June 30, 2022 to 1.25 times the utility's average wholesale cost for the most recent year. Generators installed before the end of 2017 shall continue to receive full retail credit until July 1, 2047 and those installed in the years 2018 to 2022 shall receive full retail credit for their generation until July 1, 2032 [15, 22].
- 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 [15].
- Renewable Energy Property Tax Exemption provides property tax exemptions for solar thermal, PV, wind, hydroelectric and geothermal systems [15].
- 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 source [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 [15].
- 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 [15].
- 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* [15, 23, 24].

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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 hydropower was 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 2017. 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 43 percent of the renewable electricity generated in the U.S. in 2017 [3, 4].

There are several different types of hydropower facilities today. They include impoundment hydropower, diversion, run-of-the-river, microhydro and pumped storage.

Impoundment hydropower involves storing water in a dam. This water is released through the turbines to meet electricity demand or to maintain a desired reservoir level. Figure 7-1 shows the schematic of an impoundment hydropower plant [5].

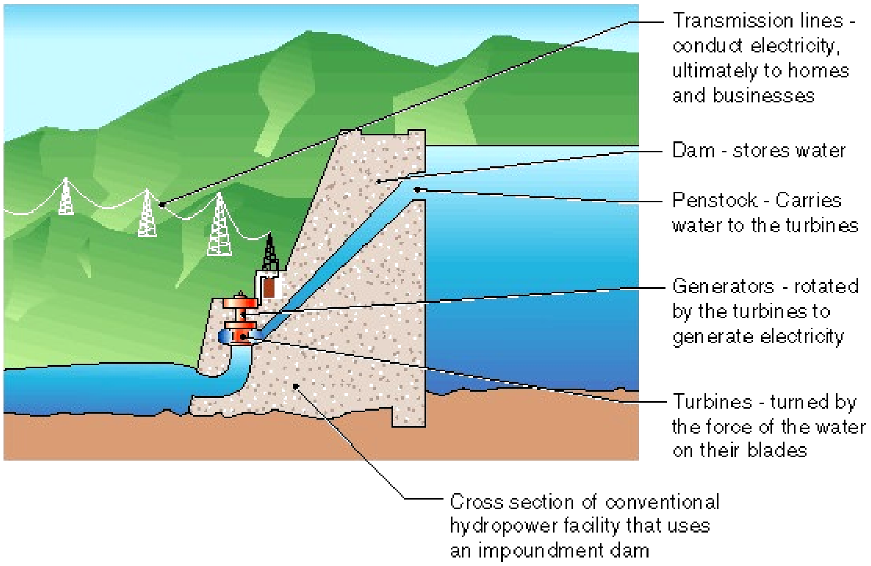

Figure 7-1: Schematic of impoundment hydropower facility (Source: DOE [6])

Diversion hydropower facilities channel some of the water through a canal or penstock. They may require a dam but are less obtrusive than impoundment facilities. Figure 7-2 shows the schematic of a diversion hydropower plant.

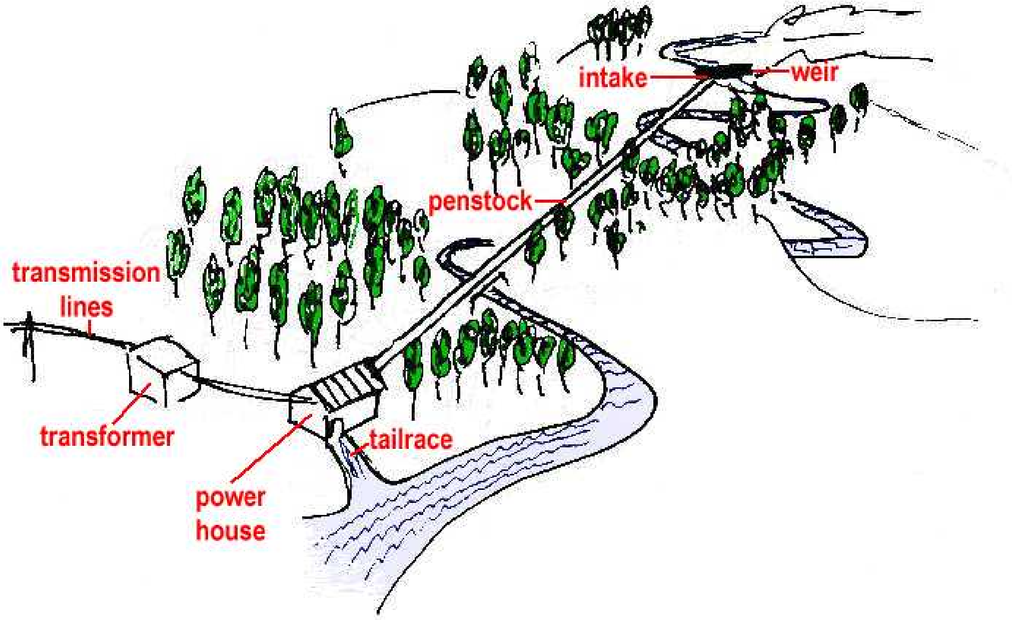

Figure 7-2: Schematic of a diversion hydropower facility (Source: wordpress [7])

Run-of-river hydropower facilities utilize the natural flow of water of a river and require little to no impoundment. Examples of run-of-river hydropower plants are the NIPSCO owned Norway and Oakdale hydropower plants on the twin lakes Shafer and Freeman near Monticello. Figure 7-3 is a photograph of the Hugh Keenleyside Dam, a run-of-river hydropower station operated by BC Hydro in Canada.

Figure 7-3: A run-of-river hydropower facility in British Columbia (Source: Clean Technica [8])

Microhydro power projects are small sized facilities (about 100 kW or less). They are typically used in remote locations to serve the power needs of a single nearby home or business. Figure 7-4 shows a photograph of a microhydro power plant.

Figure 7-4: Microhydro power facility (Source: Home Power [9])

Pumped storage hydropower plants are currently the most economic large scale energy storage technology. When electricity demand and price are low, inexpensive 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. Figure 7-5 is a schematic of a pumped storage power plant.

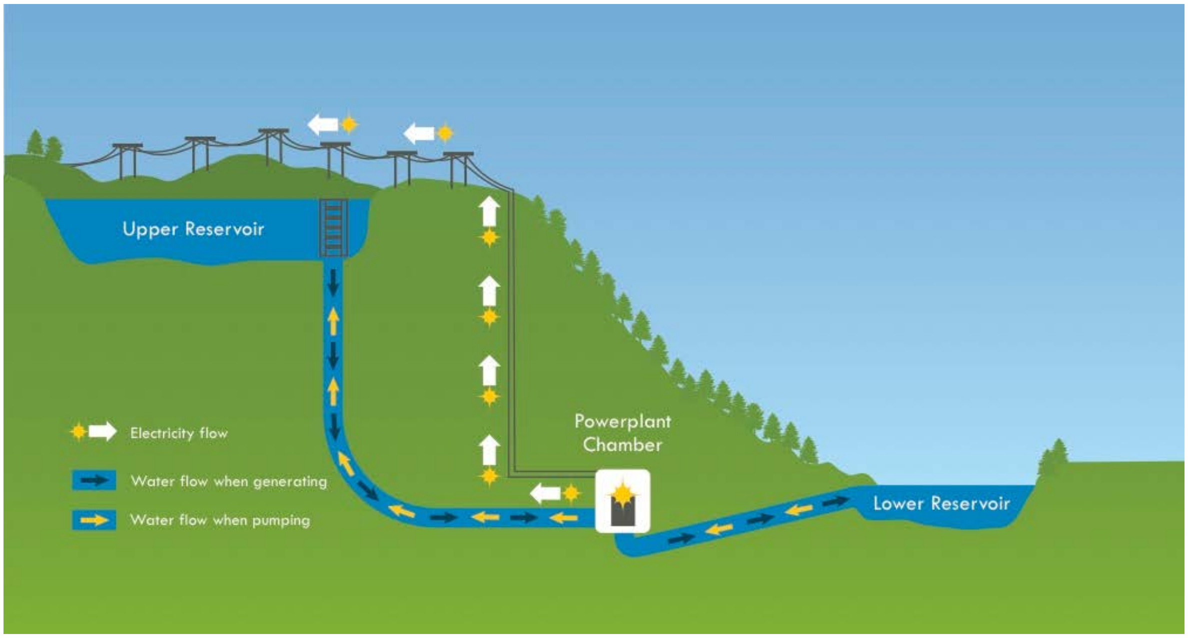

Figure 7-5: Schematic of a pumped hydro facility (Source: DC Thompson and Company [10])

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 – impulse and 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,[13] low flow application while the reaction turbine is more suited to a lower head, faster flow situation [11].

7.2 Economics of hydropower

Hydropower projects are very capital intensive and the cost is very site specific. Figure 7-6 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

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[13] Head refers to the vertical distance from the reservoir to the turbine.

that, hydropower projects added to dams already in place for other purposes, such as water storage, irrigation or navigation [12].

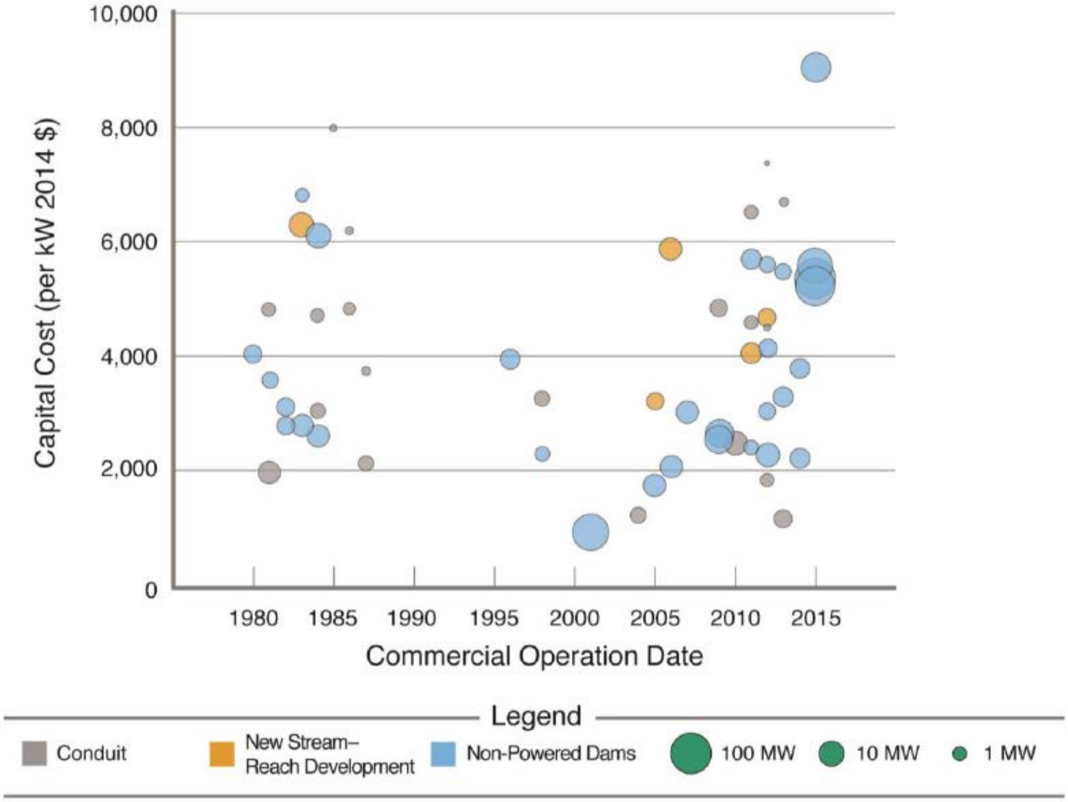

Figure 7-6: U.S. hydropower construction cost by project type and size (Source: DOE [12])

Table 7-1 shows the capital costs estimates from various sources. The capital cost estimates range from as low as $1,966/kW in 2005 dollars for the Hawaii Umauma project to $9,417/kW cost in 2014 dollars estimate for the Susitna project in Alaska.

Project		Time[*]	Initial Capital Costs ($/kW) [**]
EIA estimates		2018	2,898
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 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 the document from which Alaska project was obtained was dated 2014.

Table 7-1: Initial capital costs of hydropower projects (Data sources: EIA, Maui Electric Company, Susitna-Watana Project 2014 Annual Report, Alaska Energy Authority [13-17])

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 February 2018 EIA updated electricity generating technologies cost estimates [13], hydroelectric plants have one of the lowest O&M costs among electricity generating technologies. Figure 7-7 shows the fixed and variable O&M costs of various generating technologies. As can be seen in the Figure 7-7, hydroelectricity’s variable O&M costs are estimated at $1.33/MWh and the fixed O&M cost of $40/kW/yr for a conventional hydroelectric plant is among the lowest among renewable generating technologies. Impoundment hydro power plants have an added advantage over some other renewable resources (wind, solar) in that they are dispatchable. That is, the system operator can control the hydro power plant’s output to match the system load.

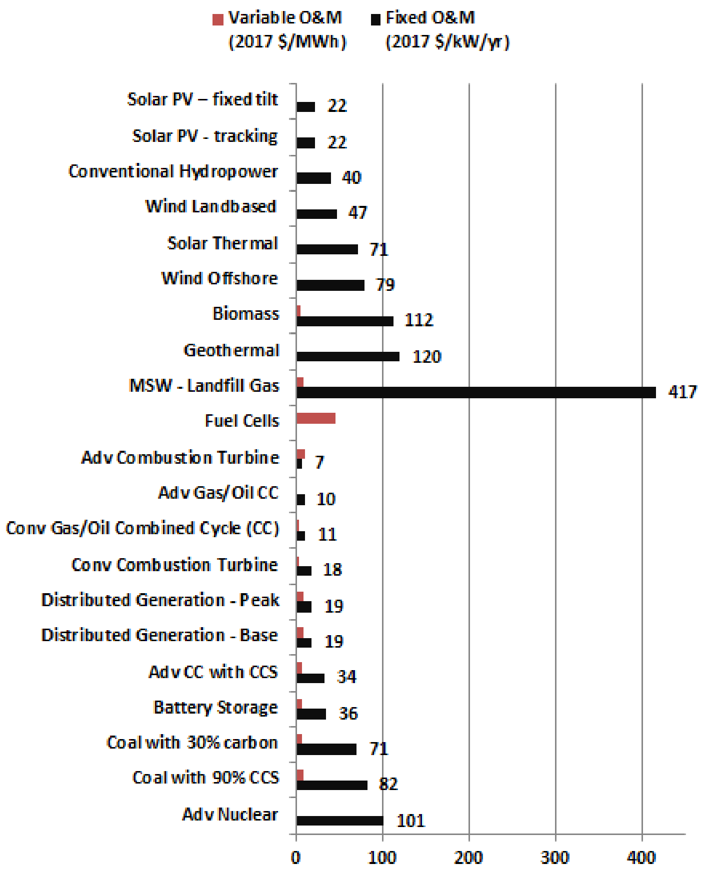

Figure 7-7: Variable and fixed O&M costs of generating technologies (Data source: EIA [13])

7.3 State of hydropower nationally

Hydropower has historically been the primary source of renewable energy in the U.S. Figure 7-8 shows the amount of electricity generated from renewable resources from 1949 to 2017. 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 2017 hydroelectricity accounted for 43 percent of the renewable electricity generated and 25 percent of the total renewable energy consumed in the U.S.

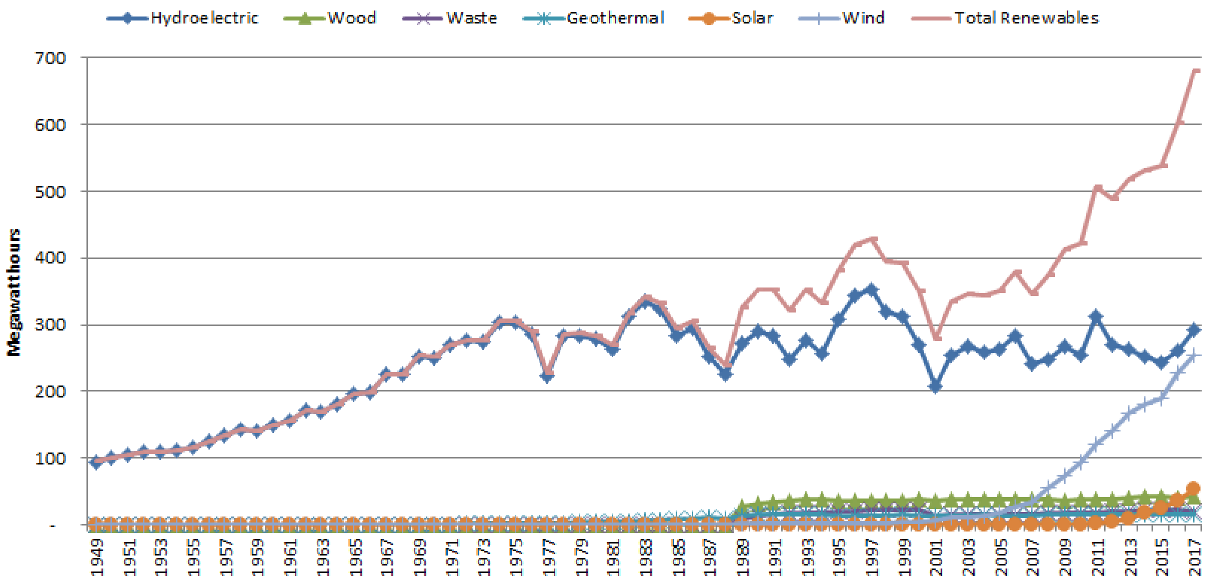

Figure 7-8: Net renewable electricity generation in the U.S. (1949-2017) (Data source: EIA [4])

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 [12, 18]. Table 7-2 is a list of the ten largest hydropower plants in the U.S.

Hydropower Plant Name	River	State	Nameplate Capacity (MW)	Year of completion
Grand Coulee	Columbia	Washington	6,495	1942
Bath County*	Little Back Creek	Virginia	2,862	1985
Chief Joseph	Columbia	Washington	2,456	1958
Robert Moses - Niagara	Niagara	New York	2,429	1961
John Day	Columbia	Oregon	2,160	1968
Hoover	Colorado	Nevada	2,079	1936
Ludington*	Lake Michigan	Michigan	1,979	1973
The Dalles	Columbia	Oregon	1,820	1957
Raccoon Mountain*	Tennessee River	Tennessee	1,714	1978
Castaic*	California Aqueduct	California	1,626	1973

*pumped hydropower stations

Table 7-2: Ten largest hydropower plants in the U.S. (Data sources: [18-22])

Table 7-3 shows the top ten hydro states ranked by their hydroelectricity output in 2016 and Table 7-4 shows the top ten hydro states ranked by installed hydro capacity at the end of 2015. Over sixty percent of the hydroelectricity generation in 2016 was from the top four states of Washington, Oregon, California, and New York.

1. Washington	78,345,809		6. Idaho	9,033,272
2. Oregon	34,549,366		7. Arizona	7,167,763
3. California	28,942,121		8. Alabama	6,984,803
4. New York	26,888,234		9. Tennessee	6,774,061
5. Montana	10,082,529		10. South Dakota	4,805,526

Table 7-3: Top ten U.S. hydropower generating states in 2016 (MWh) (Data source: EIA [23])

1. Washington	21,296		6. Arizona	2,721
2. California	10,190		7. Montana	2,748
3. Oregon	8,423		8. Idaho	2,709
4. New York	4,719		9. Tennessee	2,619
5. Alabama	3,042		10. Georgia	2,275

Table 7-4: Top ten U.S. hydropower capacity states at the end 2016 (MW) (Data source: EIA [24])

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 [25]. Figure 7-9 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.

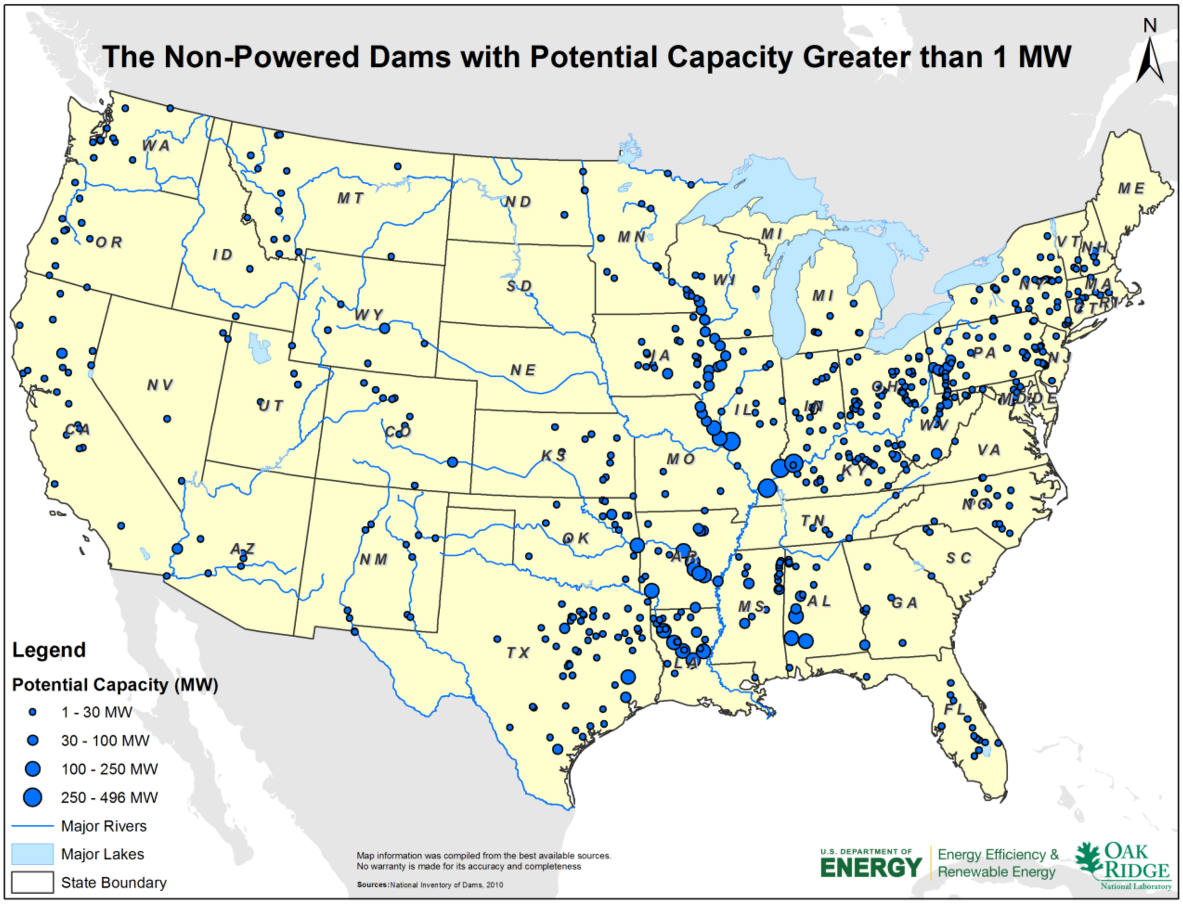

Figure 7-9: Non-powered dams with potential capacity over 1 MW (Source: DOE [25])

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 [25])

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 [26].

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 7-10. With 2,714 MW of installed wind capacity compared to 92 MW of hydroelectricity in Indiana, wind is now the dominant source of renewable electricity. Furthermore, the photovoltaic capacity has also been climbing rapidly to overtake hydropower with 254 MW installed at the writing of this report.

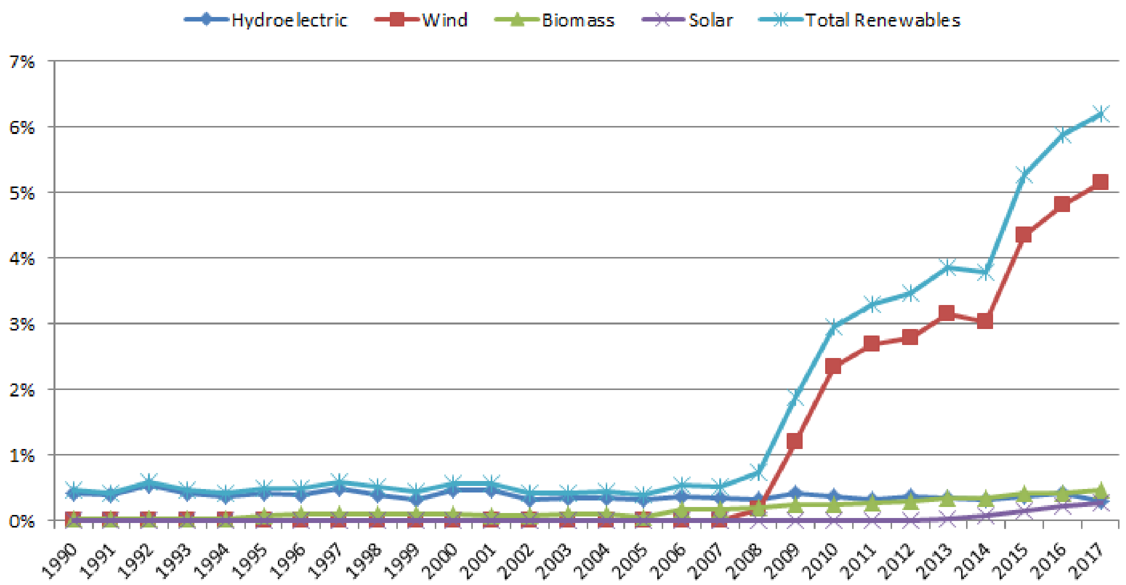

Figure 7-10: Renewables share of Indiana net electricity generation (1990-2017) (Data source: EIA [27])

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. 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 [26]. This is approximately 7 times the hydroelectricity generated in Indiana in 2016 and 3 percent of the total electricity generated in Indiana from all sources in 2016.

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 [26])

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. Three of the projects, the 105 MW Melhahl, the 44 MW Willow Island, and the 88 MW Cannelton projects were completed in 2016; while the 76 MW Smithland project is currently under construction. One of the projects, the 50 MW Robert Byrd completed its licensing process in August 2017 [28]. The Cannelton project is located on the Indiana/Kentucky section of the river and the adjoining city of Cannelton, Indiana has joined as a member of AMP [29].

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 expired on January 1, 2018 but is available for systems whose construction started before the end of 2017 [30].
- 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 [30].
- 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 [30].
- 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) [30].
- 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 [30].
- 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 [30, 31].

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

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 [30]. Indiana Senate Bill 309 signed into law in May 2017 made changes to the net metering rule to modify the compensation after June 30, 2022 to 1.25 times the utility's average wholesale cost for the most recent year. Generators installed before the end of 2017 shall continue to receive full retail credit until July 1, 2047 and those installed in the years 2018 to 2022 shall receive full retail credit for their generation until July 1, 2032 [30, 32].
- Renewable Energy Property Tax Exemption provides property tax exemptions for solar, wind, hydroelectric and geothermal systems [30].
- 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 [30].
- 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 [30].

7.6 References

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