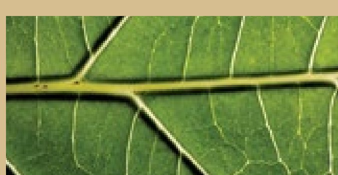
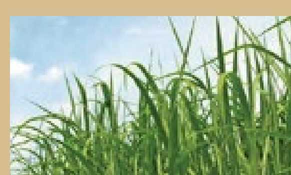
STATE UTILITY FORECASTING GROUP

October 2020

2020 INDIANA RENEWABLE ENERGY RESOURCES STUDY





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Acronyms and Abbreviations

AC	Alternating current
ADM	Archer Daniels Midland Company
ARRA	American Recovery and Reinvestment Act
AMP	American Municipal Power
AWEA	American Wind Energy Association
Btu	British thermal unit
CAFO	Concentrated animal feeding operations
CAISO	California Independent Transmission System Operator
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
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
ERCOT	Electric Reliability Council of Texas
EERE	U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy
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
ISO-NE	New England Independent Transmission System Operator
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
lb	Pound
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
MMGY	Million gallons per year
MISO	Midcontinent Independent System Operator
mmBtu	Million British thermal unit
mmscfd	Million standard cubic feet per day
MMTCO2e/yr	Million metric ton of carbon dioxide-equivalent per year
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
NYISO	New York Independent System Operator
O&M	Operation and maintenance
OED	Indiana Office of Energy Development
ORNL	Oak Ridge National Laboratory, U.S. Department of Energy
PJM	Pennsylvania-New Jersey-Maryland Interconnection
POLYSYS	Policy analysis system
PPA	Power purchase agreements
PTC	Production tax credit
PV	Photovoltaic
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
SPP	Southwest Power Pool
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 eighteenth 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 2020 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 2019 as provided by the U.S. Energy Information Administration (EIA). 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 2019, biofuels, wind and solar combined contributed 53 percent of the 11.5 quadrillion Btu of renewable energy consumed in the U.S., reducing hydroelectricity's share to 22 percent. The two main factors that caused 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 to include projects starting construction in 2020 by the Taxpayer Certainty and Disaster Tax Relief Act of 2019. The value of the production tax credit was also raised to 60 percent of its full value for projects starting construction in 2020. Prior to this recent extension the PTC was scheduled to scale down to 80 percent for projects starting construction in 2017, 60 percent for projects starting construction in 2018, and 40 percent for projects starting construction in 2019. The investment tax credit started phasing down from its previous 30 percent of the project cost to 26 percent in 2020, to 22 percent in 2021 and to 10 percent in 2022 [1, 2].

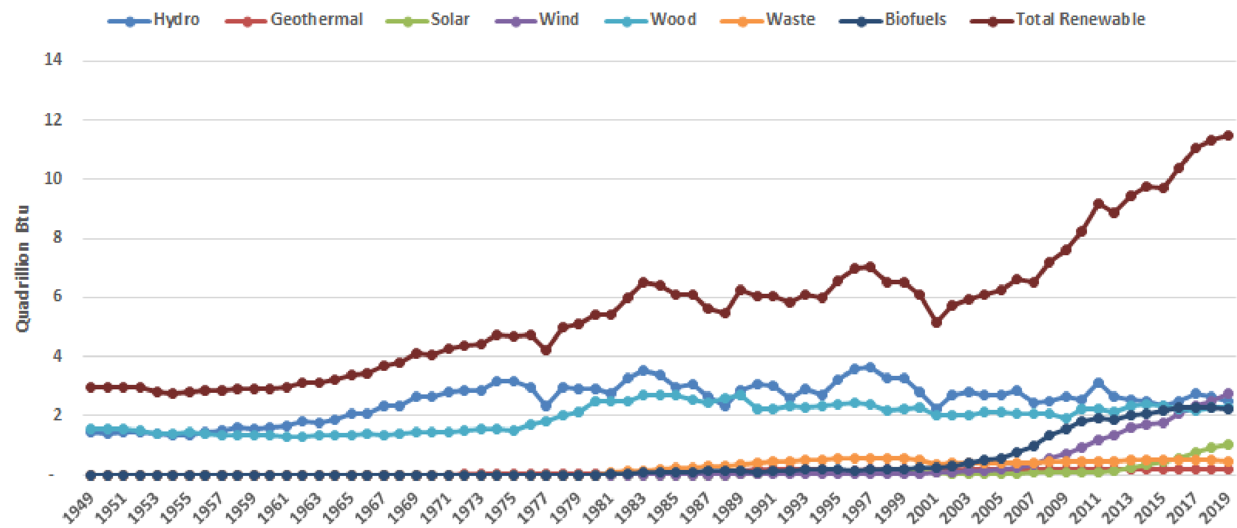

Figure 1-1: Renewable energy consumption in the U.S. (1949-2019) (Data source: Energy Information Administration (EIA) [3])

Despite the growth in renewable resources shown in Figure 1-1, renewable energy's share of the total energy consumed in the U.S. remains modest at over 11.4 percent. In 2019 fossil fuels supplied 80 percent of the energy consumed in the U.S while nuclear energy supplied 8.4 percent. Figure 1-2 shows the sources of total energy consumed in the U.S. from 1949 to 2019.

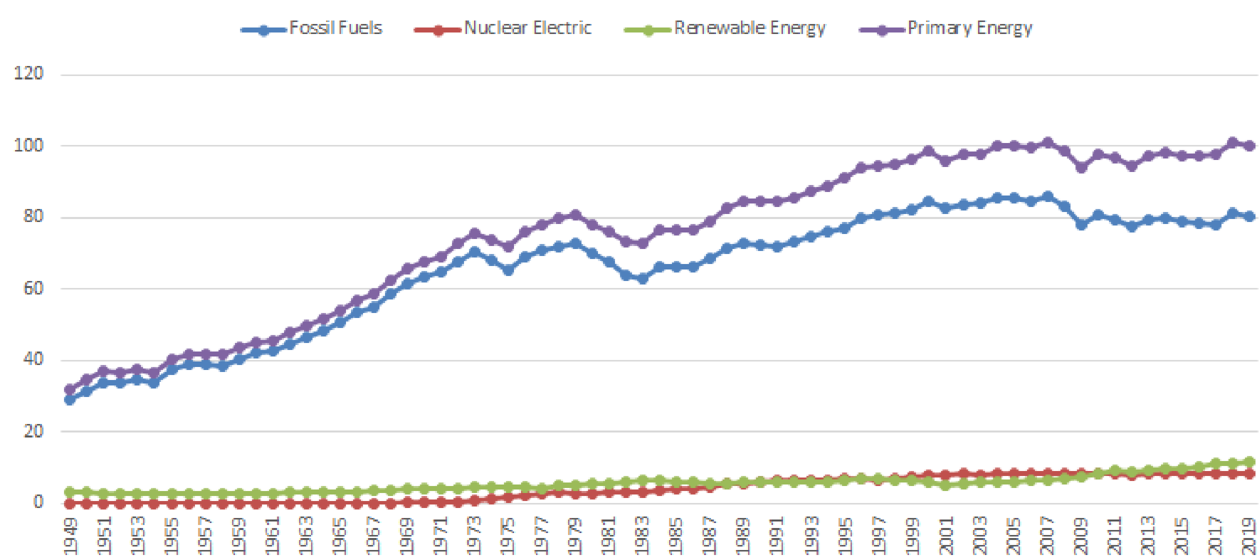

Figure 1-2: U.S. energy consumption by source (1949-2019) (Data source: EIA [4])

Figure 1-3 shows the contribution of the various energy sources to the total energy consumed in the U.S. in 2019. Petroleum continued to be the largest energy source supplying 37 percent of the energy, followed by natural gas at 32 percent. Coal's share dropped from 13 percent in 2018 to 11 percent, while the total renewable energy share remained at slightly above 11 percent. Among the renewable resources, biomass (including wood, biofuels, municipal solid waste, landfill gas and others) comprised 44 percent of the total renewable energy. For the first time wind energy surpassed hydroelectricity to contribute 24 percent of the renewable energy compared to hydroelectricity's 22 percent. Solar energy's contribution increased from 8 percent of the renewable energy in 2018 to 9 percent in 2019 while geothermal remained at 2 percent.

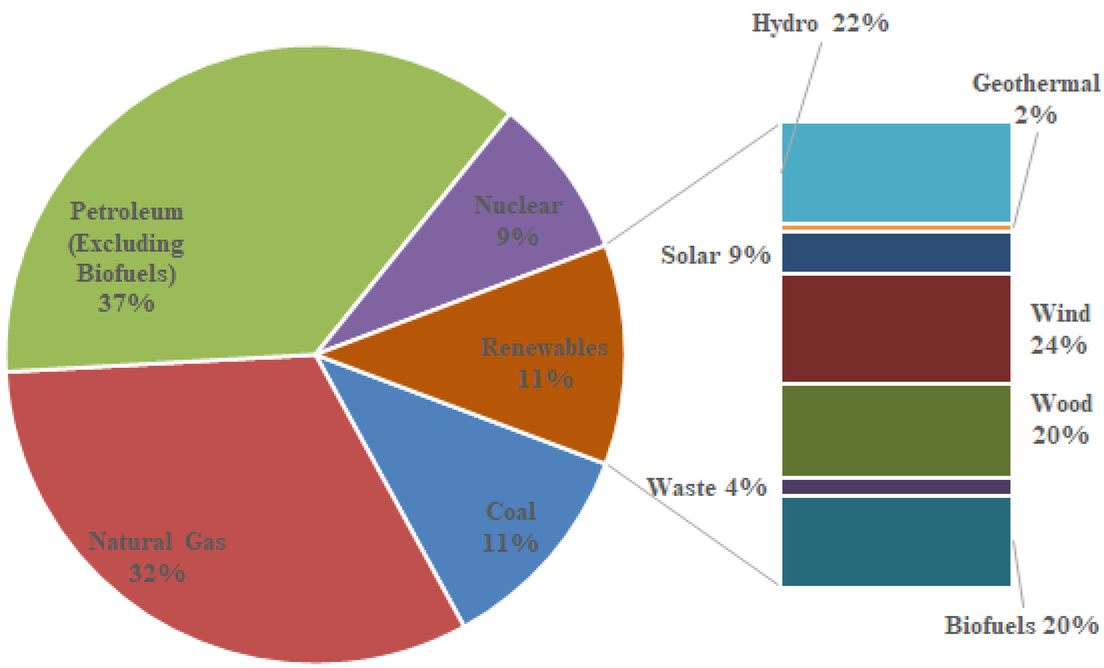

Figure 1-3: U.S. total energy consumption by energy source in 2019 (Data source: EIA [3, 5])

Figure 1-4 shows the growth of renewable resources in electricity generation from 1949 to 2019. Through the late 1980s hydroelectricity was the sole significant source of renewable electricity annual generation 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. In 2019 wind accounted for 42 percent of the renewable electricity generated, for the first time surpassing hydroelectricity, whose share of the total renewable electricity generated in the U.S. dropped from 40 percent in 2018 to 38 percent in

2019. Solar electricity generation has risen rapidly in the last ten years contributing 10 percent of the U.S. renewable electricity generation in 2019.

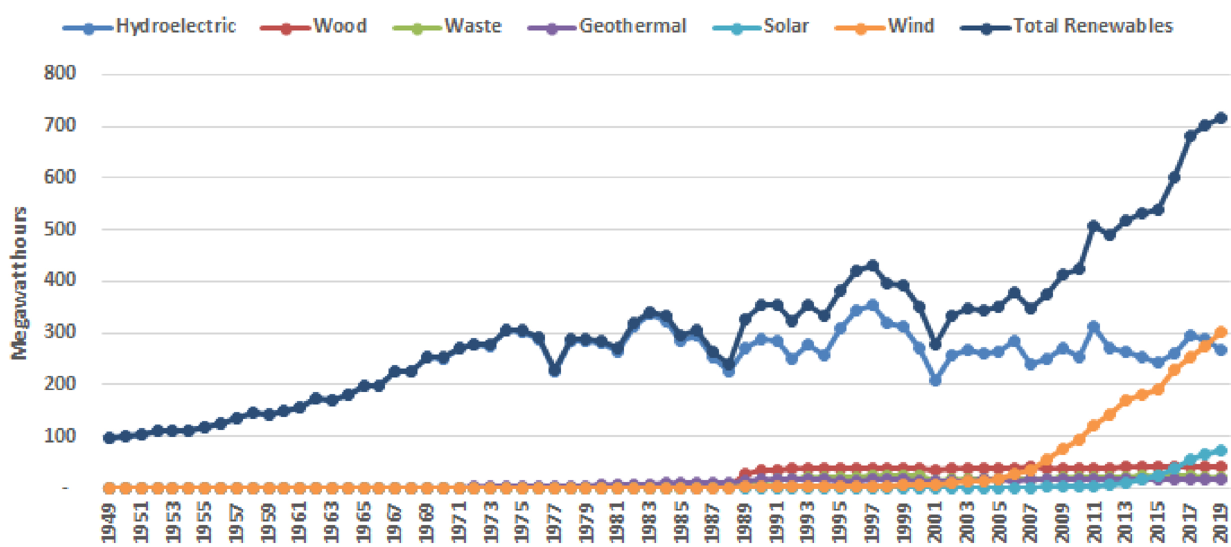

Figure 1-4: Renewable electricity generation in the U.S. (1949-2019) (Data source: EIA [6])

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 electricity generation in the U.S. Figure 1-5 shows the amount of electricity generated from all sources from 1949 to 2019.

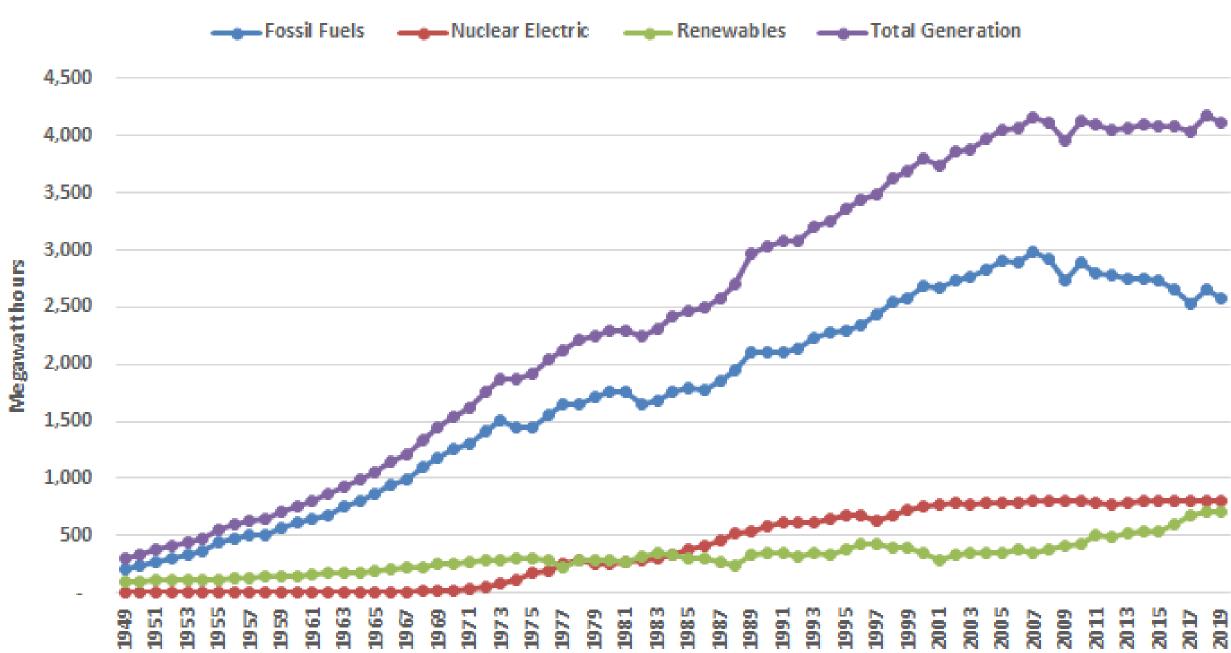

Figure 1-5: U.S. electricity generation by source (1949-2019) (Data source: EIA [6])

Figure 1-6 shows the share of electricity generated from various energy sources in the U.S. in 2019. Natural gas, coal and nuclear energy dominate electricity generation, jointly accounting for 82 percent of the electricity generated in 2019. Renewable resources contributed 17 percent and petroleum half a percent. Among renewable resources hydroelectricity and wind played the dominant role, jointly contributing 80 percent of the total renewable electricity generated (42 percent from wind and 38 percent from hydro). Solar contributed 10 percent, woody biomass 6 percent, waste biomass 3 percent, and geothermal 2 percent. As expected, pumped hydroelectricity's net energy contribution was negative.[1]

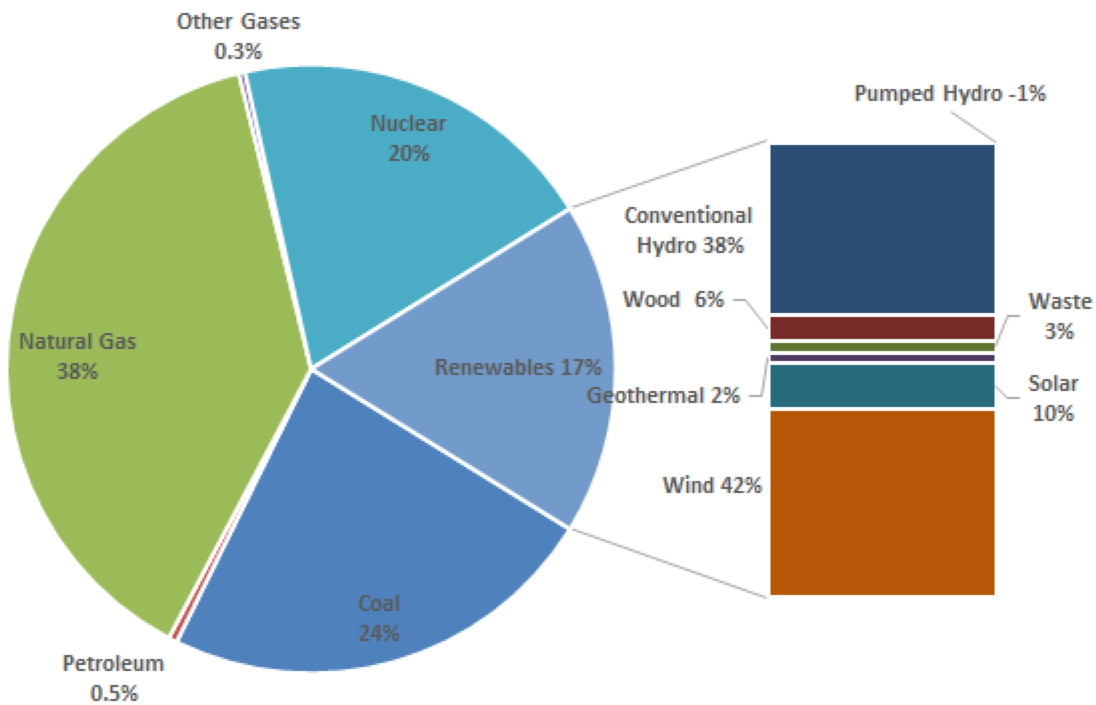

Figure 1-6: Net U.S. electricity generation by energy source in 2019 (Data source: EIA [6])

[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.

1.2 Trends in renewable energy consumption in Indiana

Figure 1-7 shows renewable energy consumption in Indiana from 1960 to 2018. 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 expansions in ethanol and wind in the last decade increased renewable resources' share to 6.8 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 largest source of renewable energy, supplying 49 percent of the renewable energy consumed in 2018, followed by wind energy contributing 27 percent. Wood and wood waste contributed 19 percent, geothermal 2.5 percent and solar 2 percent. The share of the renewable resources to Indiana's total energy consumption dropped slightly (by 2 percent) from 2017 to 2018. The reduction was mainly from energy from fuel ethanol and hydroelectricity.

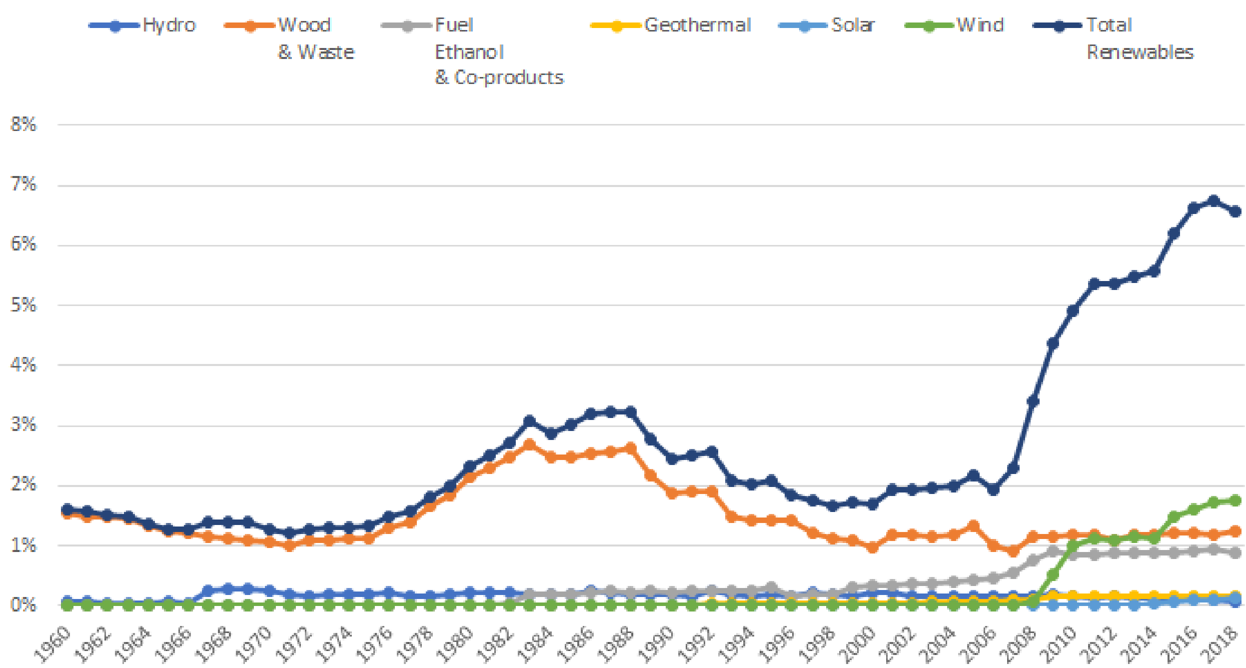

Figure 1-7: Renewables share of Indiana total energy consumption (1960-2018) (Data source: EIA [7])

Figure 1-8 shows the contribution of renewable energy to Indiana's net electricity generation from 1990 to 2018. The construction of utility-scale wind energy projects beginning 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 before dropping to 5.6% in 2018. The percentage drop in 2018 was mainly due to a big jump in electricity generation from natural gas in 2018 compared to 2017. The share of hydroelectricity, which until 2007 was the primary source of renewable electricity, dropped to 0.2 percent of Indiana's 2018 generation. Wind energy has become the dominant source of renewable electricity in Indiana, contributing 85 percent of the renewable electricity generated in 2018. Solar photovoltaic generation has grown from virtually none in 2011 to 291 GWh in 2018 which was approximately 0.3 percent of Indiana's total generation.

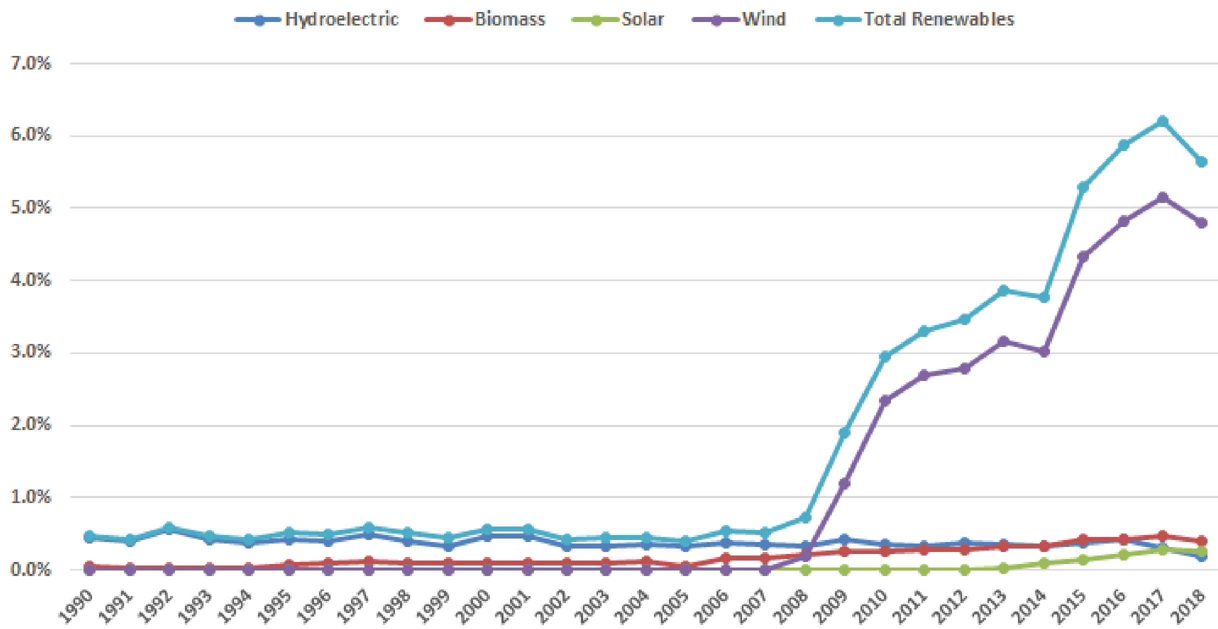

Figure 1-8: Renewables share of Indiana electricity generation (1990-2018) (Data source: EIA [8])

As can be seen in Figure 1-9 Indiana's wind energy capacity has increased steadily since the installation of the first utility scale wind farm in 2008. At the end of 2019 the installed utility scale wind farm capacity stood at 2,314 MW. Four wind farms with a combined capacity of 832 MW were under construction and expected to be completed before the end of 2020, while one wind farm with a capacity of 307 MW was expected to be completed in 2021, bringing Indiana's utility-scale wind farms installed or under construction to 3,453 MW.

Indiana utilities have a total 2,267 MW of wind capacity contracted through power purchase agreements, with 1,847 MW from wind farms in Indiana and 420 MW from out of state wind farms. The power purchase agreements include 805.6 MW contracted by NIPSCO from three Indiana wind farms expected to be completed in 2020.

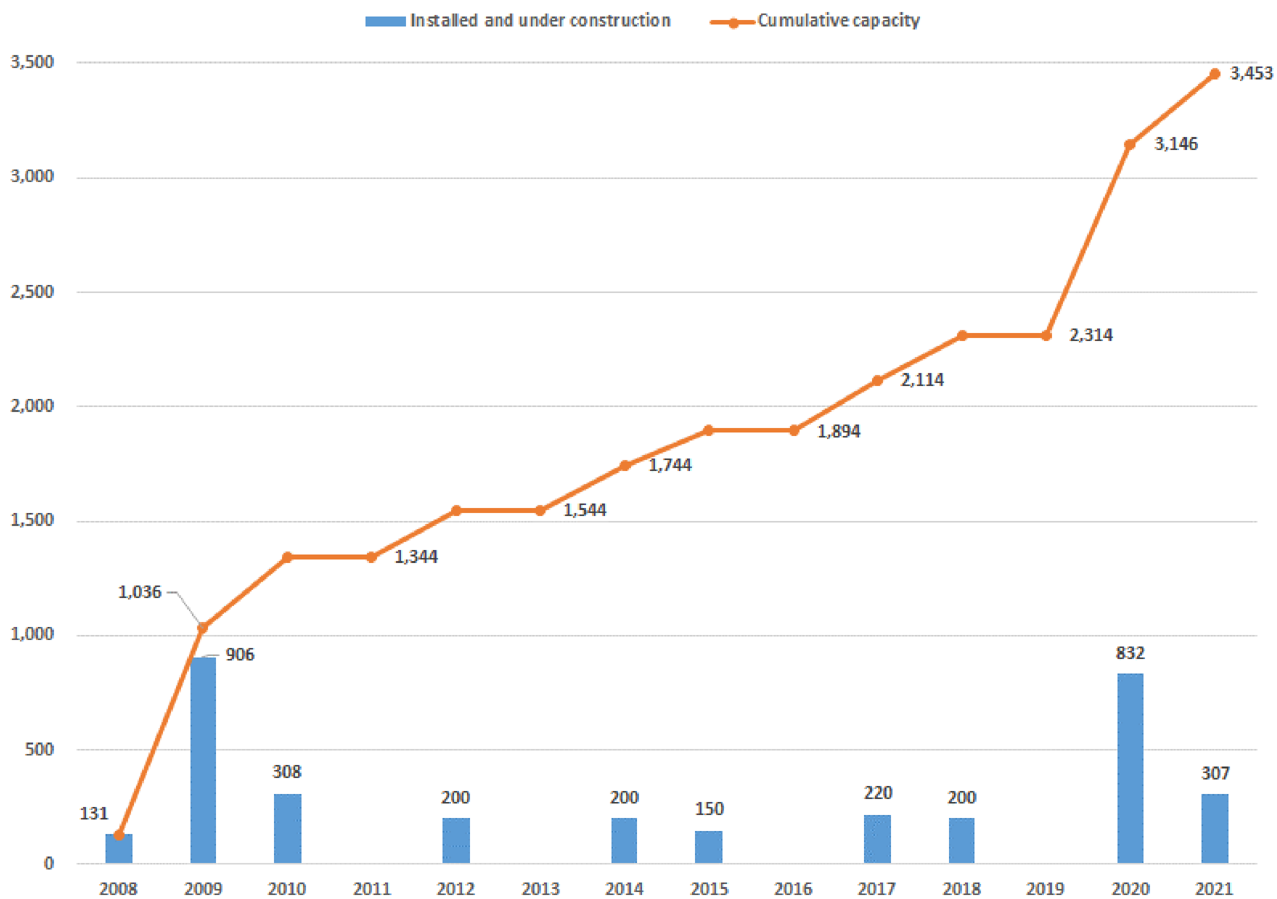

Figure 1-9: Wind energy capacity in Indiana (Data source: IURC [9])

Another renewable resource, solar photovoltaic, has been experiencing rapid growth with the installed capacity increasing from virtually none in 2008 to nearly 335 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: 38 percent (129 MW) through feed-in tariffs, 25 percent (84 MW) through net metering[2] tariffs, 27 percent (123 MW) through either direct ownership by utilities or through power purchase agreements.[3]

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

[2] The net met 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.

[3] 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 Energy Delivery, and WVPA – Wabash Valley Power Association.

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, increasing the capacity cap on renewable generating systems up to 1 MW, and the increase of the cap at which a utility may limit system-wide net metering capacity from one-tenth of a percent to one percent of its most recent summer peak [10]. The net metering rule has since been modified by Indiana Senate Enrolled Act 309 (2017) 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 will continue to receive full retail credit until July 1, 2047 and those installed in the years 2018 to 2022 will receive full retail credit for their generation until July 1, 2032 [10, 11].

	Feed-in-Tariff (MWAC)	Net Metered PV (MWAC)	Utility Owned or Purchase Agreement (MWAC)	Total (MWAC)
IPL	94	4		**98**
Duke		35	42	**77**
NIPSCO	35	21		**56**
IMPA			55	**55**
I&M		13	10	**24**
Vectren		11	4	**15**
Hoosier			12	**12**
Total	**129**	**84**	**123**	**335**

Table 1-1: Total installed Indiana PV capacity (Data source: IURC [9]

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 90.5 MW of renewable capacity contracted via net metering in the respective territories of Indiana utilities, while Table 1-3 shows the 128 MW of renewable capacity contracted to two Indiana utilities under their feed-in tariffs. The renewable capacity contracted under the net metering tariff has increase by 20 percent from last year's 76 MW while the renewables connected under the feed-in tariffs have not changed.

[4] A feed-in tariff is a long-term contract offered by a utility 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.

Utility	Solar PV (kW)	Wind (kW)	Biomass (kW)	Total (kW)
Duke	34,947	4,349		39,296
NIPSCO	21,002	2,197		23,199
I&M	13,412	157	240	13,809
Vectren	10,684	16		10,700
IPL	3,465	50		3,515
Total kW	**83,510**	**6,769**	**240**	**90,519**

Table 1-2: Renewable generation capacity contracted under net metering (Data source: IURC [9])

Utility	Solar (kW)	Wind (kW)	Biomass (kW)	Total
IPL	94,384	-	-	**94,384**
NIPSCO	19,155	180	14,348	**33,683**
Total kW	**113,539**	**180**	**14,348**	**128,067**

Table 1-3: Renewable generation capacity contracted under feed-in tariffs (Data source: IURC [9])

Indiana's PV capacity is on track to increase very significantly in the next three years if all the currently proposed projects filed with the IURC are completed as proposed. Table 1-4 is a list of PV projects with a capacity of one MW or above proposed for Indiana. The added projects would grow Indiana's grid connected PV capacity from the current 335 MW to 1,840 MW at the end 2024.

Project	Utility Owner or Buyer	County	Capacity (MW_{AC})	Planned In-service Date
Fairbanks Solar Energy Center	Merchant	Sullivan	250	2023
Riverstart Solar Park	Hoosier	Randolph	200	2022
Brickyard Solar Project	NIPSCO	Boone	200	2022
Elliott	Merchant	Gibson	200	2023
Speedway Solar (Ranger)	WVPA	Shelby	199	2023
Ratts 2 Solar Project	Merchant	Knox	150	2023/2024
Lone Oak Solar Energy	Merchant	Madison	120	2023
Greensboro Solar Project	NIPSCO	Henry	100	2022
Vectren Spencer County Project	Vectren South	Spencer	50	2021
South Bend Solar Farm	IM Power	St. Joseph	20	2023
Richmond 4 Solar Park	IMPA	Wayne	8	2019
Scottsburg Solar Park	IMPA	Scott	8	2019
Centerville Solar Park	IMPA	Wayne	1	2020

Table 1-4: Proposed PV projects with a capacity 1 MW or greater (Data sources: IURC [9], IMPA [12], IIB [13])

1.3 Cost of renewable resources

Although the capital cost of renewable generation has been falling steadily in the last ten years, it is still for the most part higher than the capital cost for traditional generating technologies. Figure 1-10 shows the average cost of a generating plant installed in 2018 released by EIA in August 2020. As can be seen in the figure the average capital cost of the wind turbines installed in 2018, 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 2018 and 129 percent higher than simple-cycle combustion turbines installed in 2018, the two fuel fossil fuel technologies in common use today.

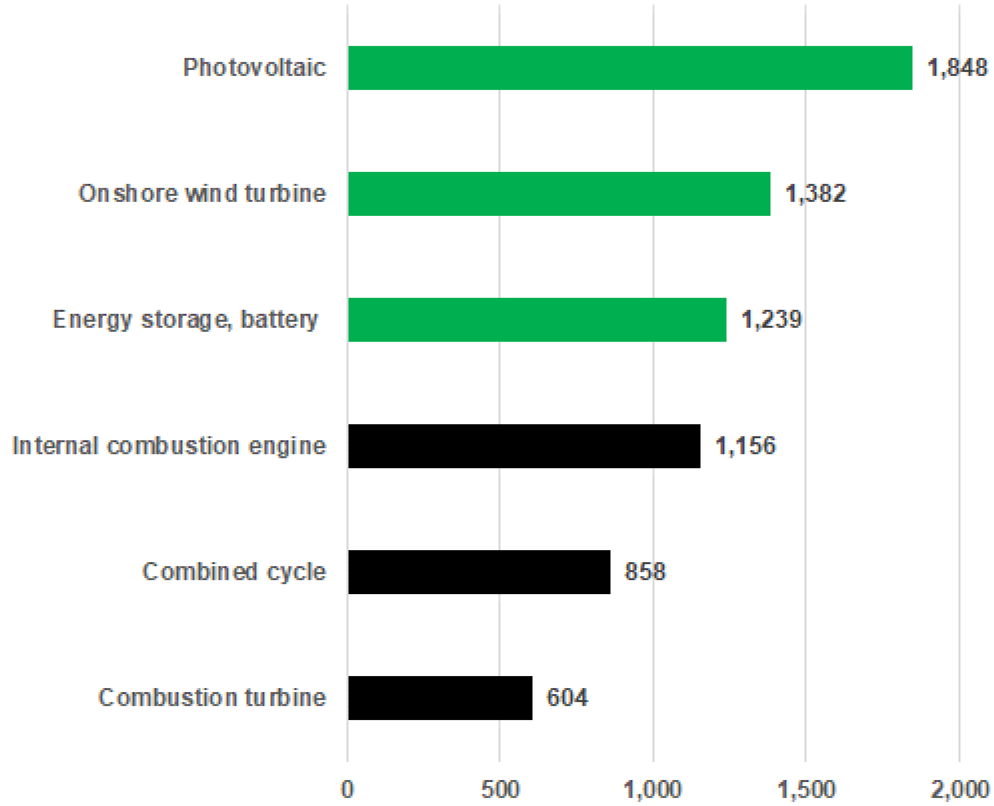

Figure 1-10: Average construction cost ($/kW) of generation installed in 2018 (Data source: EIA [14])

Figure 1-11 shows the estimated cost of future generating plants modeled in the 2020 EIA Annual Energy Outlook. The EIA estimated capital cost of wind energy from a wind farm in the Great Plains is 32 percent higher than that of a multi-shaft natural gas combined cycle plant and 77 percent higher than that of an industrial frame combustion turbine. The estimated capital cost of a utility scale PV plant is 37 percent higher than that of a multi-shaft combined cycle plant and 84 percent higher than the capital cost of an industrial frame combustion turbine. However, when one considers the more expensive aeroderivative combustion turbine at 1,175 $/kW, wind energy is only 8 percent higher at 1,265 $/kW and utility scale PV 12 percent higher at 1,313 $/kW.

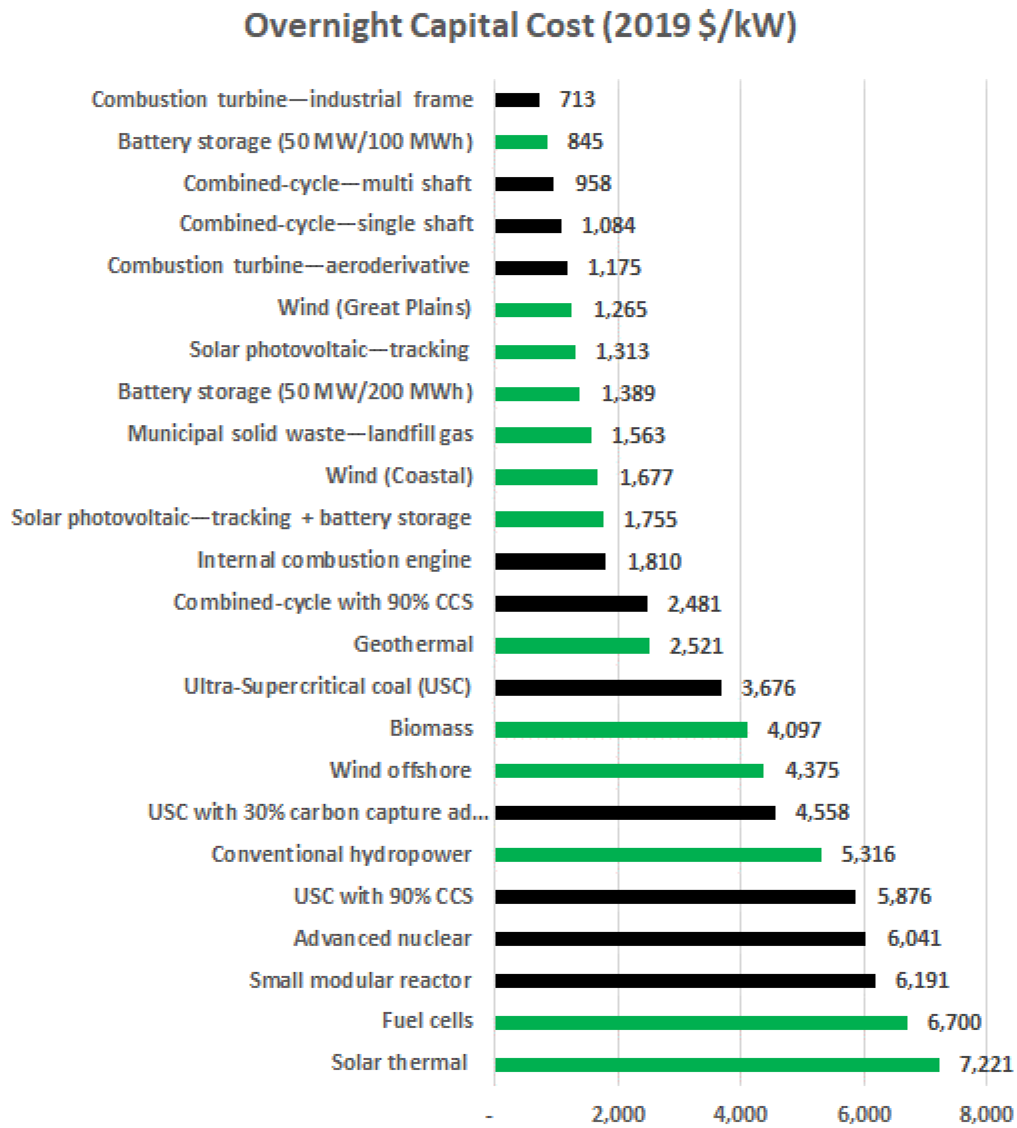

Figure 1-11: Estimated generating technologies capital cost (Data source: EIA [15])

Figure 1-12 shows the EIA estimated fixed and variable operating and maintenance (O&M) costs of the future generating technologies modeled in the 2020 EIA Annual Energy Outlook. As can be seen in 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 in variable O&M since they do not consume fuel, the primary component of variable O&M cost.

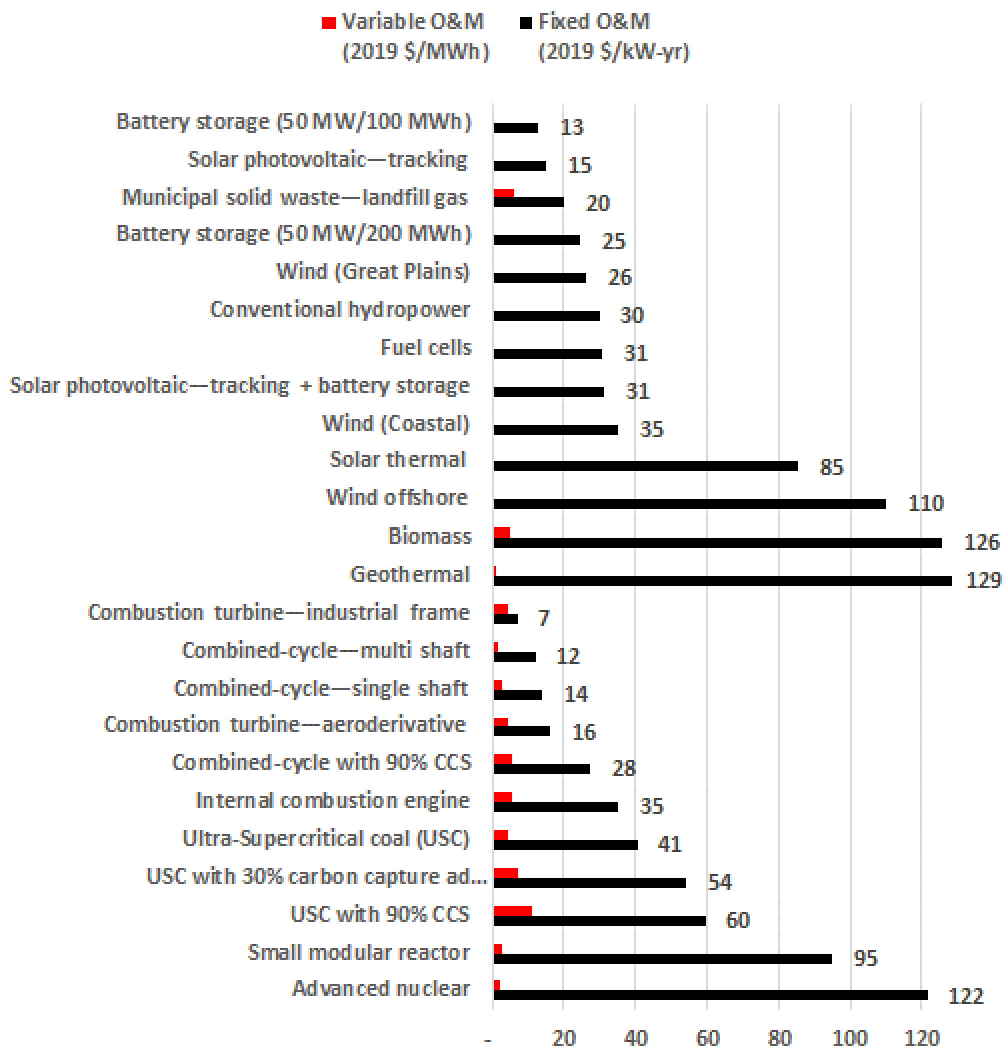

Figure 1-12: Estimated generating technologies fixed and variable O&M cost (Data source: EIA [15])

The cost of generating electricity from renewable resources has fallen dramatically over time. Figure 1-13 shows the mean levelized cost of electricity generated from various sources. The levelized cost is the total cost of building and operating a power plant spread over the total energy generated by the power plant over its lifetime.

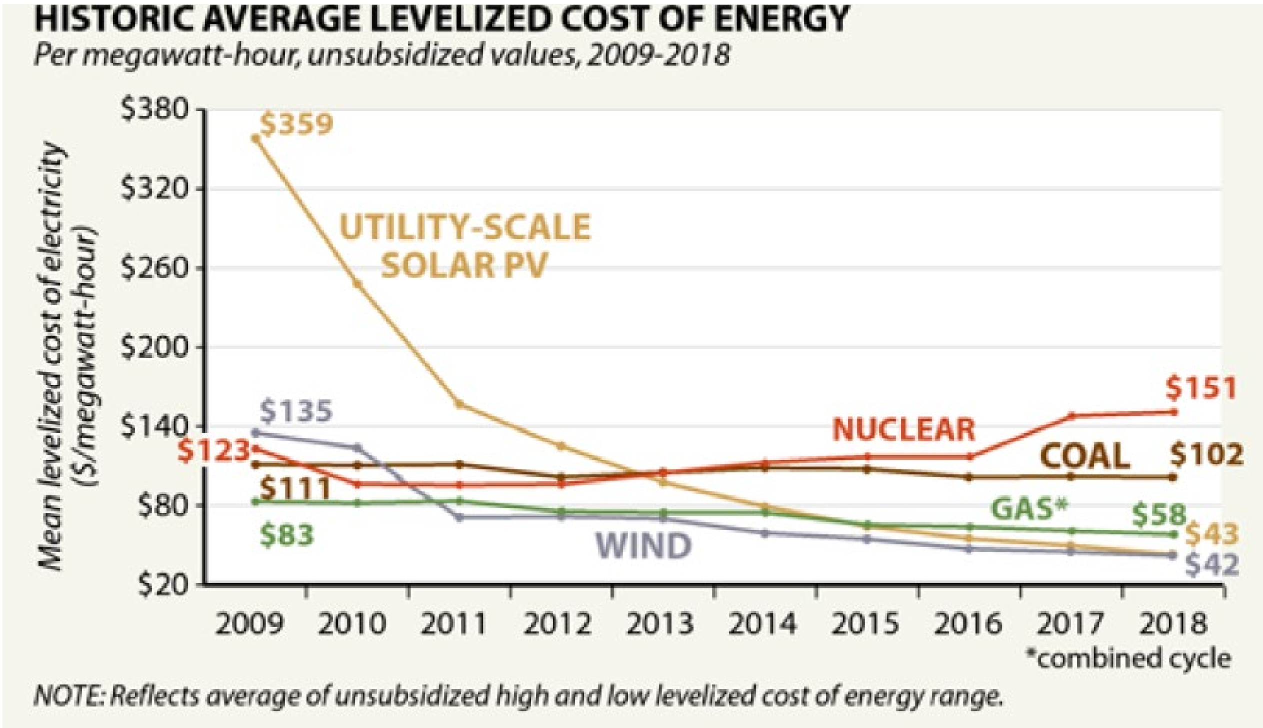

Figure 1-13: Historic average levelized cost of energy from various technologies (Source InsideClimateNews using data from Lazard [16])

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2. Energy from Wind

2.1 Introduction

Wind turbines convert the kinetic energy in moving air 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. The vertical wind turbines are more suitable for smaller urban applications where space is limited and safety of much greater concern. The horizontal axis wind turbines not only capture more energy per volume of moving air but they also can be mounted at much greater heights to capture higher speed and less turbulent winds [1]. Figure 2-1 shows the basic parts of a modern horizontal axis wind turbine used for electricity generation.

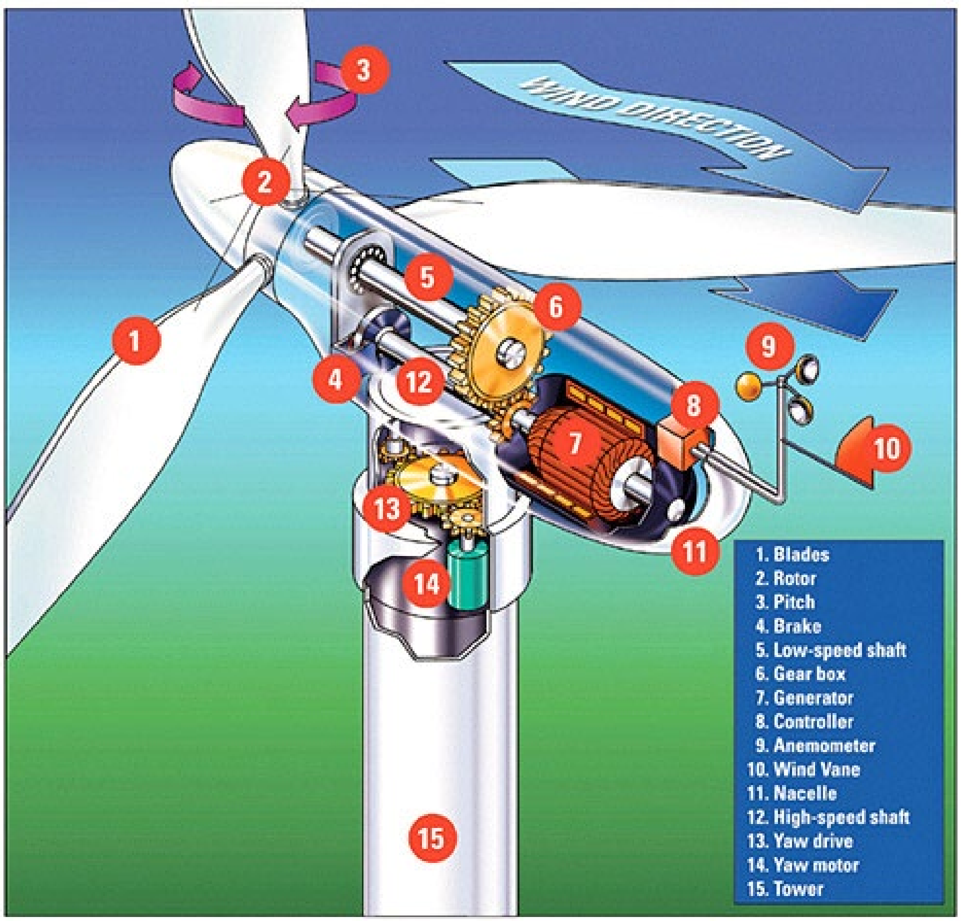


Figure 2-1: Horizontal wind turbine configuration (Source: Alternative Energy News [2])

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 [3]. 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). Turbine capacity and wind farm sizes have grown steadily to the point where the two-megawatt (MW) turbine and wind farms with hundreds of MW of capacity are common [4, 5].

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 [6].

Wind speeds are important in determining a turbine's performance. Generally, annual average wind speeds of greater than 9 miles per hour (mph) are required for small electric wind turbines not connected to the grid, whereas utility-scale wind plants require a minimum wind speed of 10 mph. 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". 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 [7]. Table 2-1 shows the wind class categories currently used.

[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 [8])

Wind energy's main advantage is that it is a carbon-free virtually inexhaustible resource. The placement of a wind turbine does not materially diminish the power of the wind, the only limitation being the space available to build wind farms where good quality wind blows. By the same token wind has the main disadvantage in that it is intermittent. That is, the output from a wind farm is determined by the level of the wind blowing at the moment and is not at the control of the grid operator. The only control the grid operator can assert is to curtail the output from the wind from feeding into the grid. This intermittency reduces the wind generator's value at both the operational and the system capacity planning levels. At the capacity planning level the system planner needs to know how much energy they can count on from a generator at a future planning date which for wind is unknown. Another significant disadvantage of wind energy is that good wind sites tend to be located far from main load centers and from existing 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.

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

2.2 Economics of wind energy

Figure 2-2 shows capital cost estimates for electricity generating plants modeled by the EIA in the 2020 Annual Energy Outlook. In these estimates utility-scale wind power plants are divided into three categories: wind farms in the Great Plains, coastal wind plants and off-shore wind power plants. At $1,265/kW wind power plants in the Great Plains have the lowest cost among the renewable resource options. At $1,677/kW coastal wind power plants have a higher cost than PV power plants mounted on a tracking base, while off-shore wind power plants at $6,542/kW have one of the highest capital costs among renewable resource power plants, only lower than that for hydroelectric power plants.

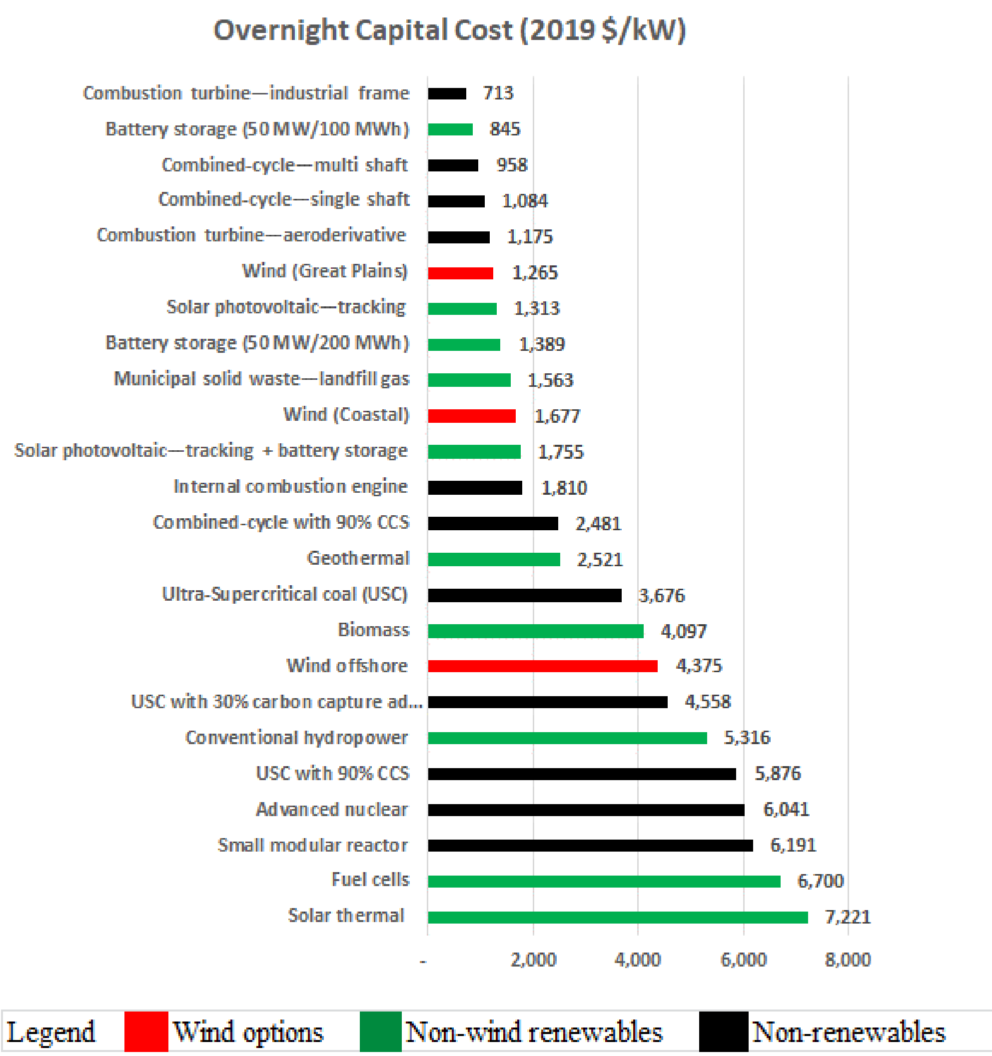


Figure 2-2: Estimated capital costs of various electric generation options (Data source: EIA [9])

Figure 2-3 shows the trend in installed wind power plant costs for the projects from 1982 to 2020 contained in the 2018 *Wind Energy Technology Data Update* 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 2019 capacity-weighted average installed project cost of $1,436/kW was 43 percent lower than the peak $2,508/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.

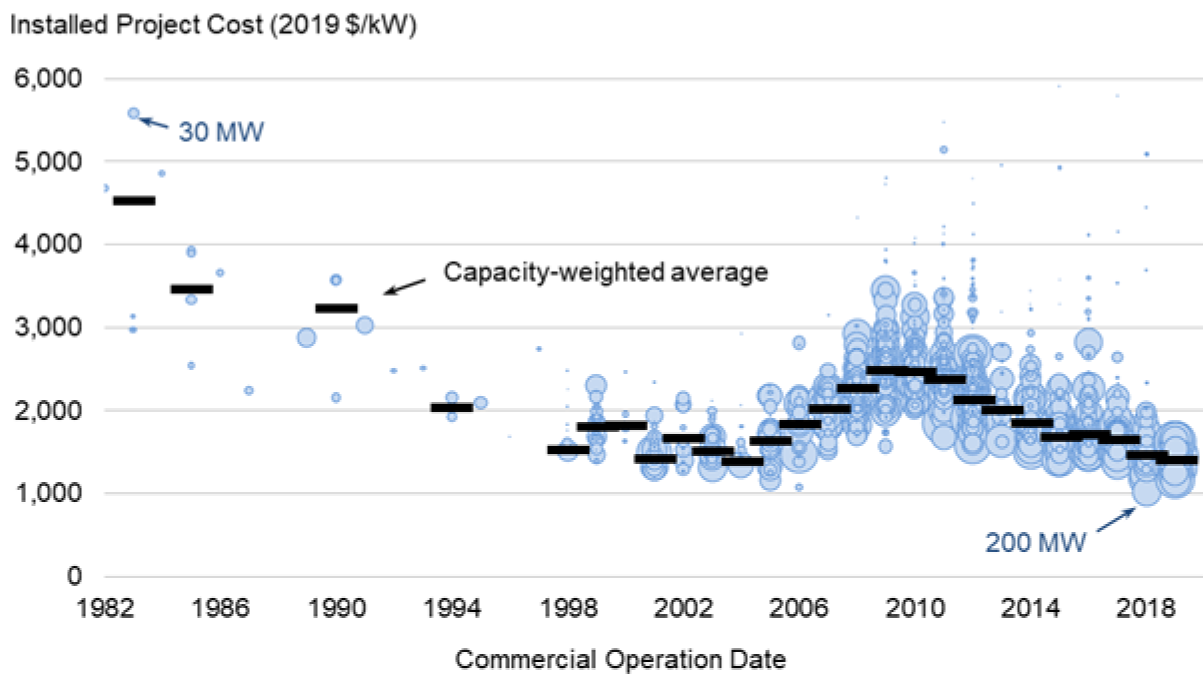


Figure 2-3: Installed wind power project costs over time (Source: LBNL [10])

Figure 2-4 shows the O&M costs of electricity generating plants according to the EIA February 2020 estimates. EIA estimates the variable O&M to be zero for all three categories of wind farms modeled (wind farms in the Great Plains, coastal wind farms and off-shore wind farms). The fixed O&M for wind farms is estimated as follows $26/kW for wind farms in the Great Plains, $35/kW for coastal wind farms and $110/kW for off-shore wind farms.

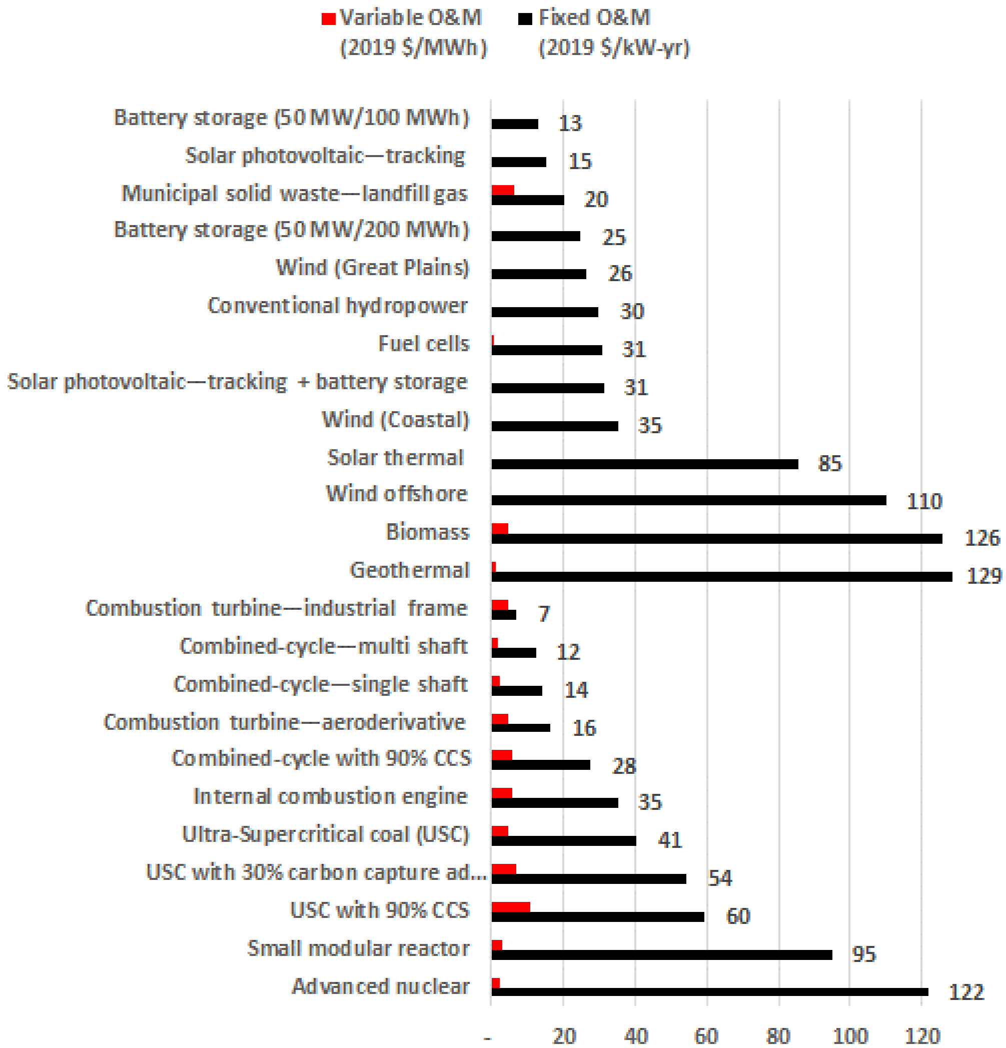


Figure 2-4: Generating technologies O&M costs (Data source: EIA [9])

Figure 2-5 shows the project-level O&M costs by commercial operation date in the *2018 Wind Technologies Market Report.* It represents the O&M costs in $/kW/yr for the 83 installed wind power projects totaling 11,062 MW with commercial operation dates between 1983 and 2017 in the LBNL database for which 2018 O&M data is available. 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 2018, using however many years of available data for that period. According to LBNL 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 $72/kW/yr, which dropped to $60/kW/yr for the 37 projects installed in the 1990s, to $29/kW/yr for the 65 projects installed in the 2000s, and stayed at $29/kW/yr for the 42 projects installed since 2010.

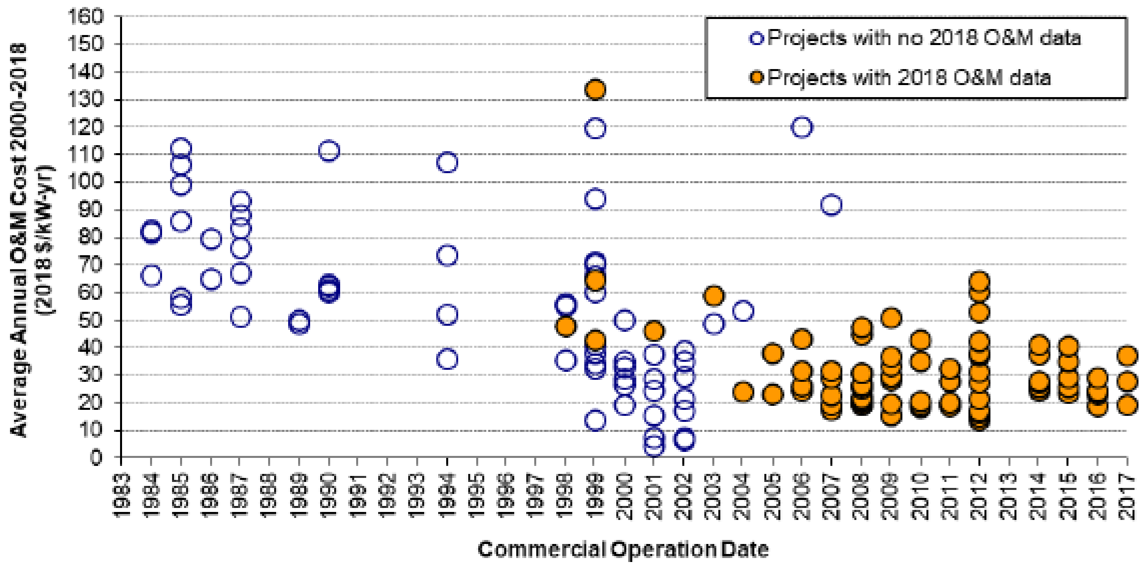


Figure 2-5: Average O&M costs for available data years (Source: LBNL [11])

Figure 2-6 shows a comparison between the wholesale value (capacity and energy) of wind across seven regional electricity markets and nationwide generation-weighted levelized wind power purchase agreement (PPA) prices based on the year the PPA was executed. The wholesale value of wind is obtained using the regional hourly wind output profiles and the real-time hourly wholesale energy prices at the nearest pricing point. As can be seen in the figure, the average value of wind has declined in the last decade and then increased in the last two years. With the sharp drop in wholesale electricity prices in 2009 precipitated by the 2007-2008 financial crisis, wind PPA prices exceeded the market value of wind energy in the period between 2009 and 2012. The declining prices of wind PPAs came back to within the range of wind's market value in 2013 and has mainly remained that way to date. The upwards trend in wind's market value in 2017 and 2018 caused some PPAs to be lower than wind's market value in a majority of the markets, making wind energy very competitive. During those years when the PPA prices were higher than the value of wind energy, wind energy's competitiveness was aided by the federal production tax credit.

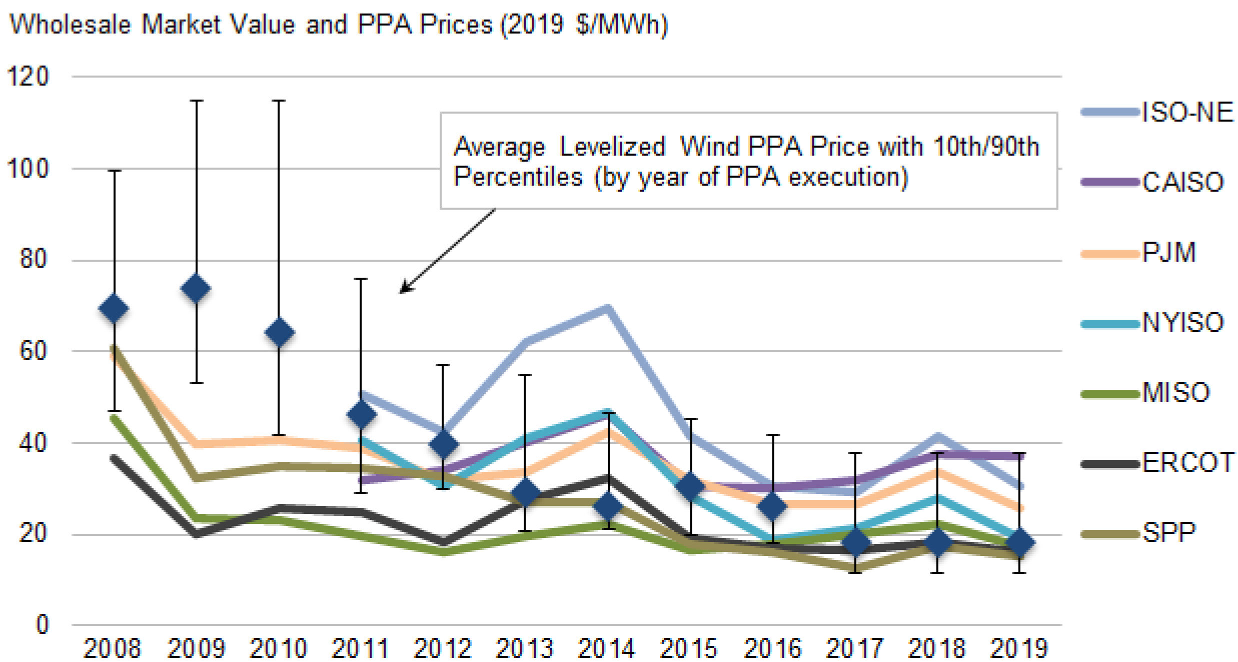


Figure 2-6: Wholesale energy value of wind (Source: LBNL [10])

2.3 State of wind energy nationally

As can be seen in Figure 2-7, U.S. installed wind energy capacity has increased steadily from 2,472 MW total installed capacity at the end of 1999 to 109,919 MW total installed capacity at the end of June 2020. In that period wind energy has grown to rival hydroelectricity as the nation's main source of renewable electricity. In 2019 wind for the first time overtook hydroelectricity as the largest source of renewable electricity generation in the U.S. The 300 GWh of electricity generated from wind constituted 40 percent of renewable generation while hydroelectricity's 268 GWh constituted 38 percent of the renewable electricity generated. Solar generation's 72 GWh constituted 10 percent of the renewable generation in 2019.

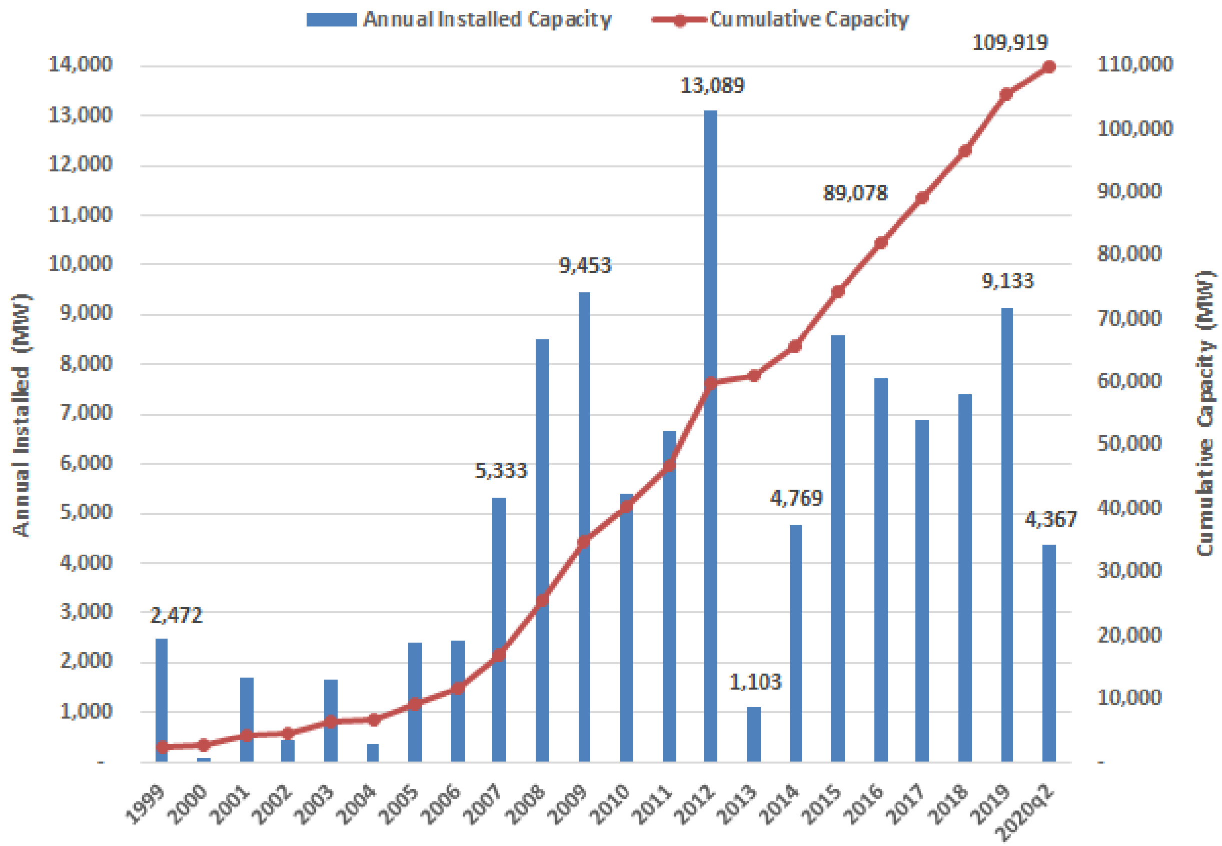


Figure 2-7: U.S. wind capacity growth (Sources: DOE [12], AWEA [13])

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. 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. The PTC was subsequently extended by the Taxpayer Certainty and Disaster Tax Relief Act 2019 to include projects starting construction in 2020 with the credit set at 40 percent of its full value for projects commencing construction in 2020.

Figure 2-8 is a map showing the states that have enacted some form of renewable or clean energy 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. Three states have binding clean energy standards while two states have non-binding clean energy goals. Clean energy standards and goals differ from renewable portfolio standards in that in addition to renewable resources include low carbon resources such as nuclear energy, coal-bed methane that are deemed to contribute to a reduction in net greenhouse gas emissions.

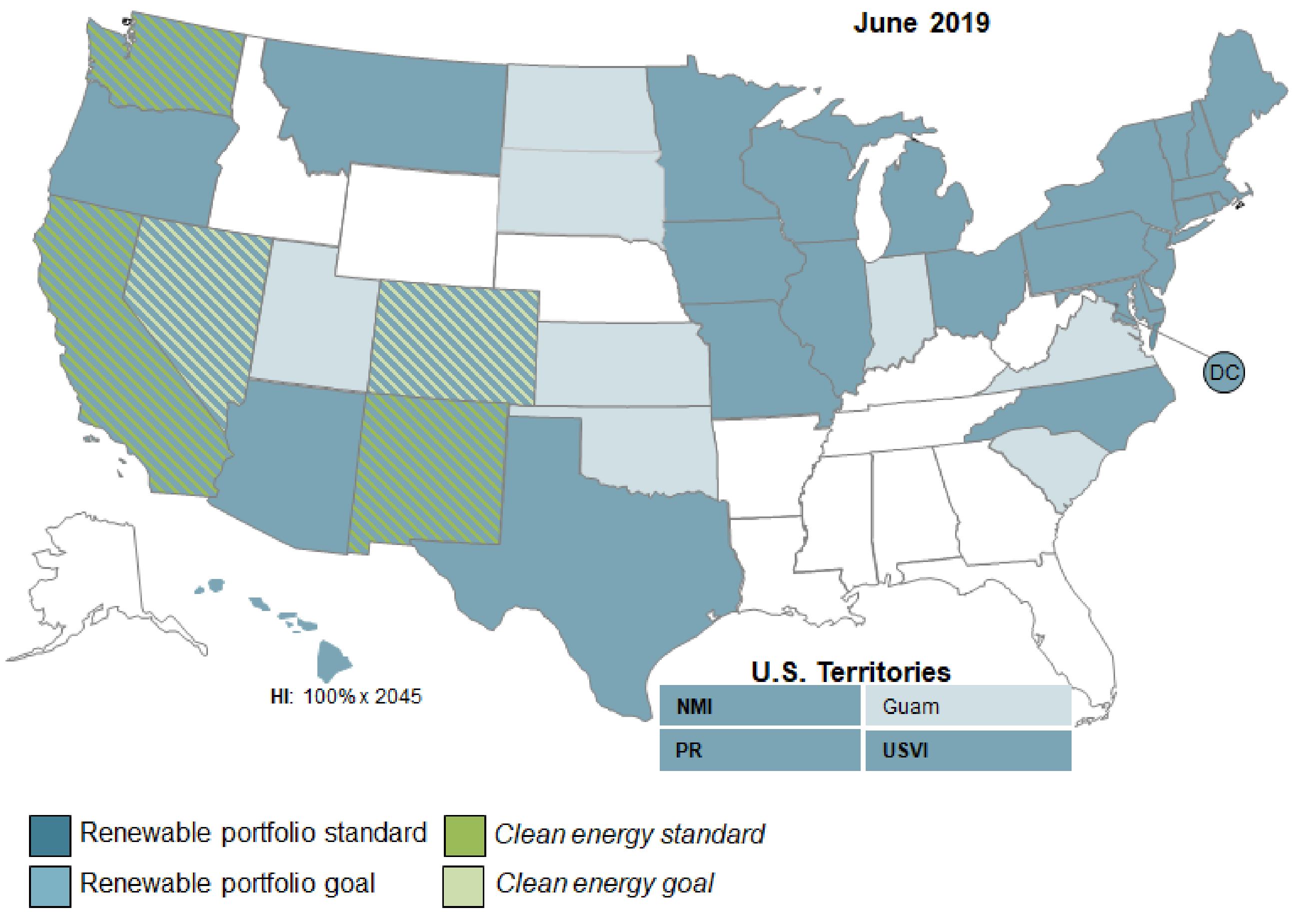


Figure 2-8: Renewable portfolio standards across the U.S. (Source: DSIRE [14])

Figure 2-9 shows the cumulative capacity of utility-scale wind farms installed in the U.S. by state as of the end of the first quarter of 2020. Texas continued to lead with a total capacity of 29,407 MW installed, two and a half times more than its closest follower Iowa, which had 10,664 installed. Oklahoma followed closely with 8,173 MW installed. Indiana ranked 13th overall with 2,317 MW of utility-scale wind capacity.

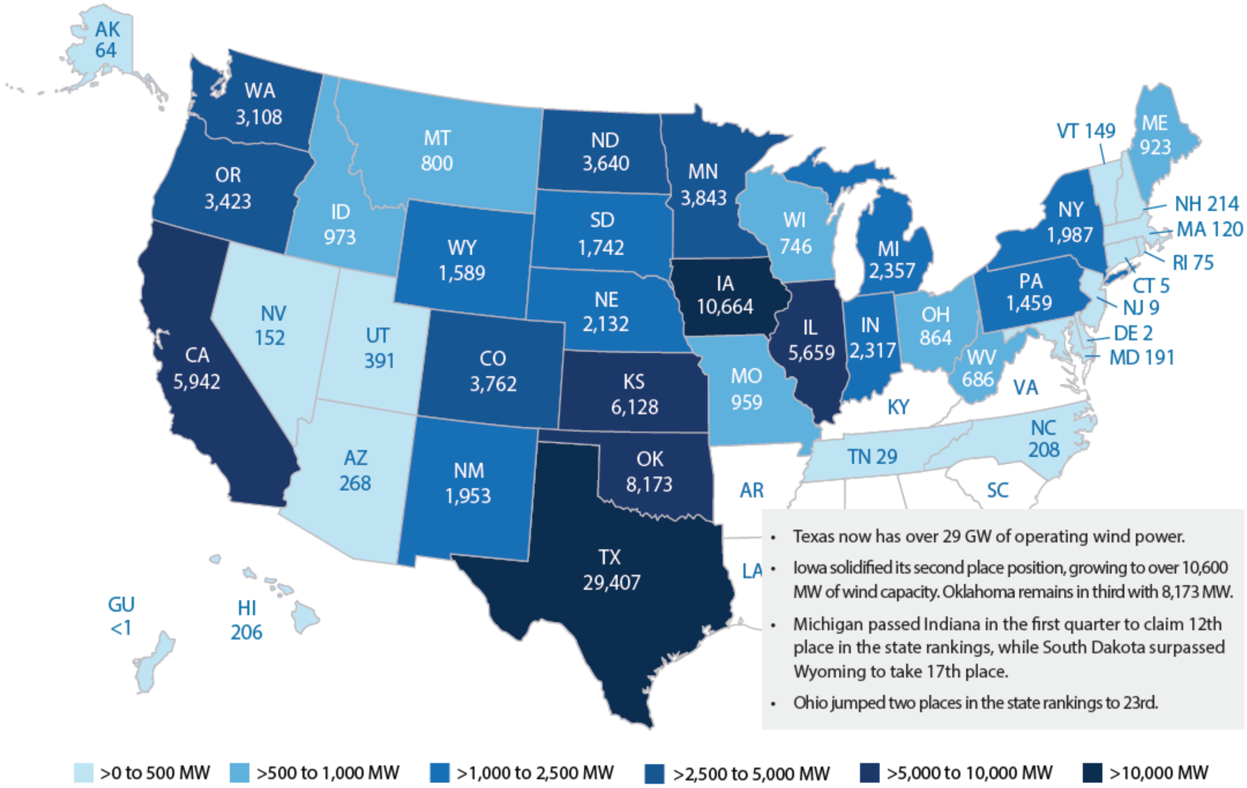


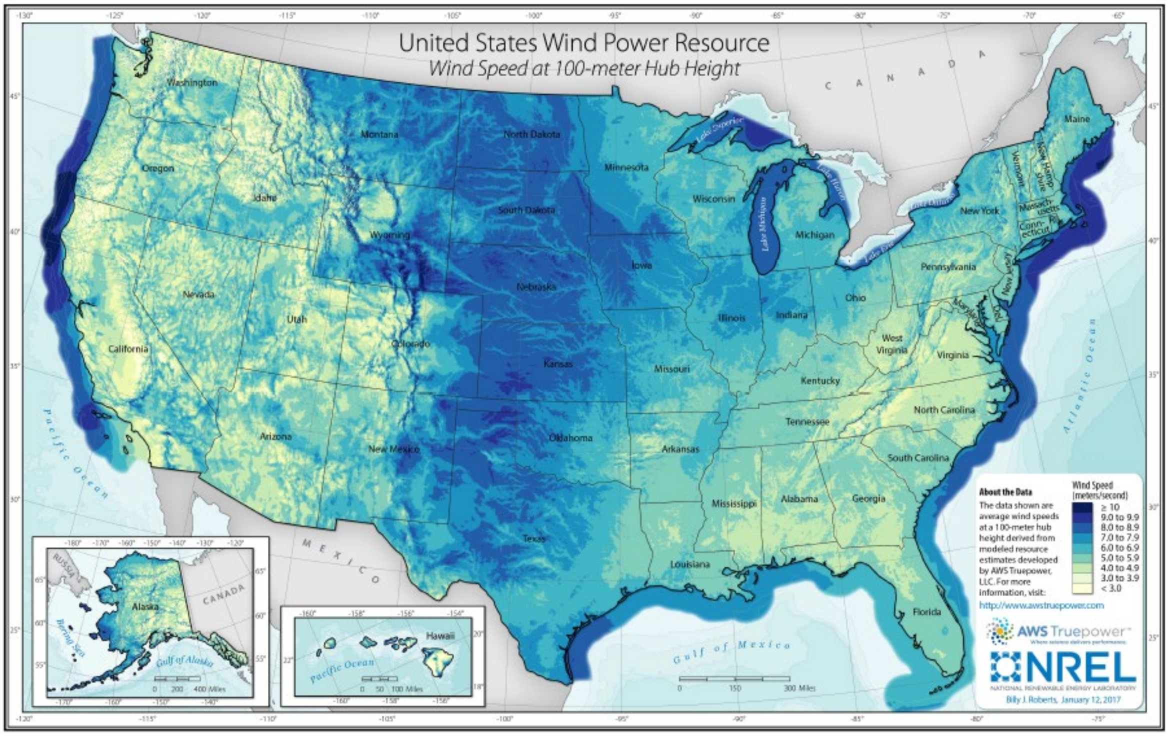
Figure 2-9: Wind power capacity by state at the end of March 2020 (MW) (Source: AWEA [13])

While Texas led in capacity installed, Iowa led in percentage of electricity generated by wind in 2019 at 42 percent. Kansas followed closely with wind contribution to electricity generated in Oklahoma at 41.4 percent. Indiana ranked 21st overall in share of wind in the electricity generation in 2019 at 6 percent which was lower than the 7 percent wind contribution to the national electricity generation in 2019. Table 2-2 shows the top twenty-five rankings in wind energy capacity installed and wind electricity generation share of instate electricity generation.

State	Installed Wind Capacity March 2020 (MW)		State	Wind Share of Electricity Generation 2019 (Percent)
Texas	29,407		Iowa	42.0
Iowa	10,664		Kansas	41.4
Oklahoma	8,173		Oklahoma	34.6
Kansas	6,128		North Dakota	27.5
California	5,942		South Dakota	23.9
Illinois	5,659		Maine	23.8
Minnesota	3,843		Nebraska	19.9
Colorado	3,762		New Mexico	19.5
North Dakota	3,640		Colorado	19.4
Oregon	3,423		Minnesota	19.1
Washington	3,108		Vermont	17.6
Michigan	2,357		Texas	17.5
Indiana	**2,317**		Idaho	16.2
Nebraska	2,132		Oregon	11.5
New York	1,987		Wyoming	9.8
New Mexico	1,953		Montana	8.6
South Dakota	1,742		Illinois	7.6
Wyoming	1,589		California	7.3
Pennsylvania	1,459		Washington	7.3
Idaho	973		Hawaii	6.0
Missouri	959		**Indiana**	**6.0**
Maine	923		Michigan	5.0
Ohio	864		Missouri	3.8
Montana	800		New York	3.3
Wisconsin	746		Rhode Island	2.9

Table 2-2: U.S. wind power rankings: top 25 states (Data source: AWEA [13, 15]

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 33 million gigawatt hours (GWh). This is approximately eight times the electricity generated from all sources in the U.S. in 2019 [16, 17]. Figure 2-10 shows the distribution of the wind resource.



<u>Figure 2-10:</u> <u>100-meter U.S. wind resource map</u> (Source: DOE [18])

As can be seen in Figure 2-10 there is an abundance of wind energy resources along the U.S. coast lines and in the Great Lakes. Offshore winds tend to be of higher speed and steadier relative to onshore wind. According to a 2016 DOE assessment, the technically feasible capacity of offshore wind in the U.S. is approximately 2,000 GW and is capable of generating 7,200,000 GWh in a year. This is more than one and a half times the 4,118,050 GWh of electricity generated from all generation resources in the U.S. in 2019 [19].

The prospects for installation of offshore wind projects has improved substantially, and several states on the Eastern Seaboard have set ambitious targets for offshore wind to meet their renewable energy and climate mitigation goals. Their targets as of April 2020 are as shown in Table 2-3.

	Target Capacity (MW)	Target Date
New York	9,000	2035
New Jersey	7,500	2035
Virginia	5,200	2034
Massachusetts	3,200	2035
Connecticut	2,000	2030
Maryland	1,200	2030
Total	**28,100**	

Table 2-3: Off-shore wind capacity targets by states on the Eastern Seaboard (Source: AWEA [20])

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. The progress on the second off-shore wind project, the 800 MW Vineyard Wind Farm located off of the coast of Massachusetts, has had its 2022 targeted online date suffer a significant setback when the Federal Government's Bureau of Ocean Energy Management revised its expected Fall 2019 permit approval date to now December 2020. This pushes back the commissioning date of the Vineyard project to at least 2023 [21].

A 21 MW demonstration project, the Icebreaker, is being developed jointly by DOE and Fred Olsen Corporation in Lake Erie offshore near Cleveland, Ohio. The project will study the challenges unique to offshore wind projects in fresh water bodies such as fresh water ice. The project's construction start is planned for the summer of 2022 [22].

2.4 Wind energy in Indiana

Since the installation of the first utility scale wind farm in Benton County in 2008, Indiana's wind generating capacity has grown steadily, increasing from 131 MW in 2008 to 2,314 MW at the end of 2019 and 3,453 MW when all of the five wind farms currently under construction are completed. Four wind farms with a combined nameplate capacity of 832 MW are expected to be completed before the end of 2020, the largest single year capacity addition since 2009. One wind farm with a capacity of 307 MW, currently under construction in White County, is scheduled to be completed in 2021. In addition to the utility scale wind farms, there is 6.95 MW of small wind projects connected through net metering and feed-in tariffs offered by Indiana utilities. Figure 2-11 shows the utility-scale wind capacity installed or under construction as of August, 2020.

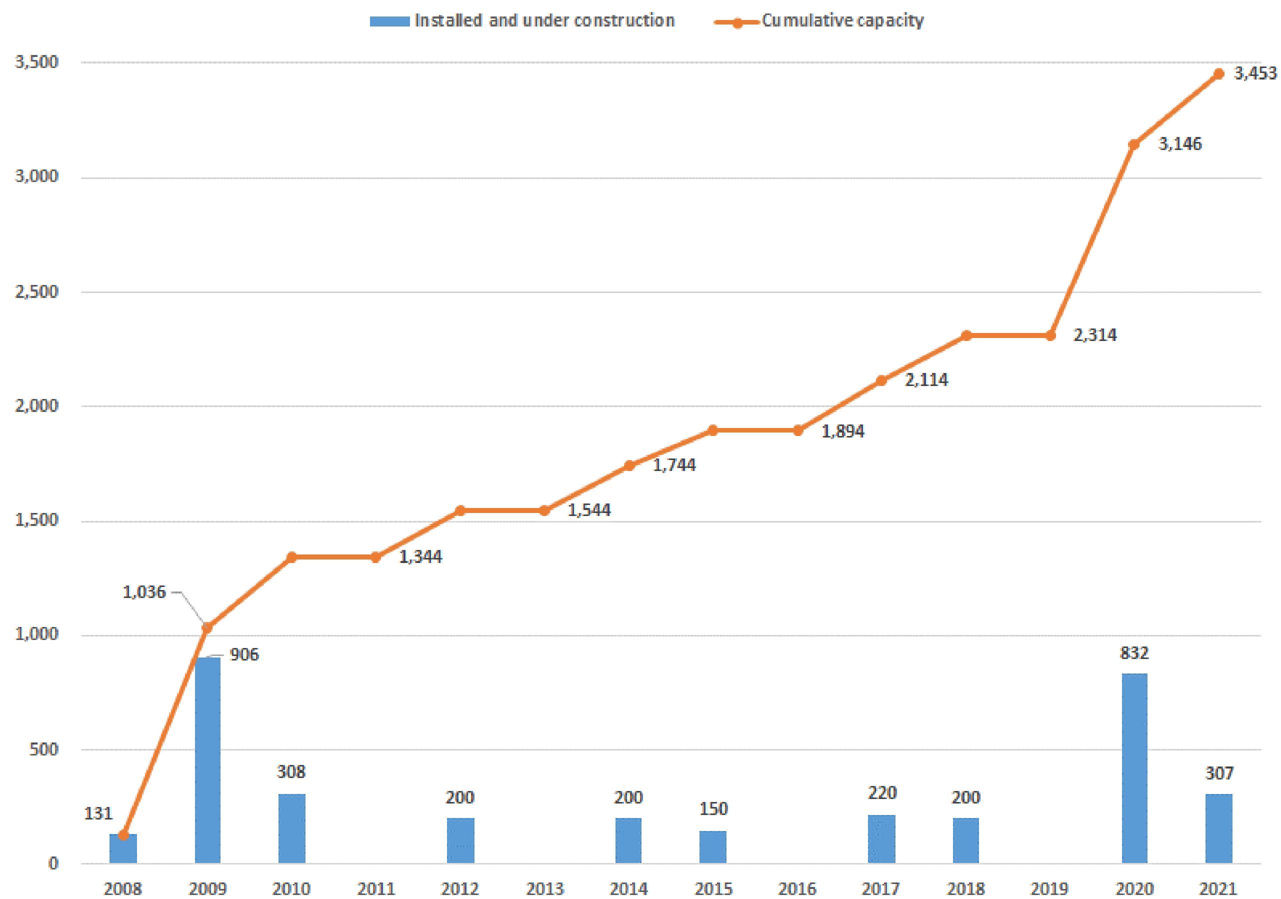


Figure 2-11: Wind energy capacity in Indiana (Data source: IURC [23]).

Table 2-4 is a list of utility scale wind farms in Indiana. Fifteen of the wind farms, with a combined capacity of 2,314 MW are operational. Five wind farms with a combined capacity of 1,139 MW were under construction at the writing of the report while two proposed wind farms with a combined capacity of 300 MW had not yet started construction.

Project Name	County	Capacity (MW)	In-Service Date
Operating projects			
Benton County Wind Farm	Benton	130.5	2008
Fowler Ridge Wind Farm I	Benton	301.3	2009
Fowler Ridge Wind Farm II-A	Benton	199.5	2009
Fowler Ridge Wind Farm III	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 Windfarm 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 Wind Farm	Jay/Randolph	119	2017
Meadow Lake Wind Farm VI	White	200	2018
	Total operating projects	**2,314**	
Project under construction			
Headwaters II Wind Farm	Randolph	200	Sep 2020
Jordan Creek Wind Farm	Warren	400	Nov 2020
Bitter Ridge Wind Farm	Jay	130	Dec 2020
Rosewater Wind Farm	White	102	Dec 2020
Indiana Crossroads Wind Farm	White	307	Dec 2021
	Total projects under construction	**1,139**	
Proposed projects (not yet filed with IURC)			
Gibson	Gibson	200	
Plum Tree	Huntington	100	

Table 2-4: Indiana wind farms; operating, under construction and proposed (Data source: IURC [23])

As of August 3, 2020, Indiana utilities had a total 2,267 MW[7] of wind power contracted on power purchase agreements (PPAs). Out of the total PPAs, 1,847 MW (81 percent) is with Indiana wind farms and 420 MW (19 percent) with wind farms in Iowa, Illinois, Minnesota and South Dakota. Table 2-5 shows the wind capacity contracted to Indiana utilities.

Utility	Project	State	Power Purchase Agreement (MW)
Duke Indiana	Benton County	Indiana	110.7
I&M	Fowler Ridge I	Indiana	100.4
I&M	Fowler Ridge II	Indiana	50
Vectren	Benton County	Indiana	30
Vectren	Fowler Ridge II	Indiana	50
I&M	Headwaters I	Indiana	200
I&M	Wildcat I	Indiana	100
I&M	Bluff Point	Indiana	119
IPL	Hoosier	Indiana	106
WVPA	Meadow Lake V and VI	Indiana	100
Hoosier	Meadow Lake	Indiana	75
NIPSCO	Rosewater (when completed in 2020)	Indiana	102
NIPSCO	Bitter Ridge (when completed in 2020)	Indiana	303.6
NIPSCO	Jordan Creek (when complete in 2020)	Indiana	400
NIPSCO	Barton	Iowa	50
NIPSCO	Buffalo Ridge	South Dakota	50.4
IPL	Lakefield	Minnesota	201
WVPA	Agriwind, Pioneer Trail, Harvest Ridge	Illinois	118.4
	Total Power Purchase Agreements		**2,267**

Table 2-5: Wind energy purchase agreements by Indiana utilities (Data sources: IURC [23], Hoosier [24], WVPA [25])

In addition to the power purchase agreements in Table 2-5 three Indiana wind farms have signed a total of 349 MW in virtual power purchase agreements with corporate clients as shown in Table 2-6. Virtual power purchase agreements are financial instruments where the power purchaser buys the power and the renewable energy credits at a fixed price from a wind farm without receiving delivery of the power, while the wind farm sells the power into the wholesale market at the market price. If the market price is higher than the agreed virtual PPA price the wind farm

[7] This includes 805.6 MW contracted from wind farms currently under construction.

pays the virtual client the difference and conversely if the market price is less than the virtual PPA price the client pays the wind farm the difference.

Wind Farm	**Buyer**	**Virtual Power Purchase Agreement (MW)**	**Year**
Fowler Ridge Wind Farm Phase IV	Amazon Web Services	150	2015
Headwaters Wind Farm Phase II	Facebook	139	2020
Headwaters Wind Farm Phase II	Walmart	60	2021

Table 2-6: Wind energy virtual purchase agreements by Indiana utilities (Data sources: IURC [23])

Figure 2-12 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 2-13 shows the distribution of the wind resource at 50 m, a height at which smaller scale community wind projects operate.

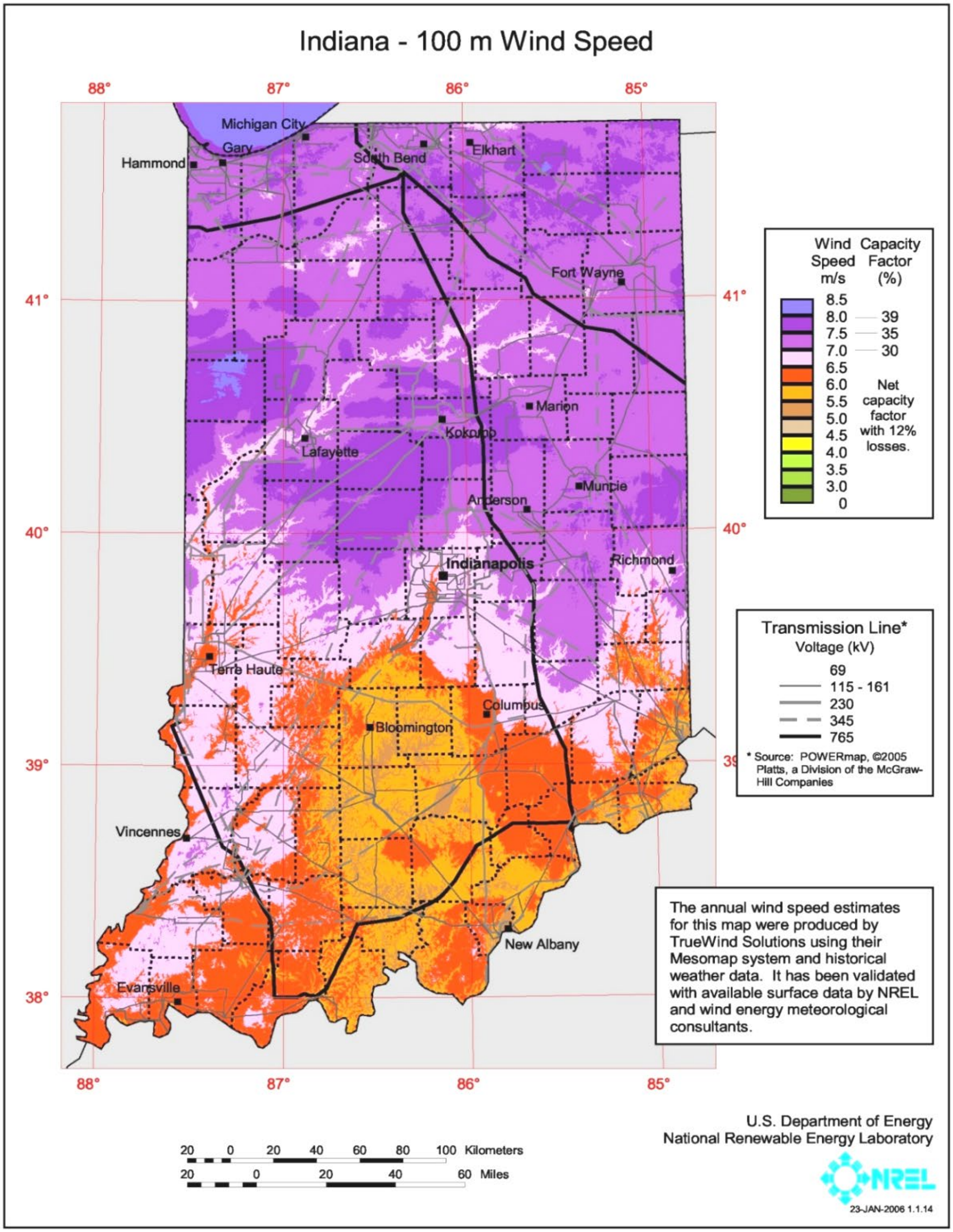


Figure 2-12: Indiana wind speed at 100 meters height (Source: OED/NREL [26])

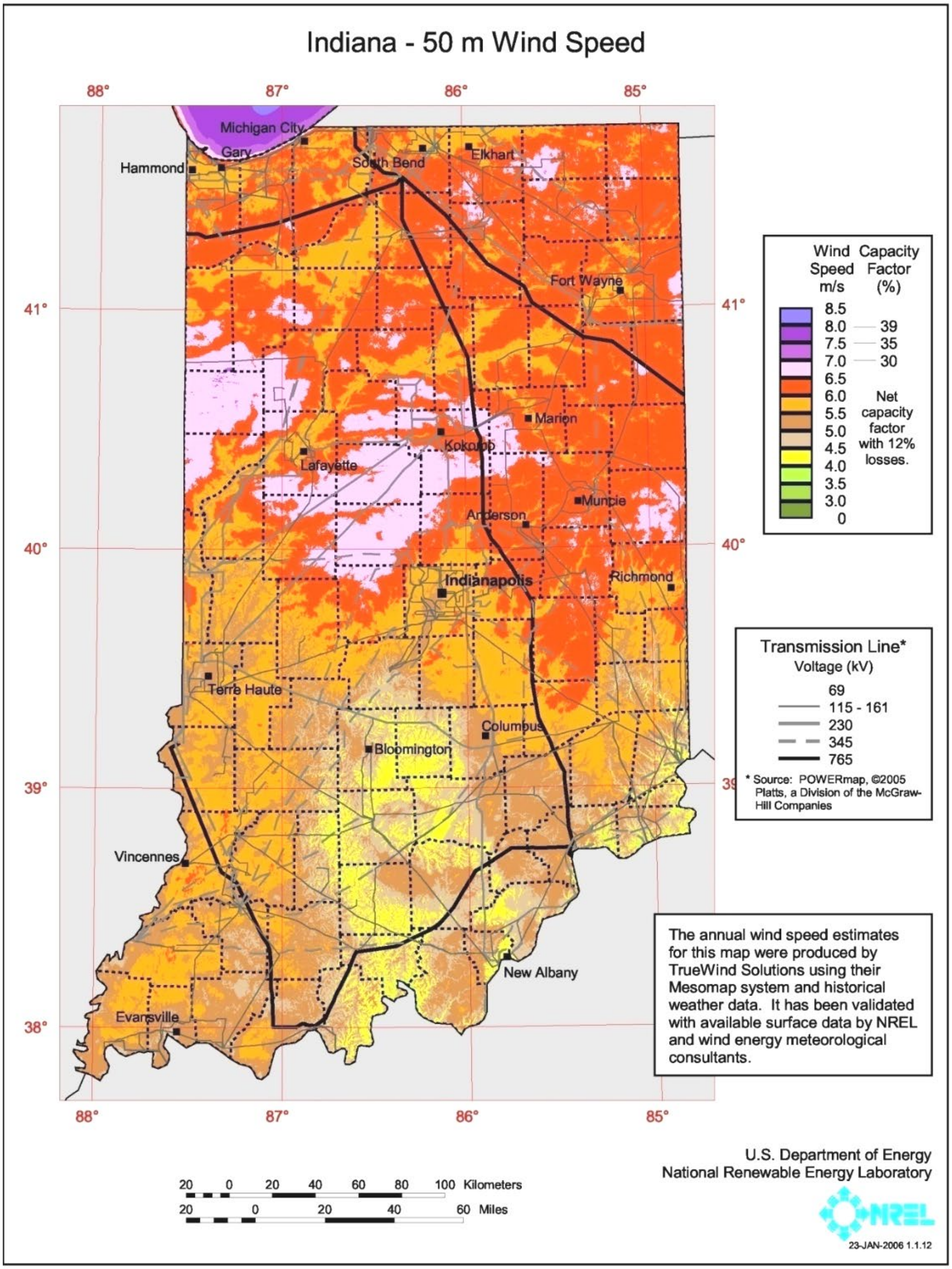


Figure 2-13: Indiana wind speed at 50 meters height (Source: OED/NREL [26])

With the rapid expansion of utility scale wind farms in Indiana and across the U.S., resistance has arisen in some communities resulting in the writing of local government ordnances restricting their installation in some counties. One such local ordinance was passed in Tippecanoe County in May 2019 restricting the maximum height of wind turbines to 140 feet. This effectively bans utility scale windfarms, since the typical utility-scale wind turbine tower ranges anywhere from 300 to 600 feet [27].

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 factor supplied by the IRS for the calendar year. 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. The tax credit was extended to the end of 2020 by the Taxpayer Certainty and Disaster Tax Relief Act of 2019 and the credit for projects commencing construction in 2020 is set at a 40 percent reduction from the full amount. The resulting tax credits are as follows: 1.8 cents/kWh for projects commencing construction in 2017, 1.4 cents/kWh for projects commencing construction in 2018, 1.0 cents/kWh for projects commencing construction in 2019 and 1.5 cents for projects commencing construction in 2020 [14, 28, 29].
- Residential Renewable Energy Tax Credit is a personal tax credit that credits up to 30 percent of expenditures, with no maximum credit, on wind systems installed on residential properties. The tax credit scales down to 26 percent in 2020, 22 percent in 2021 and expires at the end of 2021. The home on which the wind system is installed does not have to be the taxpayer's principal place of residence [14].
- Business Energy Investment Tax Credit (ITC) credits wind projects with 30 percent of their construction cost in lieu of the production tax credit. The ITC for large wind projects was scaled down to 20 percent for projects which began construction in 2017, to 18 percent for projects beginning construction in 2018, 12 percent for projects beginning construction in 2019 and expired at the end of 2019. The ITC for small wind projects scales down to 26 percent for projects which begin construction in 2020, 22 percent for those which begin in 2021 and 2022 and expires at the end of 2022 [14].

- U.S. DOE Loan Guarantee Program (Section 1703, Title IV of Energy Policy Act of 2005) provides loan guarantees for large scale innovative, high technology risk renewable energy projects that reduce the emission of pollutants [14].
- Modified Accelerated Cost-Recovery System (MACRS) allows businesses to recover investments in qualified renewable energy technologies through depreciation deductions. In its history, bonus first year deprecation has been made available sporadically. The latest of these is a 100 percent first year depreciation for projects placed in service between September 27, 2017 to December 31, 2023 provided for by the Tax Cuts and Jobs Act of 2017 [14].
- USDA Rural Energy for America Program (REAP) promotes energy efficiency and renewable energy for agricultural producers and rural small businesses through the use of grants and loan guarantees for energy efficiency improvements and renewable energy systems. The program covers up to 25 percent of costs [14, 30].
- High Energy Cost Grant Program administered by USDA is aimed at improving the electricity supply infrastructure in rural areas having extremely high per-household energy costs; that is, 275 percent of the national average and above. Eligible infrastructure includes renewable resources generation [31].
- Green Power Purchasing Goal requires that 7.5 percent of energy used by federal agencies must be obtained from renewable resources [14].

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 [14]. Indiana Senate Enrolled Act 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 [14, 32].
- Renewable Energy Property Tax Exemption provides property tax exemptions for solar thermal, PV, wind, hydroelectric and geothermal systems [14].
- 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 [33].
- Sales and Use Tax Exemption for Electrical Generating Equipment exempts transactions involving manufacturing machinery, tools, and equipment used for the production of tangible personal property, which includes electricity, from state gross retail tax. However, only wind energy has clearly specified rules from the Department of Revenue [14].
- Clean Energy Portfolio Goal sets a voluntary goal of obtaining 4 percent between 2013 and

2018, 7 percent between 2019 and 2024, and 10 percent by 2025, of electricity from clean energy sources based on 2010 retail sales. Participation in the goal makes utilities eligible for incentives that can be used to pay for the compliance projects. The deadline to apply for incentives in the 2013 to 2018 period has expired [14].

- 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* [34].

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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.

<u>Perennial grasses</u> 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.

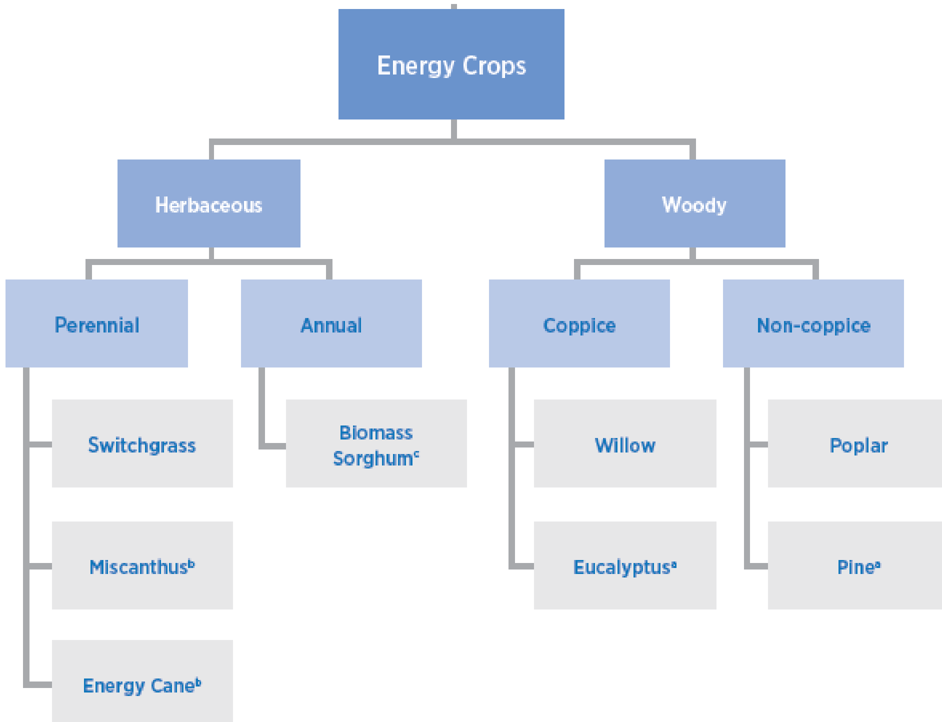
The Giant Miscanthus hybrid was developed in Japan and introduced to the U.S. as a landscape plant. The main attraction of Giant Miscanthus as an energy crop is its high level of biomass production. While a great deal of research has been done establishing its potential as an energy crop, there are still 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 an energy crop 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 (e.g. high in stalk sugar), 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 has funded 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 feedstocks and intermediate products to maximize the value obtained from the biomass feedstock.

There are currently 29 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 twelve pilot-scale projects these technologies are verified at a scale of at least one dry metric ton per 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, Inactive	Chemical
Gas technology Institute	Des Plaines, IL	Design, Inactive	Thermochemical-Pyrolysis
Algenol	Fort Myers, FL	Pilot	Algae*
American Process	Alpena, MI	Pilot	Biochemical
ADM	Decatur, IL	Pilot	Biochemical
BioProcess Algae	Shenandoah, IA	Pilot	Algae*
Frontline	Ames, IA	Pilot	Thermochemical-Gasification
Haldor Tropose	Des Plaines, IL	Pilot	Thermochemical-Gasification
ICM	St. Joseph, MO	Pilot	Biochemical
Mercurius	Ferndale, WA	Pilot	Hybrid
Renewable Energy Institute	Toledo, OH	Pilot	Thermochemical-Gasification
Solazyme	Peoria, IL	Pilot	Algae*
UOP	Kapolei, HI	Pilot	Thermochemical-Pyrolysis
Zeachem	Boardman, OR	Pilot	Thermochemical-Gasification
Flambeau River Biofuels	Parks Fall, WI	Demo	Thermochemical-Gasification
Lignol Innovations	Commerce City, CO	Demo	Biochemical
Myriant	Lake Providence, LA	Demo	Biochemical
NewPage	Wisconsin Rapids, WI	Demo	Thermochemical-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	Thermochemical-Gasification
INEOS / New Planet Bioenergy	Vero Beach, FL	Pioneer	Thermochemical-Gasification
Mascoma	Kinross, MI	Pioneer	Biochemical
POET Project Liberty	Emmetsburg, IA	Pioneer	Biochemical
Red Rock Biofuels	Lakeview, OR	Pioneer	Thermochemical-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 the price must 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[8] (willow and eucalyptus) and one rotated 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 each modeled as growing on an 8-year rotation, 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[9] 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 to the market in 2030 is from energy crops, primarily herbaceous energy crops, and 70 percent of the 588 million tons offered to the market in 2040 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.

[8] 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.

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

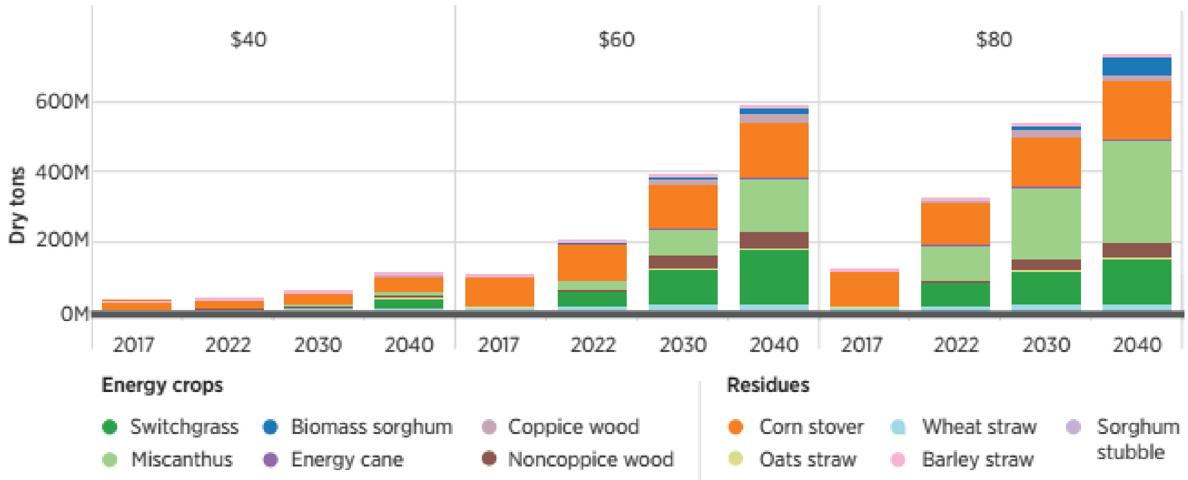


Figure 3-2: Production of energy crops at various farm-gate prices for select years (Source: DOE [1])

Figures 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.

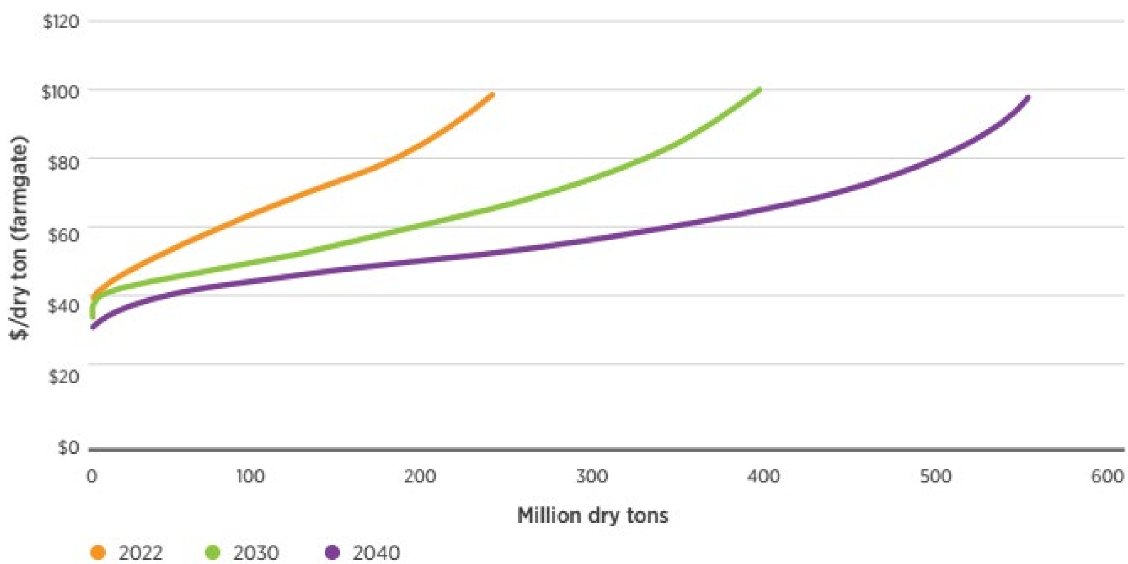


Figure 3-3: Supply curves of potential herbaceous energy crop production for select years under base-case assumptions (Source: DOE [1])

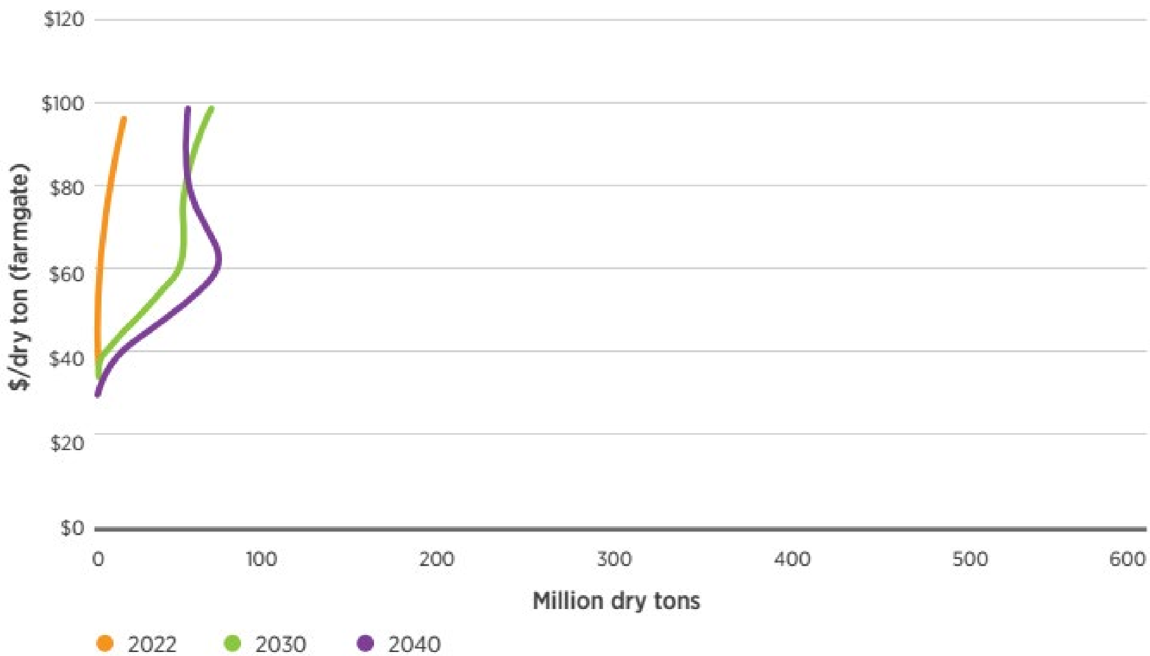


Figure 3-4: Supply curves of potential woody energy crop production for select years under base-case assumptions[10] (Source: DOE [1])

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 referenced 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,

[10] 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 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,
- 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. 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 (MMGY). Since then the capacity has grown to 1,250 MMGY in fourteen corn-ethanol plants. 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 operating ethanol plants in Indiana.

Company	Location	Capacity (MMGY*)
Cardinal Ethanol LLC	Union City	110
Central Indiana Ethanol LLC	Marion	60
Grain Processing Corp.-Washington wet mill	Washington	20
Green Plains-Mt. Vernon	Mt. Vernon	90
Iroquois Bio-Energy Co. LLC	Rensselaer	50
MGPI of Indiana	Lawrenceburg	35
Poet Biorefining-Alexandria	Alexandria	80
Poet Biorefining-Cloverdale (Temp Idle)	Cloverdale	90
Poet Biorefining-North Manchester	North Manchester	80
Poet Biorefining-Portland	Portland	80
South Bend Ethanol LLC	South Bend	65
The Andersons Clymers Ethanol LLC	Clymers	135
Valero Renewable Fuels-Bluffton	Bluffton	120
Valero Renewable Fuels-Linden	Linden	135

*MMGY denotes million gallons per year

Table 3-2: Ethanol plants in Indiana (Data source: Ethanol Producers Magazine [10], Renewable Fuels Association [11])

There are two biodiesel plants with a combined capacity of 90 million gallons per year operating in Indiana. They are the 9.42 MMGY Integrity Biofuels plant in Morristown and the 88 MMGY Louis Dreyfus plant in Claypool [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*.

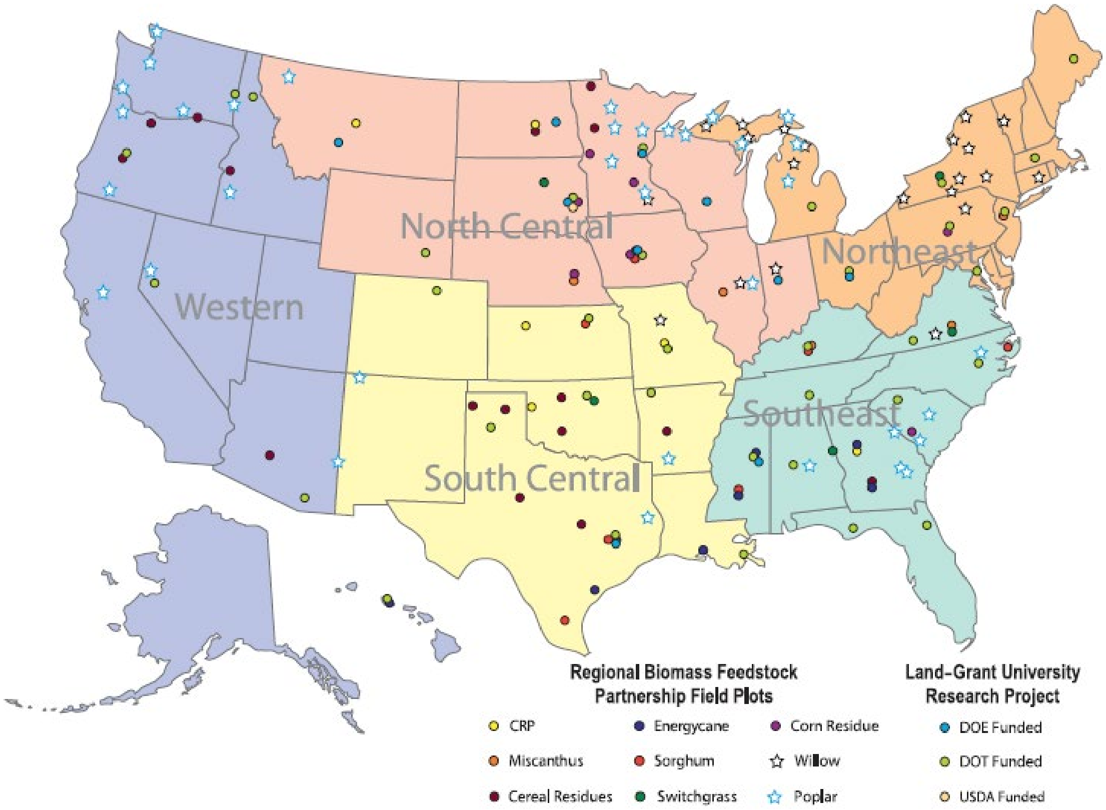


Figure 3-5: Bioenergy crop trial stations (Source DOE [17])

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 states 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.

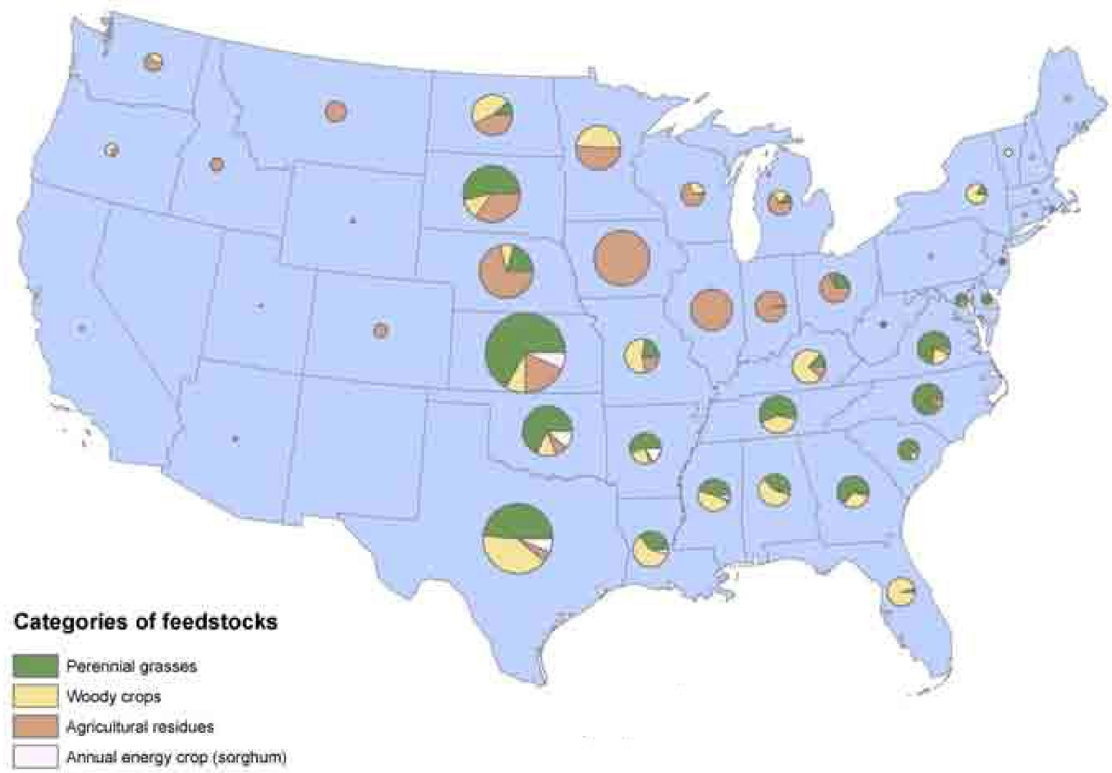


Figure 3-6: Estimated shares of energy crops and agricultural residues supplied at $60 per dry ton in 2030 (Source: DOE [4])

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.

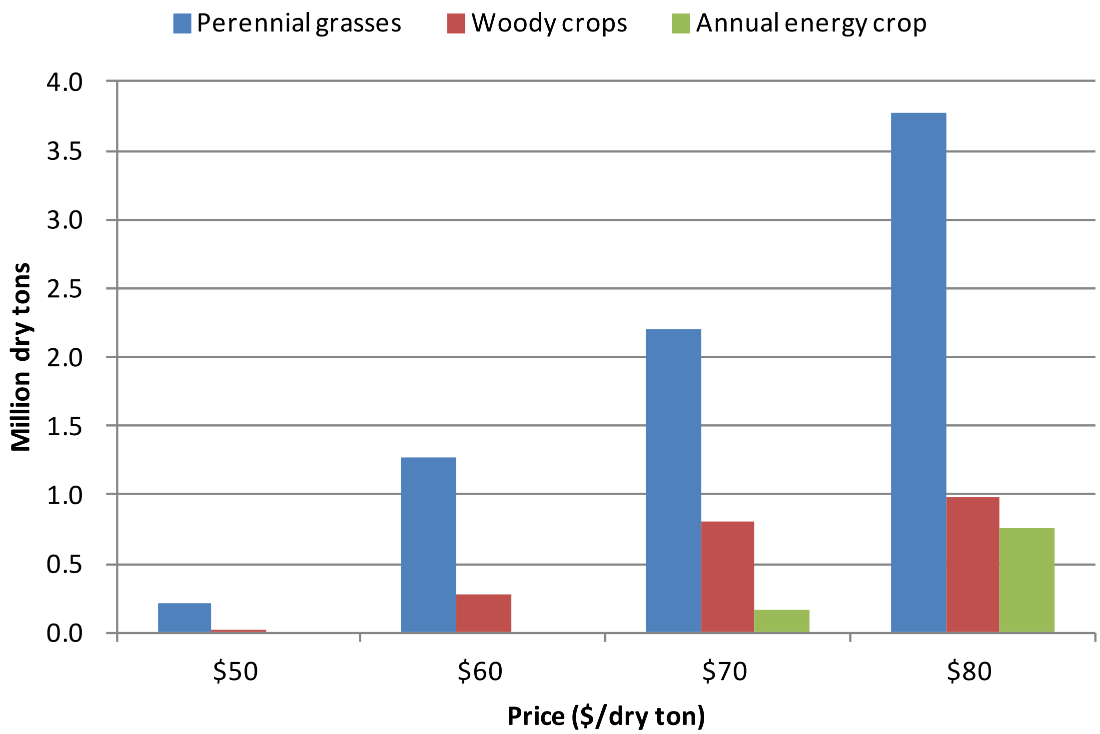


Figure 3-7: Projected production of energy crops in Indiana in 2030 (Data source: DOE [20])

In a 2011 paper, Brechbill, Tyner and Ileleji of Purdue's College of Agriculture 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 [21]. 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. 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 [23, 24].

Farm Size (Hectares)	Custom	200	400	600	800
Average Cost ($/ton)	80.98	69.22	66.23	65.23	64.73

Table 3-3: Average farm-gate cost ($/ton) for producing switchgrass in Indiana (Data source: Brechbill, Tyner & Ileleji [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. [24])

3.5 Incentives for energy crops

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

Federal Incentives

- Renewable Electricity Production Tax Credit (PTC) for dedicated energy crop energy systems (which fall under the category closed-loop biomass) credits 1.5 cents/kWh in 1993 dollars for the electricity produced, adjusted annually by inflation factors provided by the IRS. When the credit was extended in December 2019 by the Taxpayer Certainty and Disaster Tax Relief Act of 2019 closed-loop biomass and geothermal facilities, unlike wind energy, were allowed to continue drawing the full credit rate which was set at 2.5 cents/kWh for projects starting construction in 2019 [25, 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 [25].
- Modified Accelerated Cost-Recovery System (MACRS) allows businesses to recover investments in qualified renewable energy technologies through depreciation deductions. In its history, bonus first year deprecation has been made available sporadically. The latest of these is a 100 percent first year depreciation for projects placed in service between September 27, 2017 to December 31, 2023 provided for by the Tax Cuts and Jobs Act of 2017 [25].
- USDA Rural Energy for America Program (REAP) promotes energy efficiency and renewable energy for agricultural producers and rural small businesses through the use of grants and loan guarantees for energy efficiency improvements and renewable energy systems. The program covers up to 25 percent of costs [25, 27].
- High Energy Cost Grant Program administered by USDA is aimed at improving the electricity supply infrastructure in rural areas having extremely high per-household energy costs; that is, 275 percent of the national average and above. Eligible infrastructure includes renewable resources generation [28].
- USDA Biorefinery Assistance Program offers loan guarantees for the development, construction or retrofitting of commercial-sized biorefineries. The program finances 80 percent of the cost of the biorefinery up to a maximum of $250 million [25].
- Green Power Purchasing Goal requires that 7.5 percent of energy used by federal agencies must be obtained from renewable resources [25].

Indiana Incentives

- Net Metering Rule allows utility customers with renewable resource facilities with a maximum capacity of 1 MW to receive a credit for net excess generation in the next billing cycle [25]. Indiana Senate Enrolled Act 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 [25, 29].
- 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 [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 [25].
- Clean Energy Portfolio Goal sets a voluntary goal of obtaining 4 percent between 2013 and 2018, 7 percent between 2019 and 2024, and 10 percent by 2025, of electricity from clean energy sources based on 2010 retail sales. Participation in the goal makes utilities eligible for incentives that can be used to pay for the compliance projects. The deadline for applying for the 2013 to 2018 incentive has expired [25].
- 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 [31].

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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 crops. 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 MSW are typically used to produce electricity and heat. These feedstocks 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 wastewater 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 has a global warming potential 28 to 36 times that of carbon dioxide, 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, 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.

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 [2, 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 has the potential for recycling of water and nutrients in the production cycle,
- Algae have the potential for recycling of carbon dioxide from fossil fueled power plants and other industrial carbon dioxide emitters, and
- Algae is relatively easy to convert into fuels and products compatible with current transportation industry uses.

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. DOE has the strategic goal for an algal biofuel with a selling price of $2.50 per gasoline gallon equivalent [2, 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 to 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 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 2019 EIA plant cost estimates, the MSW power plant was listed as having the highest capital cost ($8,895/kW) among the technologies considered and the highest fixed O&M cost ($425/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 costs are much lower than that of MSW energy conversion facilities. The estimated cost of installing landfill gas projects by an Indiana utility is $1,406/kW, about 16 percent of the EIA estimate of the capital cost of MSW energy conversion facilities.

Like 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 on a large scale 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 Technologies Office has been under way since the early 2000s to build a national bioenergy industry. As a part of this effort in 2005 the 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 [8].

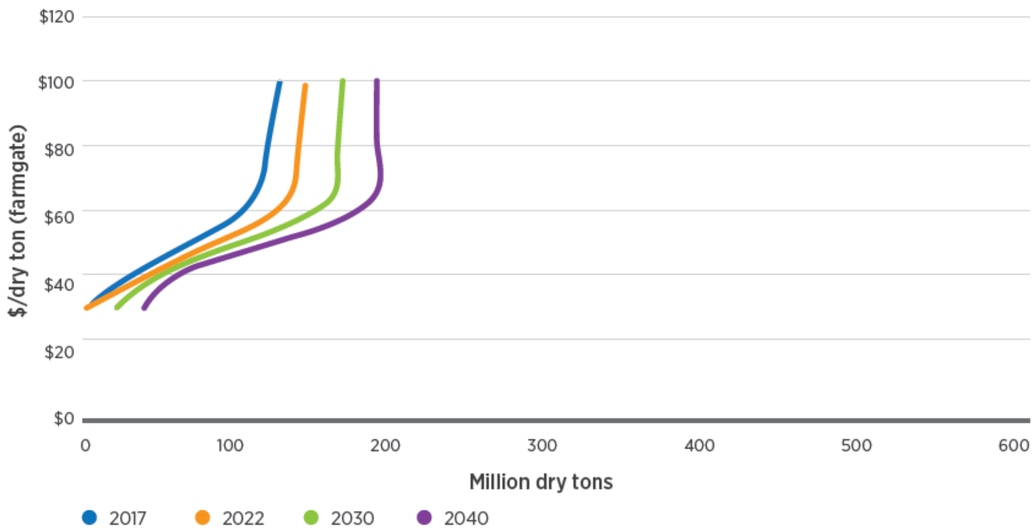


Figure 4-1 Supply curves of potential production from primary crop residues for select years under *2016 Billion-ton* study base-case assumptions[11] (Source: DOE [8])

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

[a]Current supply without regard to price

Table 4-1: Summary of secondary agricultural wastes potential at select prices and years under *2016 Billion-ton* study base-case assumptions (Source: DOE [8])

[11] 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 [9], 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.

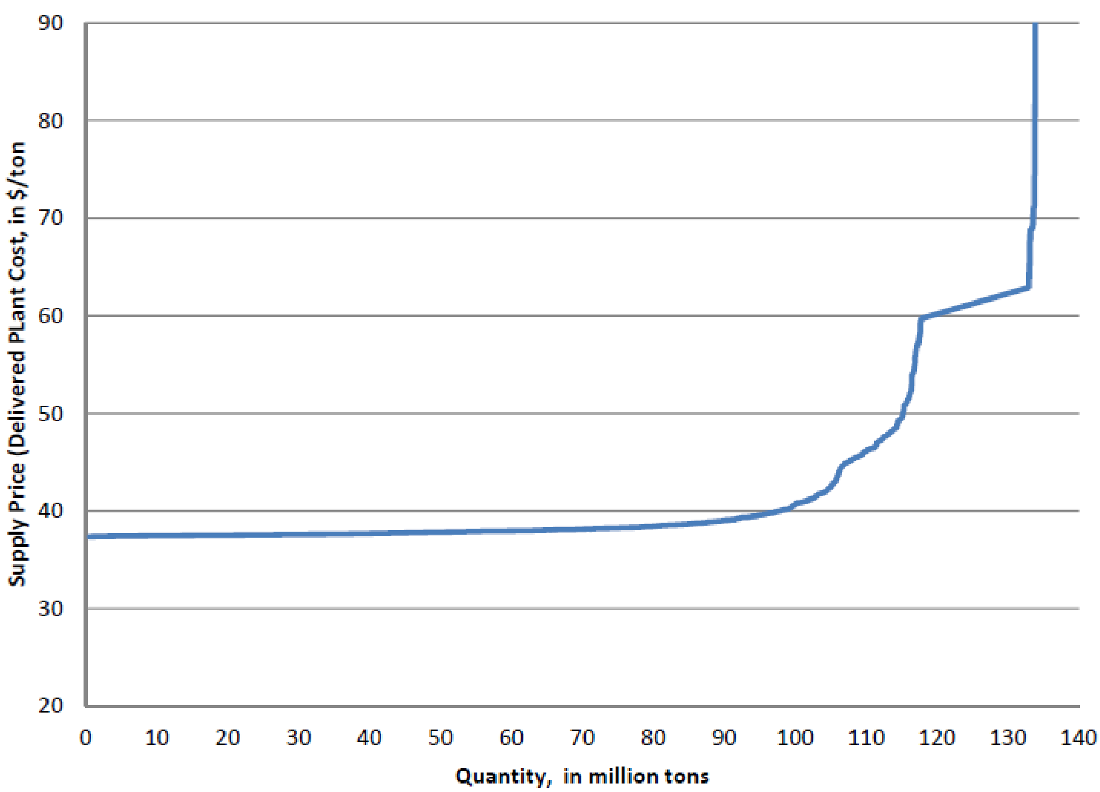
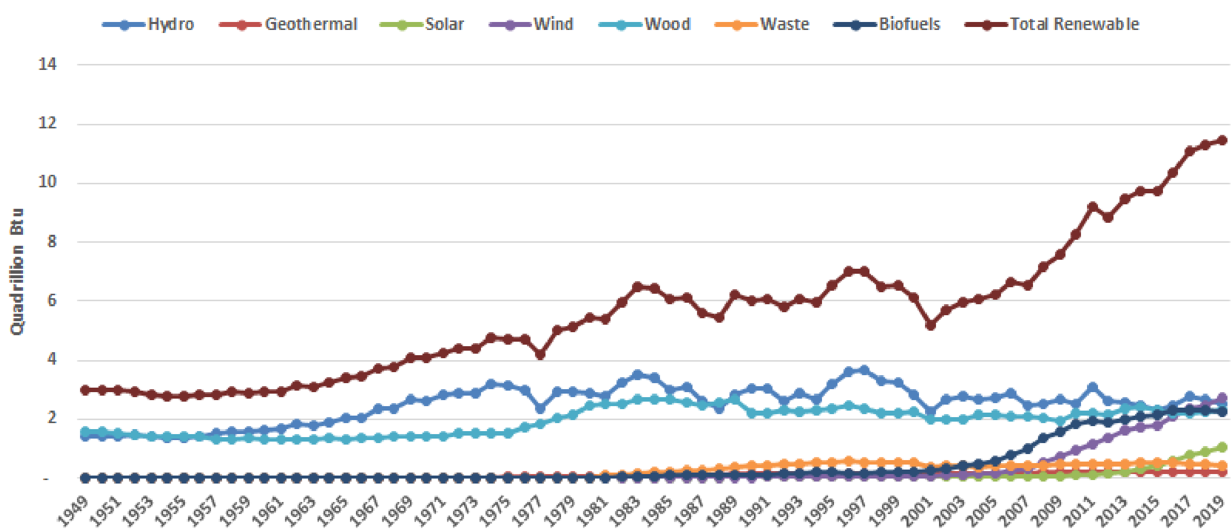


Figure 4-2: U.S. corn stover supply curve (Source: USDA [9])

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 developed and demonstrated, at a pilot level, technology improvements that, 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 [10].

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 third place as the source of renewable energy consumed in the U.S. Wood contributed 20 percent of the renewable energy consumed in 2018, behind wind energy's 24 percent and hydro's 22 percent.



<u>Figure 4-3:</u> <u>U.S. renewable energy consumption 1949-2019</u> (Source: EIA [11])

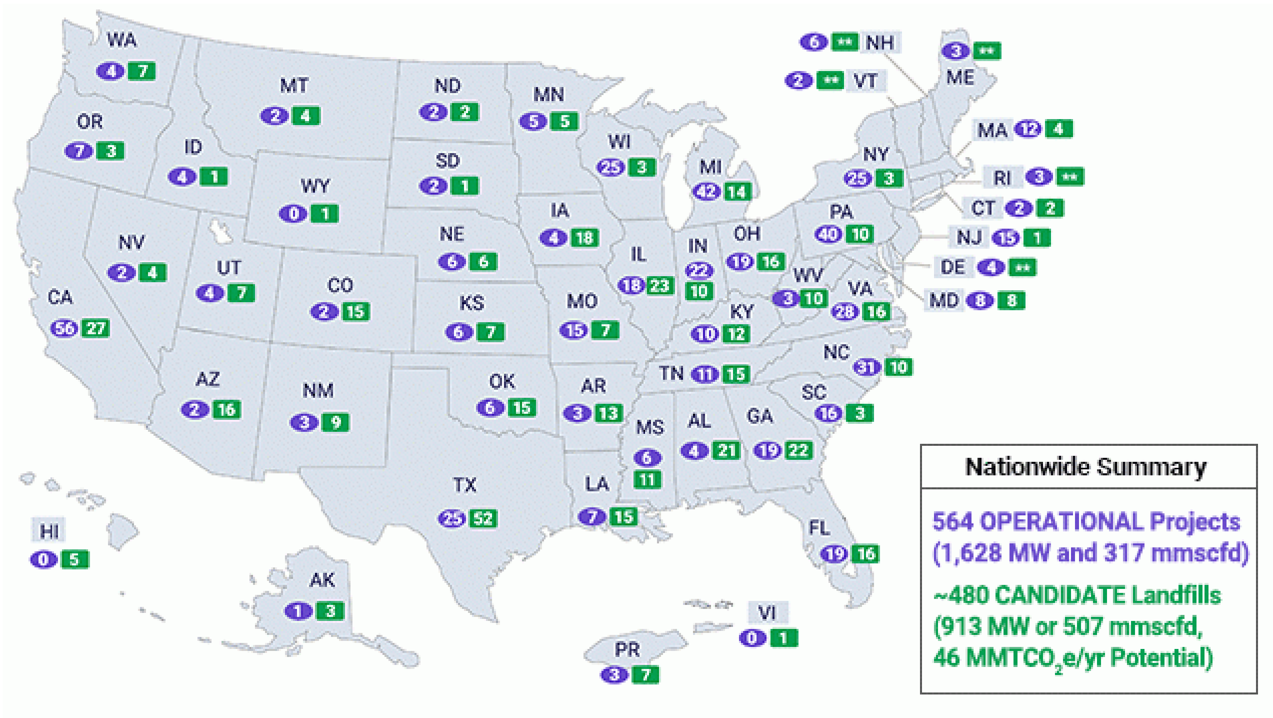
Although not as large a source as wood and wood-derived fuels, municipal solid waste (MSW) has also been a significant contributor to the nation's renewable energy mix. According to the national association of the waste to energy industry (the Energy Recovery Council) there were 75 MSW to energy plants operating in 21 states in the U.S. Of these plants, 58 had electricity as their only energy product; fourteen generated both electricity and steam, while three plants produced only steam. The combined electricity generating capacity installed in these plants was 2,534 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 2,725 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	2
Connecticut	5
Florida	11
Hawaii	1
Indiana	1
Iowa	1
Maine	3
Maryland	2
Massachusetts	7
Michigan	2

State	Number of facilities
Minnesota	8
New Hampshire	1
New Jersey	5
New York	10
Oklahoma	1
Oregon	1
Pennsylvania	6
Virginia	4
Washington	1
Wisconsin	2

Table 4-2: Location of the 75 solid waste to energy plants in the U.S. (Data source: Energy Recovery Council [12])

Another organic waste stream in use as a source of energy is landfill gas. According to the EPA there were 594 landfills with operational energy conversion projects with a combined capacity of 1,628 MW electricity generation and 317 million standard cubic feet per day (mmscfd) of gas for thermal energy production. In addition, there were 480 'candidate' landfills that have the size and capacity necessary to support energy projects. These candidate landfills have the potential for 913 MW of electricity generation or 507 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. as of March 2020 [13].



Legend
mmscfd – million standard cubic feet per day;
MMTCO$_2$e/yr – million metric ton of carbon dioxide-equivalent per year

Figure 4-4: Landfill gas projects (Source: EPA [13])

Livestock manure is currently in use as an energy source with 255 anaerobic digester biogas recovery systems in operation on livestock farms in the U.S. as of March 2020. The majority of these digesters (201) were on dairy farms, but there were also 36 on swine farms, six on poultry farms, four on beef cattle farms, four on combined cattle/swine farms, three on combined dairy/swine farms and one on a mixed cattle/swine/poultry farm [14]. In the 2018 *Market Opportunities for Biogas Recovery Systems at U.S. Livestock Facilities* report, EPA estimated that there were 8,113 dairy and swine farms that could support biogas recovery systems with a combined potential electric generating capacity of 1,667 MW supplying approximately 16 million MWh of electricity per year [15]. 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.

State	Number of Candidate Farms	Methane Emissions Reductions (Thousand Tons)	Methane Production Potential (Billion ft^3/year)	Energy Generation Potential (1,000 MMBtu/Year)	Energy Generation Potential (1,000 MWh/Year)
Swine Farms					
Iowa	2,174	331	24.30	22,430	2,070
North Carolina	761	192	12.21	11,266	1,040
Minnesota	691	64	7.64	7,052	651
Illinois	345	47	5.45	5,030	464
Indiana	302	34	4.11	3,795	350
Missouri	129	31	3.45	3,183	294
Nebraska	154	27	3.33	3,077	284
Oklahoma	45	49	3.26	3,013	278
Kansas	58	24	2.50	2,311	213
Ohio	226	15	1.73	1,594	147
Remaining 40 states	**525**	**102**	**9.46**	**8,733**	**806**
Swine Total:	**5,409**	**915**	**77**	**71,484**	**6,598**
Dairy Farms					
California	799	431	32.64	30,125	2,780
Idaho	179	138	11.56	10,668	985
Wisconsin	358	88	9.02	8,323	768
Texas	126	102	7.10	6,553	605
New Mexico	88	83	6.26	5,780	533
Washington	122	54	4.80	4,428	409
Michigan	138	47	4.79	4,420	408
Arizona	56	59	3.84	3,544	327
New York	126	32	3.29	3,033	280
Colorado	58	31	2.72	2,514	232
Remaining 40 states	**655**	**254**	**22.47**	**20,737**	**1,914**
Dairy Total:	**2,704**	**1,320**	**108**	**100,124**	**9,241**
Overall:	**8,113**	**2,234**	**186**	**171,608**	**15,838**

Table 4-3: Top ten states for potential electricity generation from swine and dairy farms (Source: AgStar [15])

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 [16]. 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

State	Number of Sites	Capacity (MW)
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 [16])

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 [17].

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 2018. 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 2018 waste biomass' contribution to Indiana's renewable energy mix (19 percent) fell to third place behind biofuel's 49 percent and wind's 27 percent.

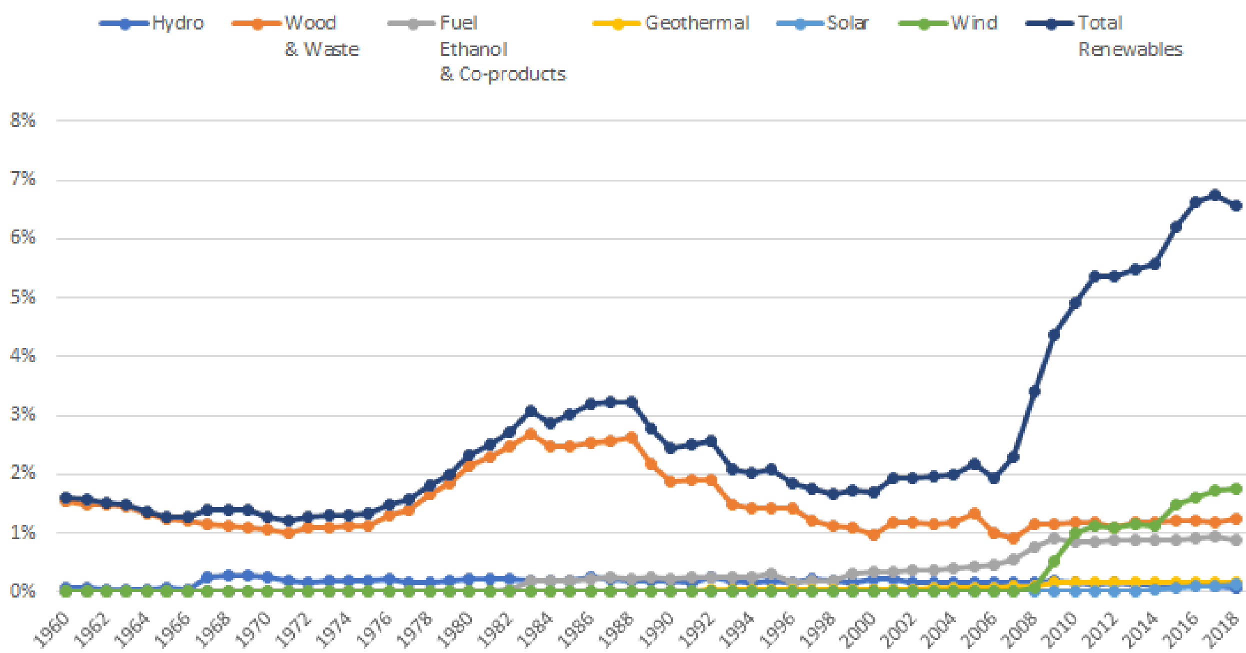


Figure 4-5: Renewables share of Indiana total energy consumption (1960-2018) (Data source EIA [18])

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 four million pounds of steam per day [19].

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 78.6 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 56 MW listed in the EPA database, is the most active user of landfill gas for electricity generation in Indiana. According to the WVPA website WVPA has 15 landfills with a combined 53.6 MW generating capacity [20].

Project Developer	Landfill Name	County	Rated Capacity (MW)	End User
Unknown	National Serv-All LF	Allen	6.4	General Motors
Aria Energy; Republic Services	County Line LF	Fulton	5.898	NIPSCO; WVPA
Granger Energy	South Side Landfill	Marion	5	Rolls-Royce
Energy Systems Group	Advanced Disposal Blackfoot	Pike	3.2	Vectren
Hoosier Energy	Clark-Floyd LF	Clark	2.14	Hoosier Energy
WVPA	Liberty Landfill	White	6.4	WVPA
WVPA	Earthmovers LF	Elkhart	4.8	WVPA
WVPA	Deercroft RDF	LaPorte	4	WVPA
WVPA	Deercroft RDF	LaPorte	3.2	WVPA
WVPA	Deercroft RDF	LaPorte	3.2	WVPA
WVPA	Jay County LF	Jay	3.2	WVPA
WVPA	Twin Bridges RDF	Hendricks	3.2	WVPA
WVPA	Twin Bridges RDF	Hendricks	3.2	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

Table 4-5: Electricity generating plants in Indiana landfills (Data source: EPA [21])

According to the WVPA website, WVPA owns and operates 14 landfill projects with a total of 49.6 MW and contracts for power from one 4 MW landfill project [20]. The projects listed on the WVPA website as shown in Table 4-6

Landfill Name	Capacity (MW)
Twin Bridges I	3.2
Twin Bridges II	3.2
Twin Bridges III	3.2
Twin Bridges IV	3.2
Prairie View I	3.2
Prairie View II	3.2
Deercroft II	3.2
Liberty I	3.2
Liberty II	3.2
Liberty III	6.4
Jay County	3.2
Oak Ridge	3.2
Earthmovers	4.8
Clinton	3.2
County Line*	4

*County Line project is on a power purchase agreement

Table 4-6: Wabash Valley Power Association landfill electricity projects (Data source: WVPA [20])

Giraldo, in his 2013 Master's thesis [22], 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 4-7.

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 4-7: Potential electricity generating capacity in Indiana landfills (Data source: Giraldo [22])

Another source of biomass fuel used for electricity generation in Indiana is the anaerobic digestion of animal manure. According to the EPA AgSTAR livestock digester database, there are ten such digesters in Indiana. Five of those digesters use the biogas to generate electricity, generating a combined average 111,000 MWh per year. In five of the farms the biogas is cleaned and pressurized into transportation fuel quality compressed natural gas (CNG) which can then be used as fuel for the milk transportation trucks. In addition to the digesters listed in the EPA AgSTAR database, SUFG is aware of digesters at the Culver Ducks Farm in Middlebury, Indiana that use the by-products from the duck processing plant to generate an average 9.960 MWh of electricity per year from three generators with a combined 1.2 MW generating capacity. Table 4-8 lists the location and some characteristics of these livestock-based digesters. The potential to expand biogas production from livestock farms in Indiana is substantial given that Indiana is ranked by the EPA among the top ten with an estimated potential for producing 3.5 billion cubic feet of biogas per year from livestock manure digesters in 296 farms [15].

Project Name	County	Animal Type and Population	Electricity Generated (MWh/yr)	Biogas Generation Estimate (ft^3/day)
Bio Town Ag, Inc. Digester	White	Cattle (4,500); Swine Other feedstocks	70,365	Cogeneration
Waste No Energy Digester	White	Cattle (300); Swine; Agricultural Residues; Fats, Oils, Greases; Food Processing Wastes; Food Wastes	8,370	408,000 Cogeneration
Prairie's Edge Dairy Site 2 Digester 1	Jasper	Dairy 12,000	7,818	1,200,000 Cogeneration, CNG
Homestead Dairy Digester	Marshall	Dairy 2,100 Fats, oils, greases	7,446	Electricity
Hidden View Digester	Jasper	Dairy 3500	7,074	Cogeneration
Bos Dairy Digester	Jasper	Dairy 3,600	NA	CNG
Green Cow Power LLC Digester	Elkhart	Dairy 1,500 Food processing wastes	NA	907,200 Cogeneration
Herrema Dairy Digester	Jasper	Dairy 3,750	NA	CNG
Prairie's Edge Dairy Site 2 Digester 2	Jasper	Dairy 4,300	NA	CNG
Windy Ridge Dairy Digester	Jasper	Dairy 7,000	NA	CNG
Culver Duck Farm (processing plant) *	Elkhart	Ducks 105,000 gallons processing byproducts per week	9,960	NA

*Data from 2G Energy Corporation [23]

Table 4-8: Operational anaerobic digesters in Indiana (Data source EPA: [14])

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 4-9.

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 4-9: Potential electricity generating capacity in Indiana concentrated animal feeding operations (Data source: Giraldo [22])

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 [24]. 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 4-10.

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 4-10: Potential electricity generating capacity in Indiana wastewater treatment plants (Data source: Giraldo [22])

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.

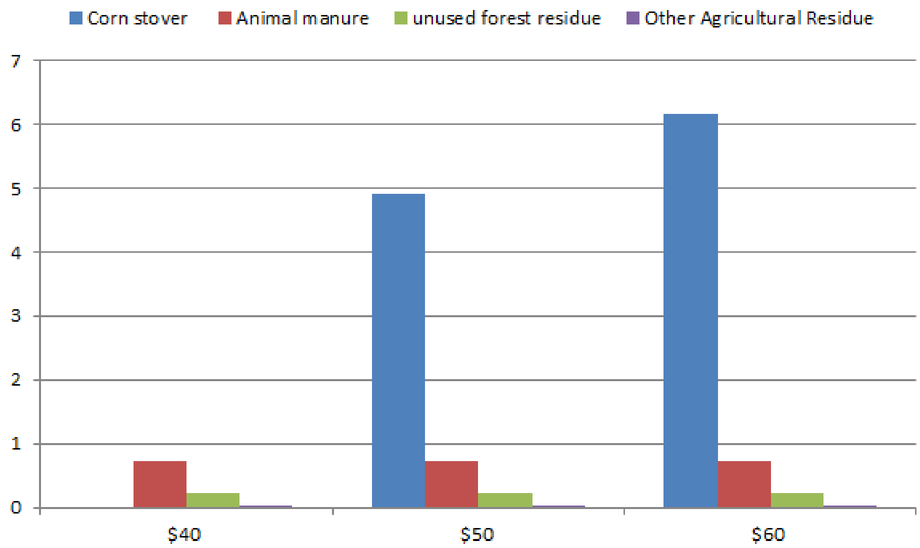


Figure 4-6: Estimated biomass production potential in Indiana (Data source: DOE [17])

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 113,000 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 [25]. Stellarwind, on the other hand, is focused on producing oil from algae that has the potential for use in producing transportation fuels [26].

4.5 Incentives for 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 expires at the end of 2020 [27, 28].
- 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. The credit is scaled down to 24 percent in 2017, 18 percent for 2018, 12 percent for 2019 and expires at the end of 2019 [27, 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 [27].
- Modified Accelerated Cost-Recovery System (MACRS) allows businesses to recover investments in qualified renewable energy technologies through depreciation deductions. In its history, bonus first year deprecation has been made available sporadically. The latest of these is a 100 percent first year depreciation for projects placed in service between September 27, 2017 to December 31, 2023 provided for by the Tax Cuts and Jobs Act of 2017 [27].
- 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 [27, 30].
- High Energy Cost Grant Program administered by USDA is aimed at improving the electricity supply infrastructure in rural areas having extremely high per-household energy costs; that is, 275 percent of the national average and above. Eligible infrastructure includes renewable resources generation [31].
- 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 [27].
- Green Power Purchasing Goal requires that 7.5 percent of energy used by federal agencies must be obtained from renewable resources [27].

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 Enrolled Act 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 [27, 32].

- 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 [33].
- Sales and Use Tax Exemption for Electrical Generating Equipment exempts transactions involving manufacturing machinery, tools, and equipment used for the production of tangible personal property, which includes electricity, from state gross retail tax. However, only wind energy has clearly specified rules from the Department of Revenue [27].
- 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 [27].
- 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 [34].

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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.

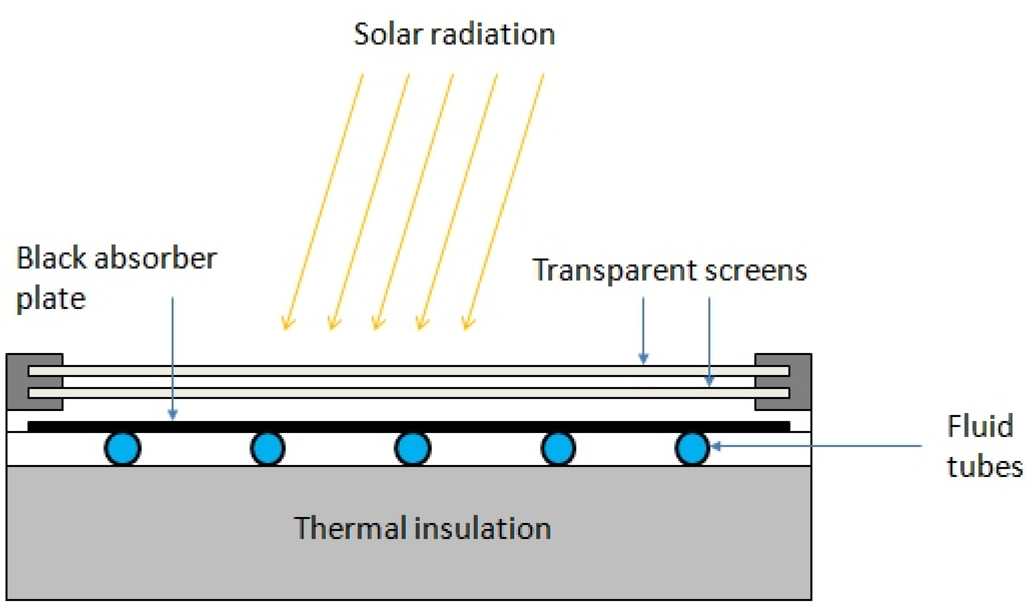


Figure 5-1: The layout of a flat-plate collector (Source: Penn State University [1])

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.

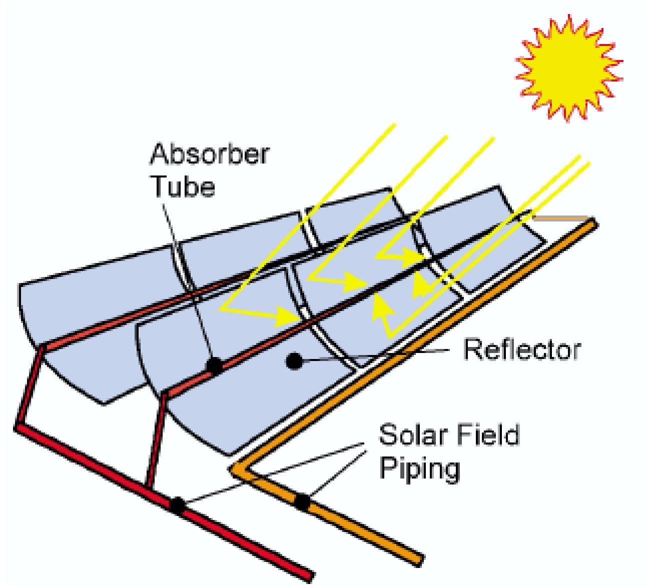


Figure 5-2: A parabolic trough CSP system (Source: IEA [2])

The linear Fresnel CSP system functions a lot like the parabolic trough system. However, 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. SUFG is aware of one currently operational Fresnel project in the U.S., the 5 MW Tucson Electric Power Sundt Boost project in Tucson, Arizona [3].

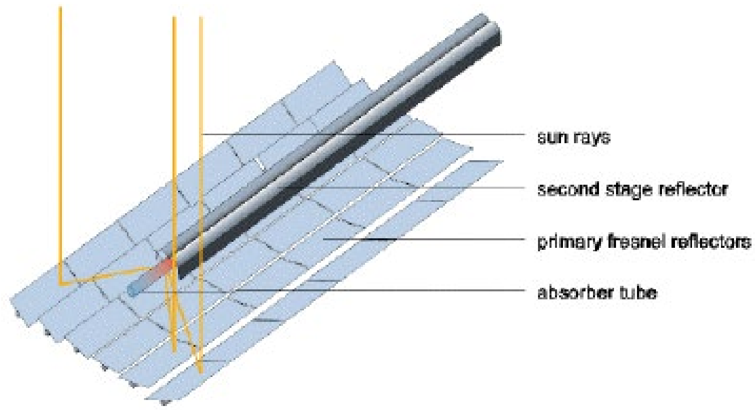


Figure 5-3: A linear Fresnel CSP system (Source: IEA [2])

The power tower CSP system utilizes thousands of flat sun-tracking mirrors, or heliostats, that 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 [4]. 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 [5].

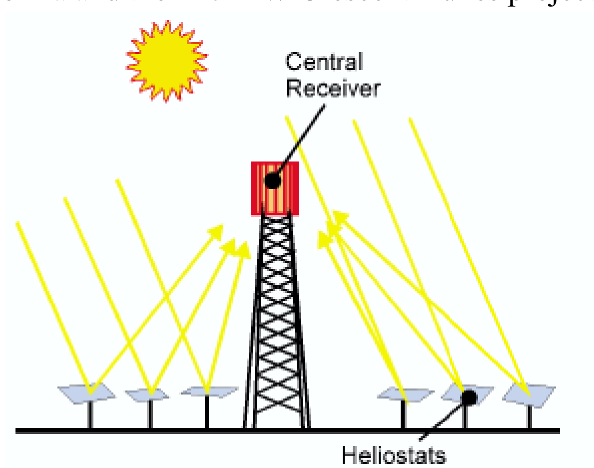


Figure 5-4: A power tower CSP system (Source: IEA [2])

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 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 [5].

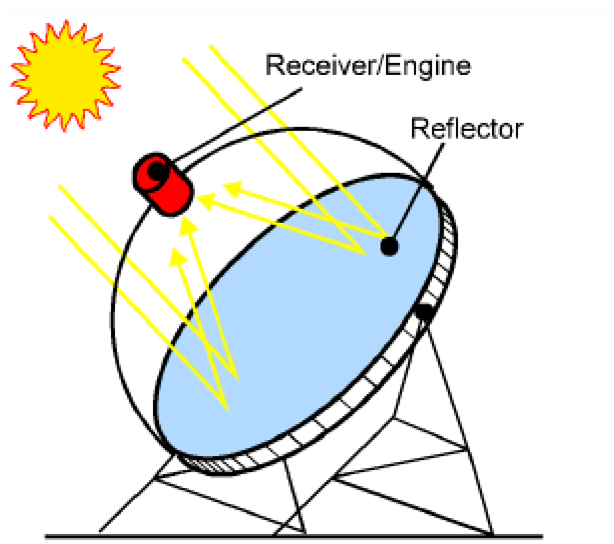


Figure 5-5: A dish/engine CSP system (Source: IEA [2])

5.2 Economics of solar technologies

Table 5-1 shows the overnight capital cost[12] 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.

[12] 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*" [6]. 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, AZ	250	Parabolic Trough	2013	8,000	6
Mojave Solar Project	Abengoa	Harper Dry Lake, CA	250	Parabolic Trough	2014	6,400	None
Martin Next Generation Solar Energy Center	Florida Power & Light	Indian Town, FL	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, NV	72	Parabolic Trough	2007	3,694	0.5
Colorado Integrated Solar Project	Xcel Energy /Abengoa Solar	Palisades, CO	2	Parabolic Trough	2010	2,250	None

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

Figure 5-6 shows the overnight capital cost estimates of utility scale electricity generating technologies given in the February 2020 EIA update of generating plant costs for the technologies modeled in the 2020 Annual Energy Outlook assessment report. The solar thermal technology's estimated capital cost of $7,221 /kW is the most expensive of the generating technologies modeled, both renewable and non-renewable technologies. The $7,221/kW estimated capital cost of solar thermal is a dramatic increase (68 percent) from the 2019 estimate of $4,291/kW.

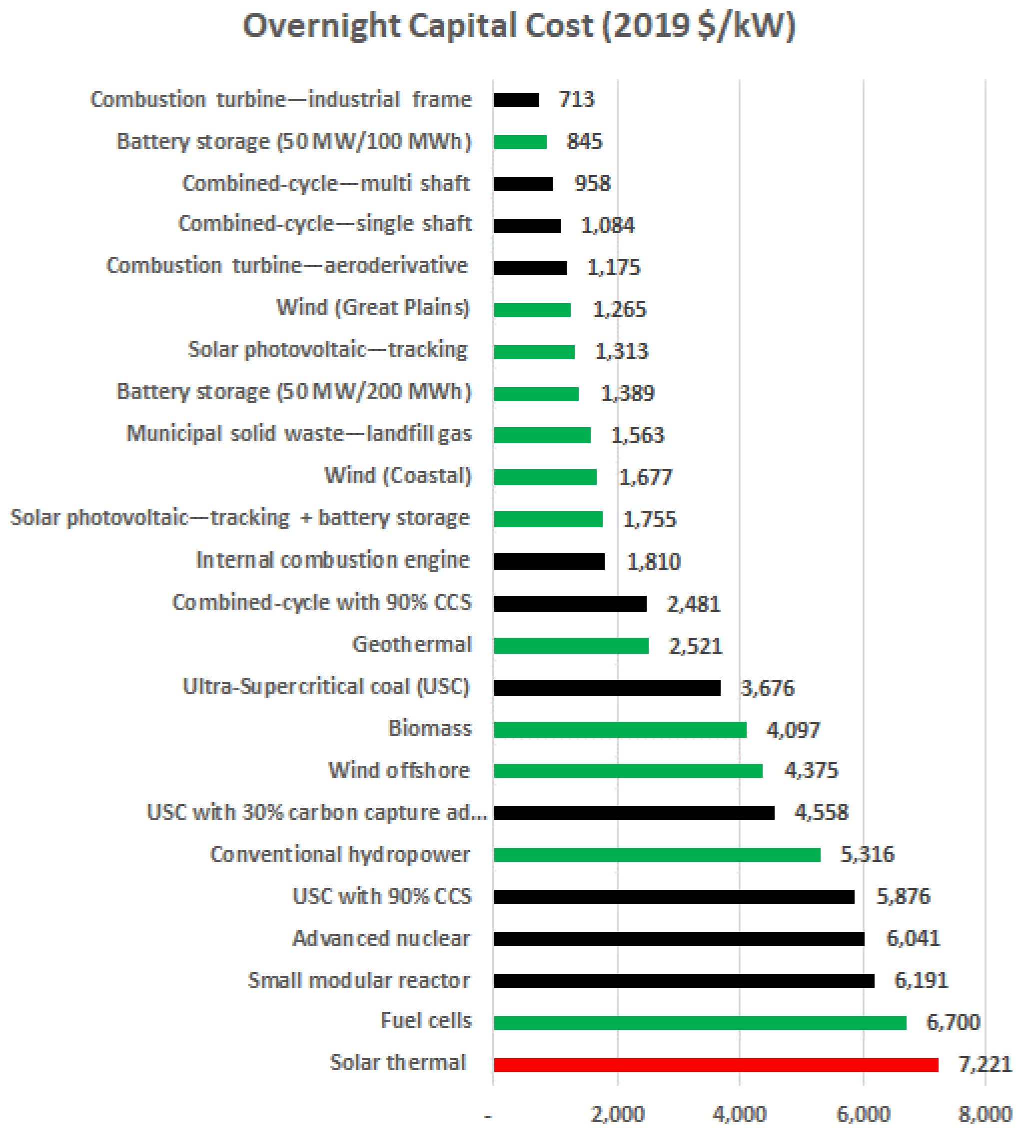


Figure 5-6: Estimated capital cost of generating technologies (Data source: EIA [6])

Figure 5-7 shows the estimate of the fixed and variable operating and maintenance (O&M) costs of the generating technologies modeled in the 2020 update of estimated generating technologies costs. As can be seen in Figure 5-7 solar thermal technology has moderate O&M cost, with almost no variable O&M cost and an estimated fixed annual O&M cost of $85/kW. The fixed O&M cost is higher than that of PV ($15/kW) and land-based wind ($26/kW) but lower than offshore wind, biomass and geothermal.

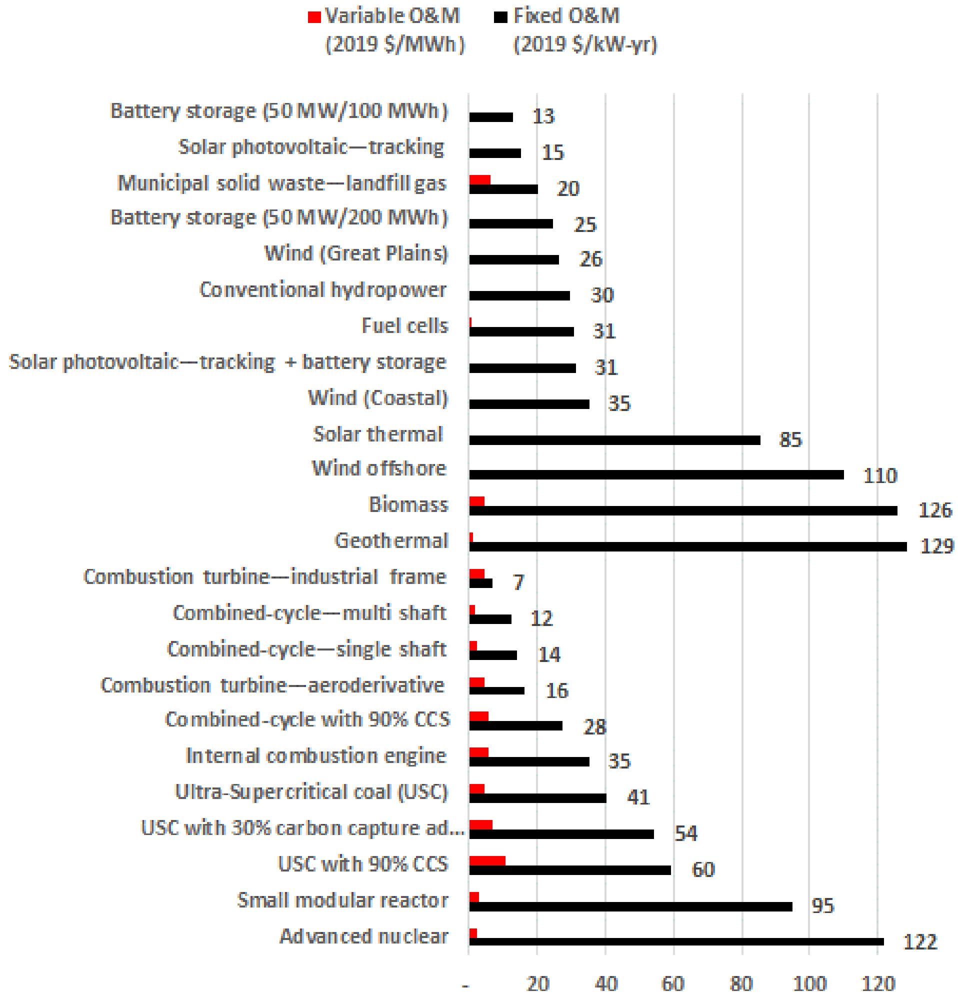
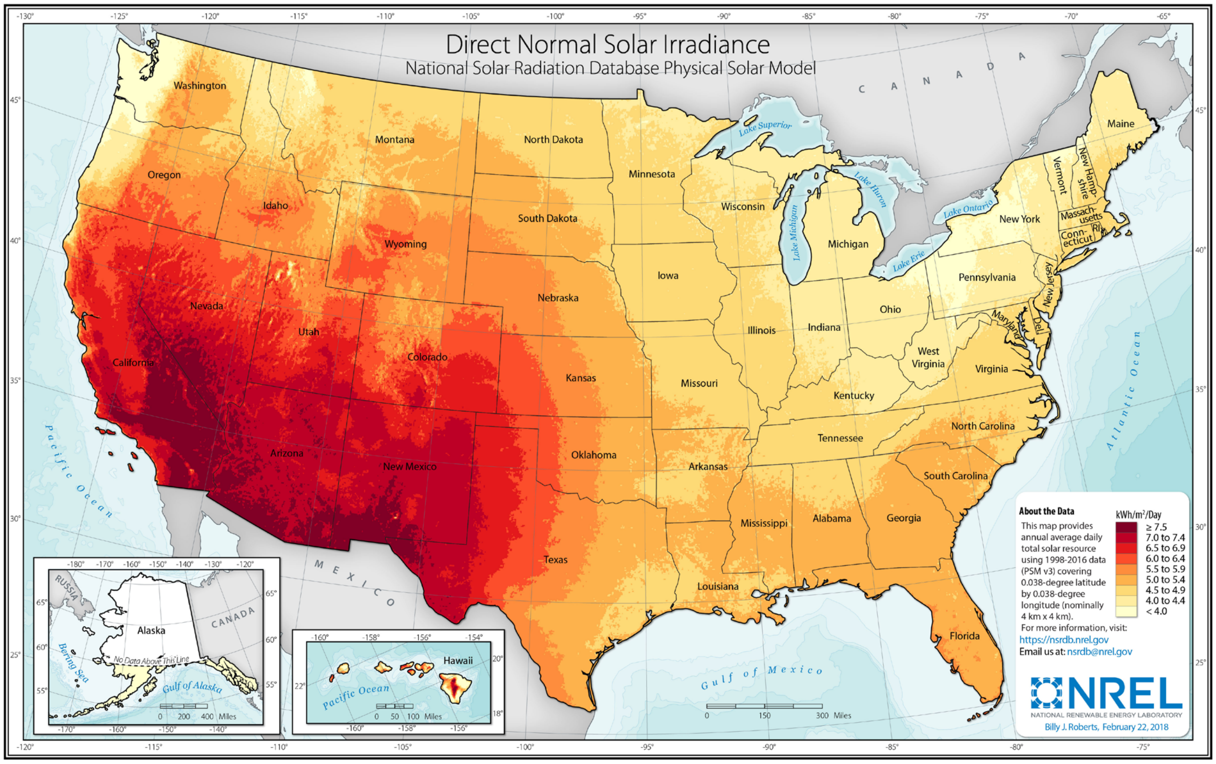


Figure 5-7: Operating and maintenance cost of generating technologies (Data source: EIA [6])

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.



<u>Figure 5-8:</u> <u>Solar power resource in the U.S.</u> (Source: NREL [7])

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.

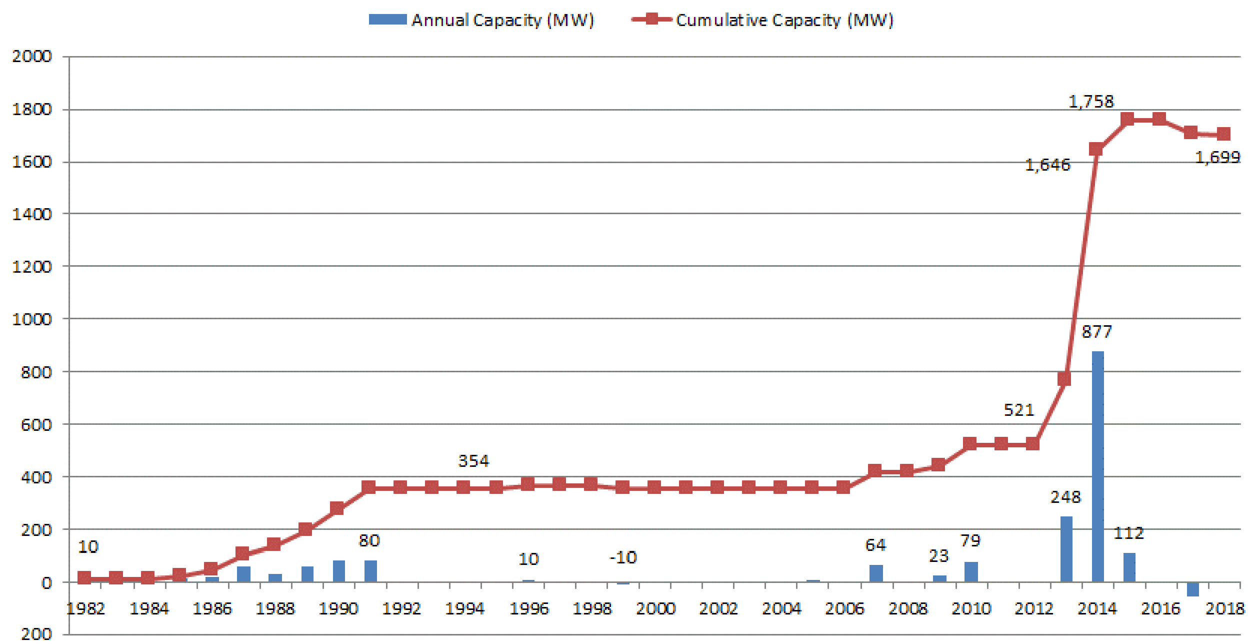


Figure 5-9: Solar thermal power capacity installed in the U.S. (Data sources: NREL [5], SEIA [8], IREC [9])

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 that 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 [5])

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 [5])

Although there have been no CSP projects developed in the U.S. in the last few years CSP development has continued in other areas of the world as shown in Figure 5-10.

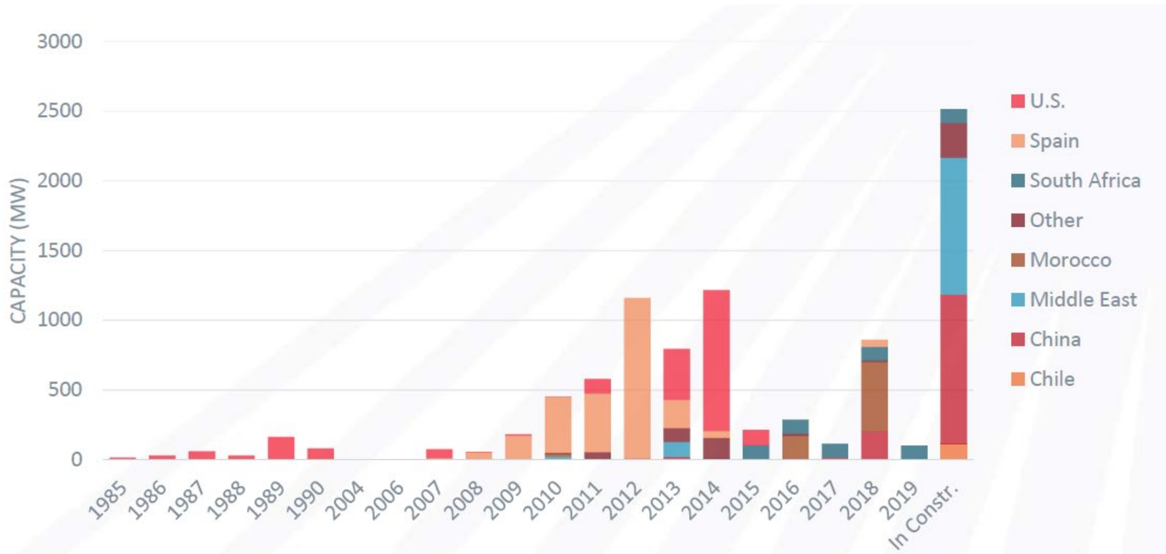


Figure 5-10: Solar thermal power capacity installation worldwide (Sources: U.S. DOE [10])

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 MW and Florida – 75 MW. However, there is some potential for water heating applications of solar thermal technologies in Indiana.

Figure 5-11 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 southwestern third of the state has the highest solar radiation available.

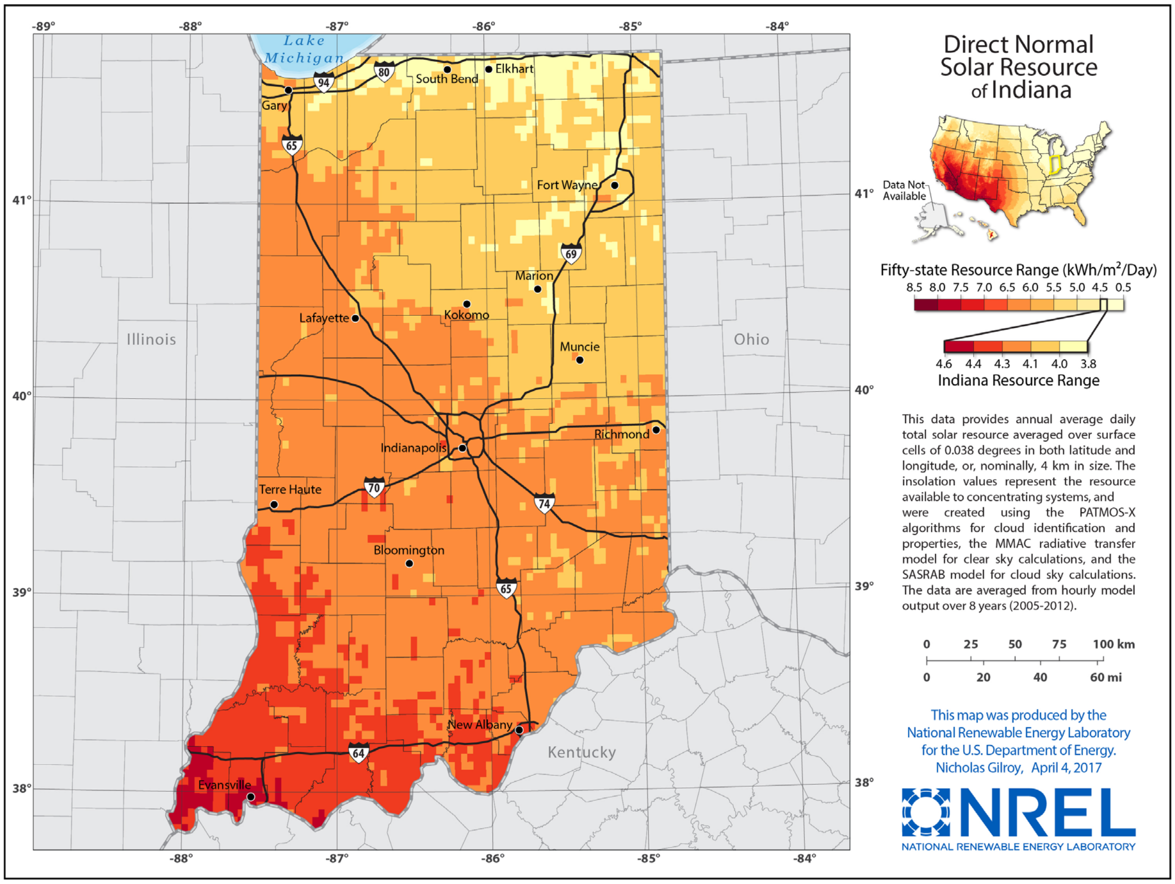


Figure 5-11: Direct normal solar radiation (flat-plate collector) in Indiana (Source: NREL [11])

5.5 Incentives for solar energy

The following incentives are available for solar thermal energy projects:

Federal Incentives

- Business Energy Investment Tax Credit (ITC) is a corporate tax credit that 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 [12].
- Residential Renewable Energy Tax Credit is a personal tax credit that credits up to 30 percent of expenditures, with no maximum credit, on solar systems, including solar water heaters, installed on residential properties. The tax credit scales down to 26 percent in 2020, 22 percent in 2021 and expires at the end of 2021. The credit does not apply to systems used to heat swimming pools and hot tubs. [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. In its history, bonus first year deprecation has been made available sporadically. The latest of these is a 100 percent first year depreciation for projects placed in service between September 27, 2017 to December 31, 2023 provided for by the Tax Cuts and Jobs Act of 2017 [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, 13].
- USDA High Energy Cost Grant Program administered by USDA is aimed at improving the electricity supply infrastructure in rural areas having extremely high per-household energy costs; that is, 275 percent of the national average and above. Eligible infrastructure includes renewable resources generation [14].
- Green Power Purchasing Goal requires that 7.5 percent of energy used by federal agencies must be obtained from renewable resources [12].
- 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 subsidizes these mortgages by insuring them through the Federal Housing Authority or the Department of Veterans Affairs [12].

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 Enrolled Act 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 [12, 15].
- 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 [16].
- 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].

- 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 [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 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.* [17].

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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].

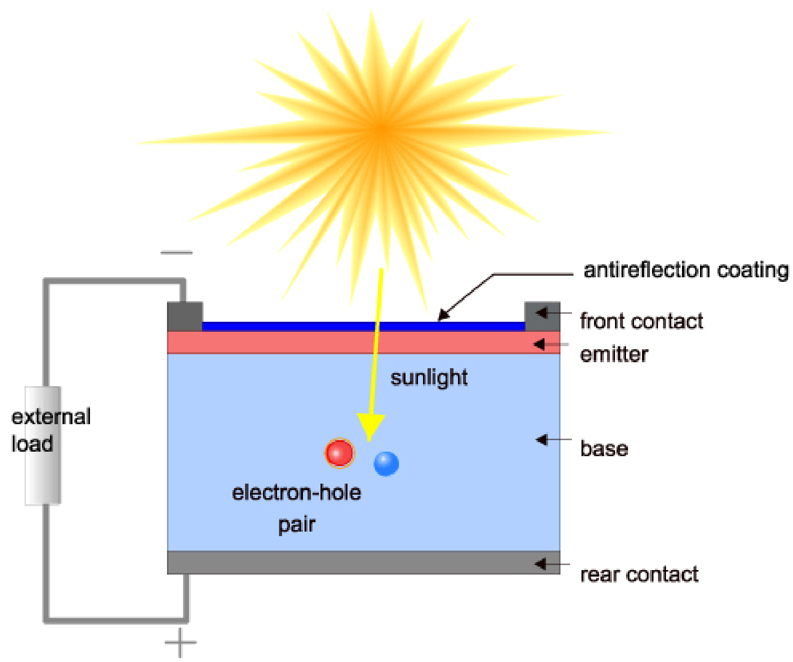

Figure 6-1: Photovoltaic cell operation (Source: EIA [2])

The photovoltaic cell is the basic building block of a PV system. Individual cells range in surface from smaller than a postage stamp to several 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[13] and mounting systems [1].

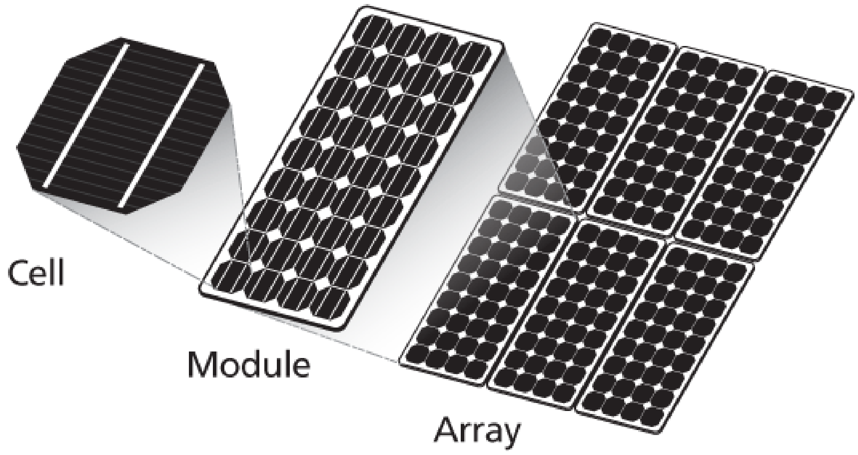

Figure 6-2: Illustration of a cell, module and array of a PV system (Source: SamLexSolar [3])

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 75 gigawatts (GW) of grid-connected PV systems installed in the U.S. since the year 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

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

the other photovoltaic technologies, CPV systems require direct sunlight and therefore their viability is restricted to sunny locations. According to a 2015 NREL report there were ten CPV systems operating in the U.S. in 2015. The largest of these was the 30 MW Alamosa Solar Generating Station in Alamosa, Colorado [5]. Figure 6-3 shows the layout of a CPV cell.

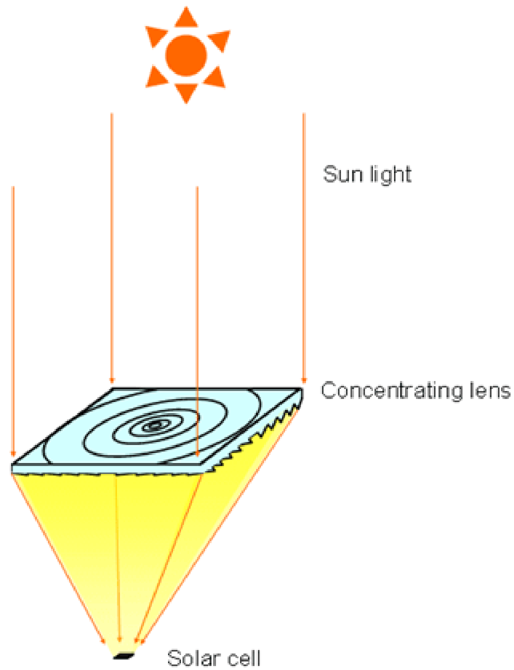

Figure 6-3: Illustration of concentrating photovoltaic cell (Source: Kuraray [6])

According to the U.S. DOE solar energy technology office approximately ninety percent of the photovoltaic systems sold today are crystalline silicon solar cells. They have advantages over other types of solar cells in conversion efficiency, low cost and long life times. Although thin film cells have a lower manufacturing cost, their conversion efficiency is lower. Concentrating photovoltaic cells, although having a high conversion efficiency are constrained by their more expensive materials, manufacturing processes and tracking systems. Organic photovoltaic cells are still in the research and development stage with limitations in their efficiency and long-term reliability being 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; 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 over \$12/W in 2002 to \$3.7/W in 2018, from over \$11/W to \$3/W for small non-residential systems and from over \$9/W in 2004 for large non-residential systems to \$2.4/W. The installed prices in Figure 6-4 is the upfront cost and does not include any financial incentives.

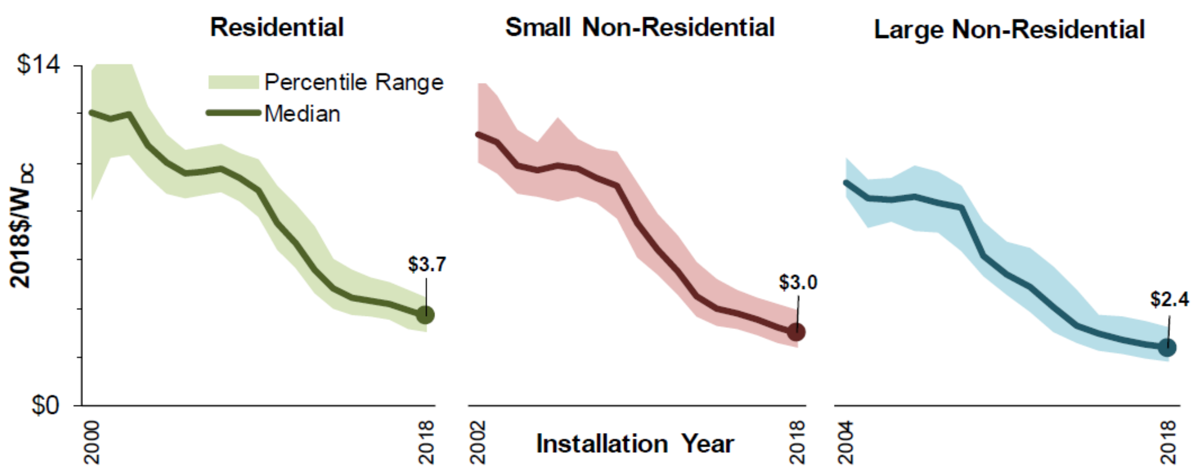

Figure 6-4: Installed price trends (\$/W$_{DC}$) for residential and commercial PV systems (Source: LBNL [9])

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.

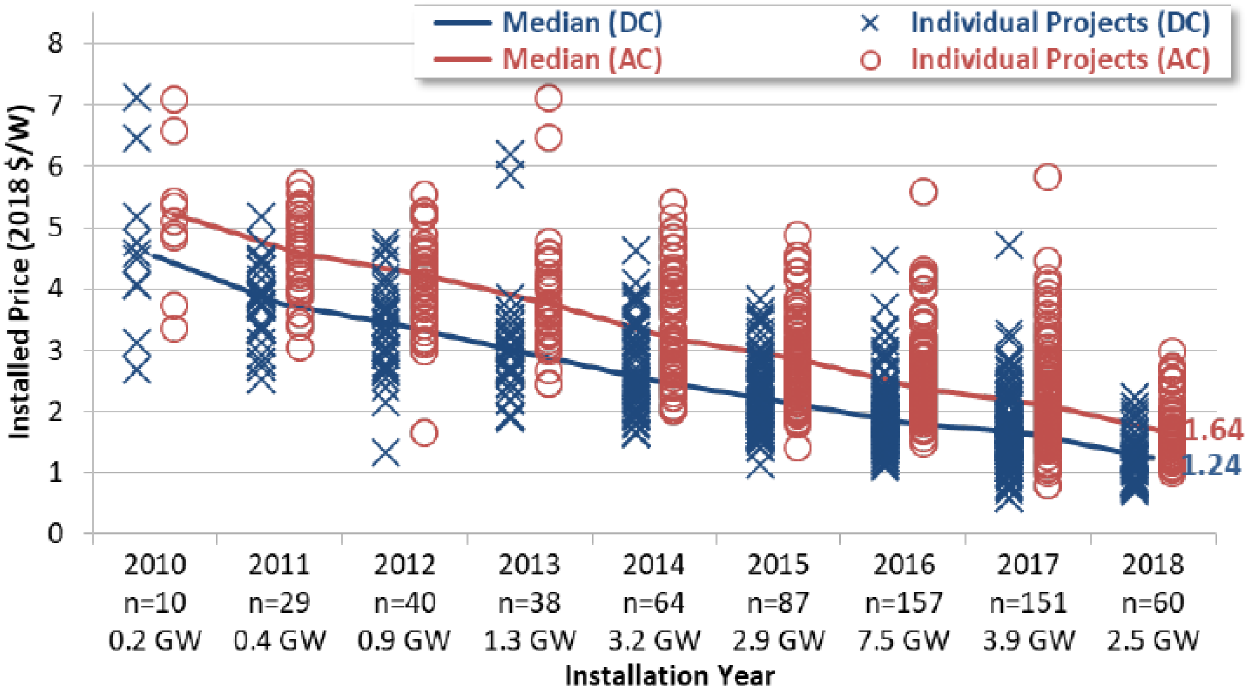

Figure 6-5: Installed price of utility-scale PV systems over time (Source: LBNL [10])

As can be seen in Figure 6-5 the median price for utility-scale PV projects in the Berkeley Lab database has dropped from $5.2/W for the projects commissioned in 2010 to $1.64/W for the projects commissioned in 2018. 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 $3/W for projects commissioned in 2018.

Figure 6-6 shows the average construction cost in $/kW for PV systems installed in the U.S. in 2018 according to a report released by EIA in August 2020. 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 2018 included in the EIA report is 1,848 $/kW. This is 13 percent higher than the $1.64/W medium price for the projects installed in 2018 that are in the Berkeley Lab database.

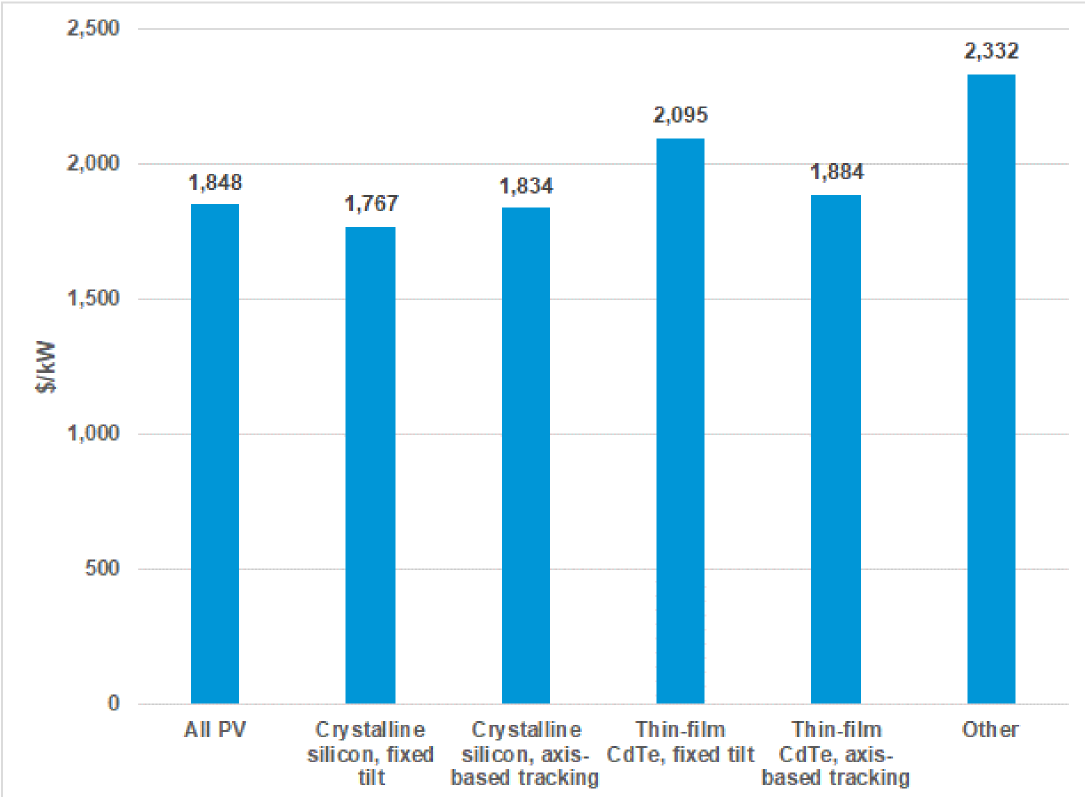

Figure 6-6: Average cost of PV systems of at least 1 MW installed in the U.S. in 2018 (Data Source: EIA [11])

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 issued in February 2020 to populate the National Energy Modeling System for the 2020 EIA Annual Energy Outlook. The estimate capital cost for 150 MW PV power plant modeled was estimated to be $1,313/kW and $1,755/kW for the 50 MW PV plant coupled with 200 MWh battery storage. The cost of the PV system modeled in 2020 is 33 percent lower than the $1,969/kW cost estimate in the 2019 EIA cost estimates, such that PV power plants now compares favorably with wind generation for capital cost. The $1,313/kW PV capital cost in this 2020 EIA estimate is only 4 percent higher than the $1,265/kW estimated capital cost of wind generation.

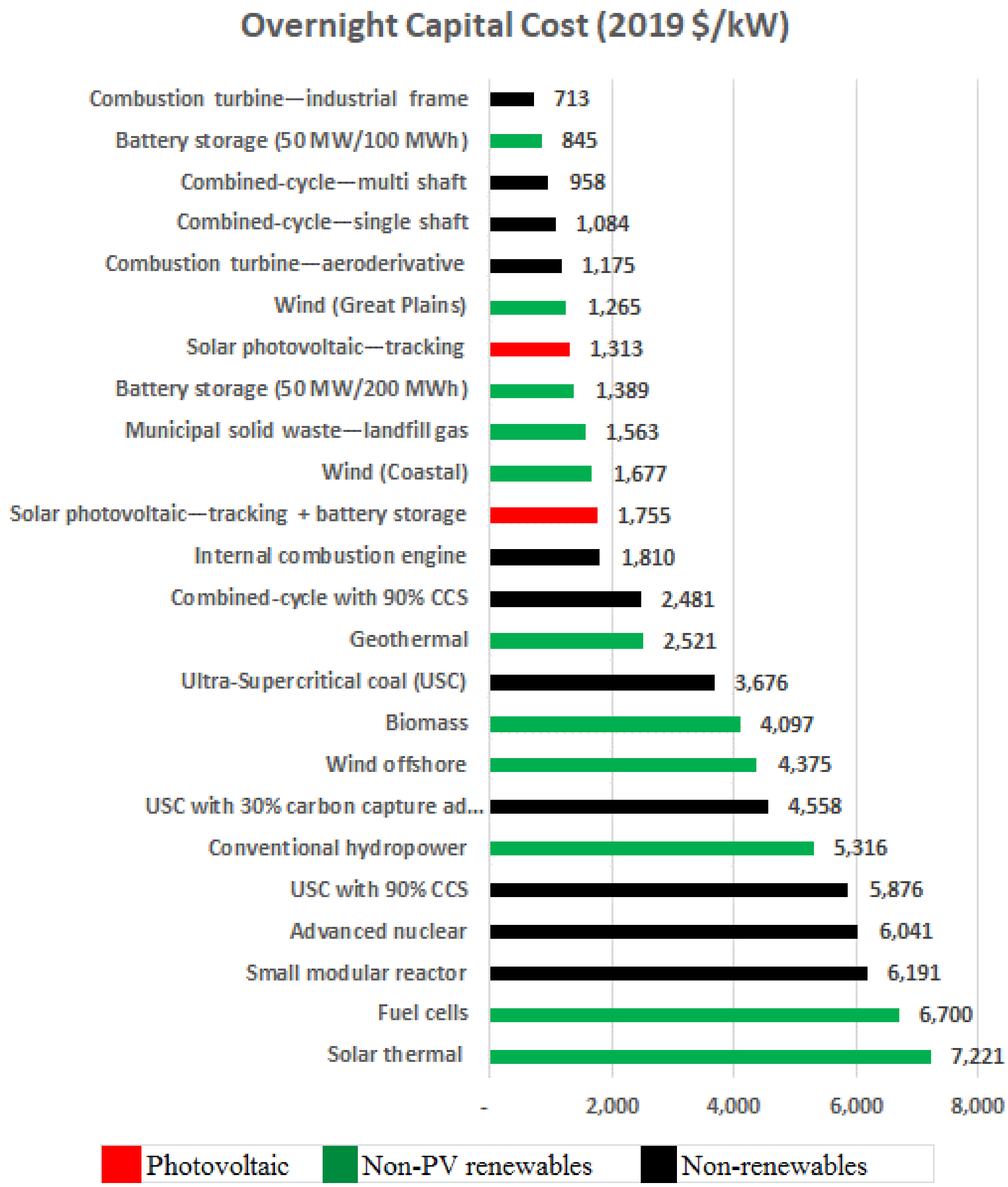

Figure 6-7: Estimated capital cost of generating technologies (Data source: EIA [12])

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 $15/kW-yr and there is virtually no variable O&M cost. A PV power plant coupled with battery storage has a higher combined fixed O&M at $31/kW-yr.

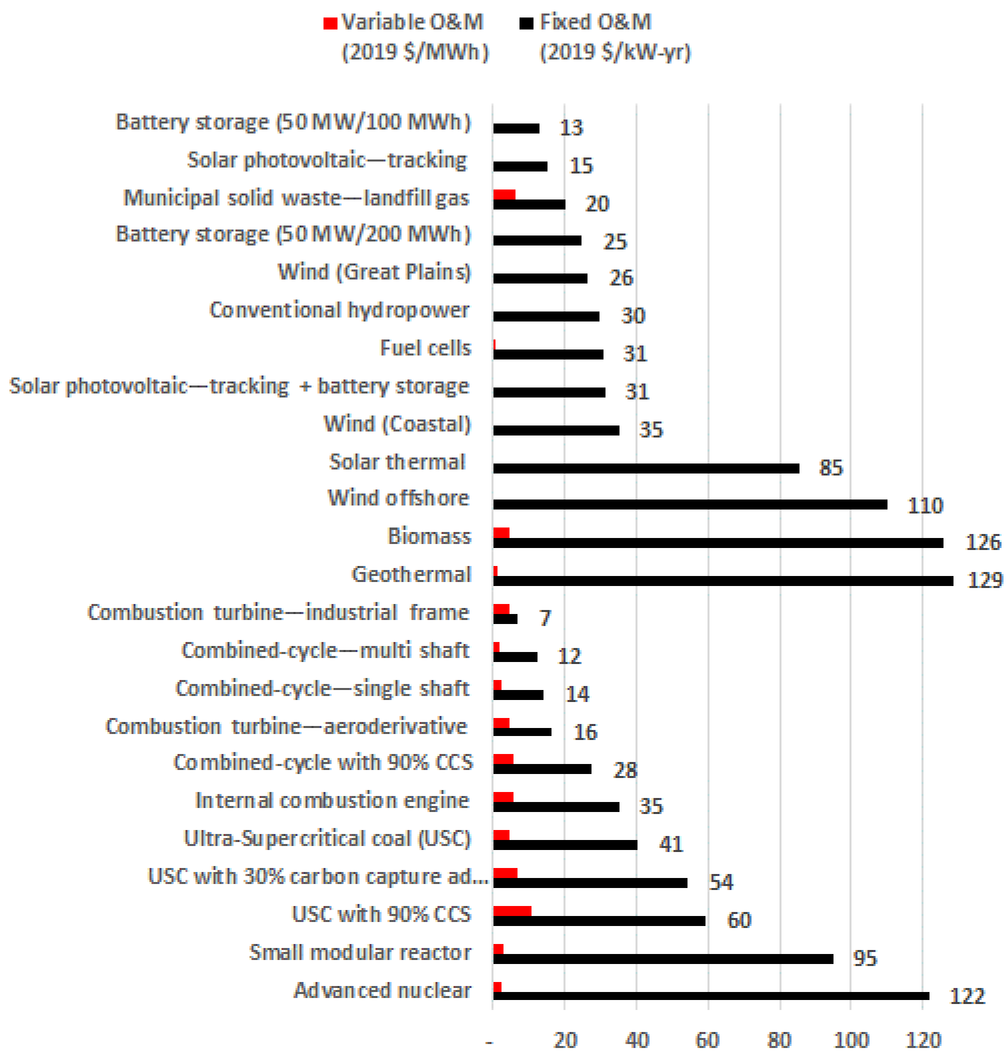

Figure 6-8: Estimated fixed and variable O&M cost of generating technologies (Data source: EIA [12])

6.3 State of PV systems nationally

PV installed capacity in the U.S. has been increasing rapidly and steadily in the last twenty years, growing from a mere 12 MW in 2000 to 75,464 MW at the end of 2019. Figure 6-9 shows the annual and the cumulative installed capacity of grid-connected PV systems in the U.S.

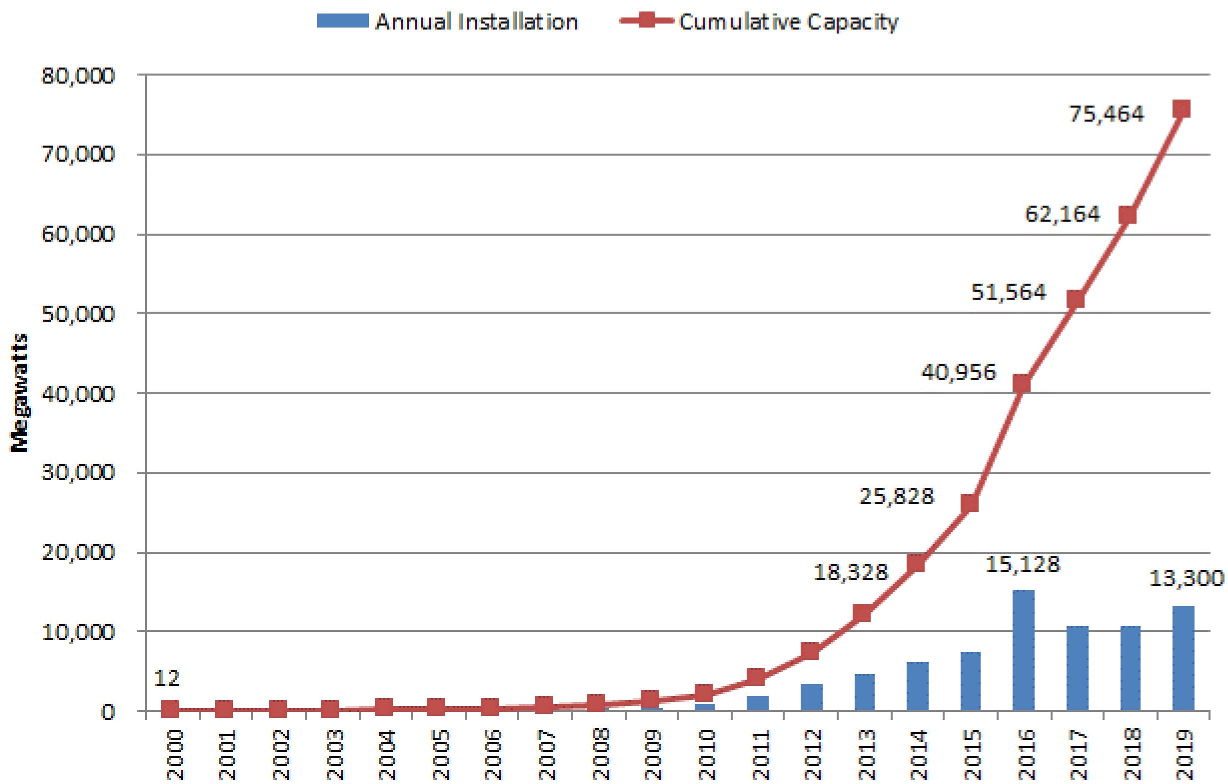

Figure 6-9: Grid-connected U.S. PV installed 2000 to 2018 (Data source: SEIA [4, 13 – 15])

The main factors behind this rapid expansion have been state and federal financial incentives, state renewable portfolio standards (RPS) with specific provisions for solar technologies and the declining costs of PV panels. The decline in the cost of PV systems is described in Section 6.2 above of this report. 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. In more recent years the concern for potential carbon regulation going into the future has caused utilities to work to incorporate more renewable resources in their generation mix.

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.

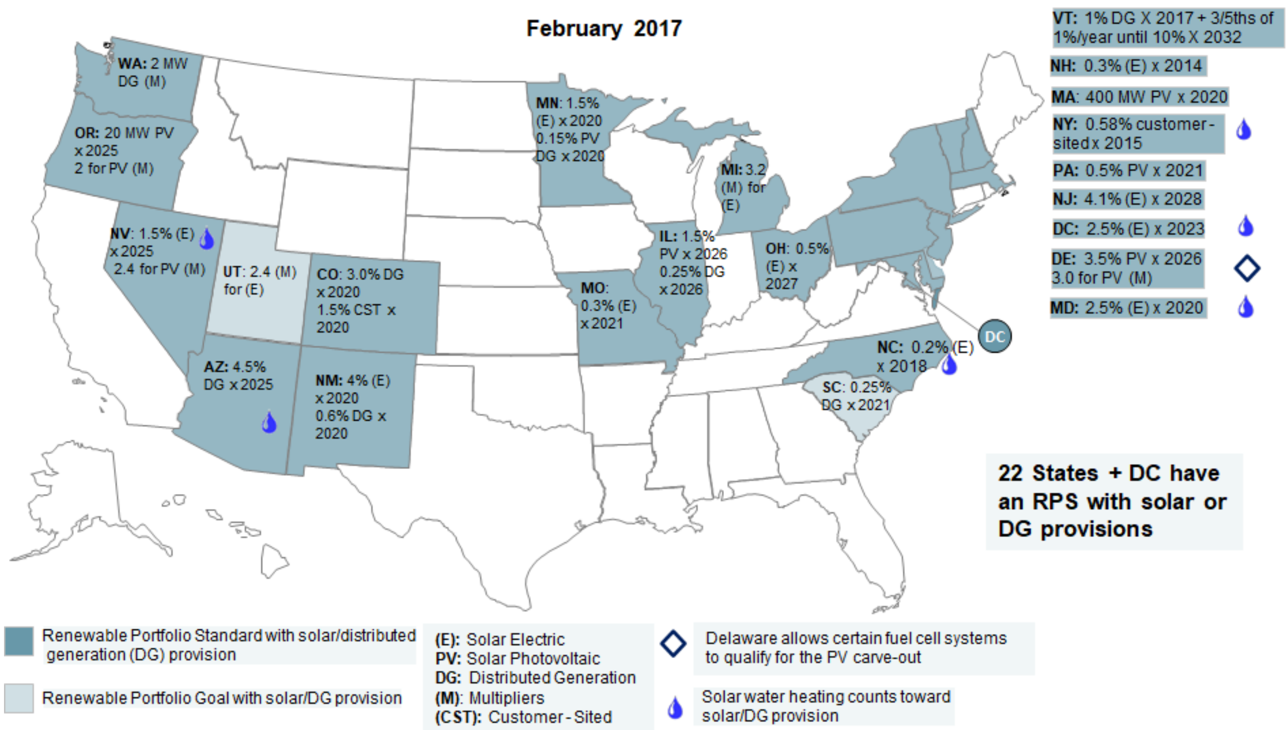

Figure 6-10: Renewable portfolio standards with solar carve-outs (Source: DSIRE [16])

Although uncertainty surrounding the imposition of the Section 201[14] tariffs on imported PV modules in the early part of 2018 caused disruption in the PV industry in 2018, the long-term effects have not been substantial. According the Solar Energy Industry Association the expected effect on project costs was muted by a faster than expected drop in global module prices. In addition, industry players pushed out project timelines to account for the tariff step down schedule. The four year tariffs started at 30 percent in 2018 and were scheduled to drop by 5 percent per year until they expire in 2021. According to the SEIA the 3 percent year-to-year drop in utility-scale PV capacity installed from 2017 to 2018 can be attributed to the disruption in the industry associated with the Section 201 tariffs [15].

Table 6-1 lists PV projects in the U.S. having a capacity of 100 MW and above, all of which have been constructed since 2011.

[14] Section 201 is a commonly used shorthand for the trade remedies section of the Trade Act of 1974 that permits the president to raise tariffs and duties to provide temporary relief to domestic industries facing injury from imports.

Project Name	Capacity (MW)	City/County	State	Online Date
Solar Star Projects	575	Rosamond	CA	2015
Desert Sunlight Solar Farm	550	Riverside	CA	2015
Topaz Solar Farm	550	San Luis Obispo	CA	2011-2014
Copper Mountain III Solar Facility	545	Boulder City	NV	2015
Mesquite Solar	400	Maricopa	AZ	2011-2016
Agua Caliente Solar Project	290	Yuma	AZ	2012
Garland Solar	272	Kern	CA	2016
Tranquility Solar	258	Fresno	CA	2016
Moapa Southern Paiute Solar Project	250	Moapa River	NV	2017
McCoy Solar Energy Center	250	Riverside	CA	2016
Silver State South Solar	250	Primm	NV	2016
California Valley Solar Ranch	250	San Luis Obispo	CA	2012-2013
Antelope Valley Solar	242	Lancaster	CA	2015
Astoria I, II	231	Kern	CA	2016
Blythe Solar Energy Center	225	Riverside	CA	2016
Mount Signal Solar	206	Calexico	CA	2014
Centinela Solar	200	El Centro	CA	2014
Springbok 2	191	Kern	CA	2016
Comanche Solar	156	Pueblo	CO	2017
Tenaska Imperial Solar Energy West	150	El Centro	CA	2016
Catalina Solar Project	143	Kern	CA	2013
Campo Verde Solar Project	139	El Centro	CA	2013
Springbok 1	137	Kern	CA	2016
Mustang Solar	134	Kings	CA	2016
Tenaska Imperial Solar Energy South	130	El Centro	CA	2013
Arlington Valley Solar Energy II	125	Maricopa	AZ	2013
Solverde 1	107	Los Angeles	CA	2016
Utah Red Hills Renewable Park	104	Parowan	UT	2015
White Pine Solar Energy Center	101	Taylor	CA	2016

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

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 ten years. As of July 2020, Indiana's installed PV capacity was 335 MW. The capacity was distributed among Indiana utility service territories as shown in Table 6-2. This capacity is set to increase even more substantially when proposed projects with a combined capacity of 1,505 MW are added between now and the end of 2024. Among these are eight projects with a capacity of 100 MW or more each. The five largest of these projects, are the 250 MW Fairbanks Solar Energy Center in Sullivan County, the 200 MW Riverstart project in Randolph County, the 200 MW Brickyard Solar Project in Boone County the 200 MW Elliott Solar Project in Gibson County and the 199 MW Speedway Solar (Ranger) in Shelby County.

	Feed-in-Tariff (MW_{AC})	Net Metered PV (MW_{AC})	Utility Owned or Purchase Agreement (MW_{AC})	Total (MW_{AC})	Percent
IPL	94	4		98	29%
Duke		35	42	77	23%
NIPSCO	35	21		56	17%
IMPA			55	55	16%
I&M		13	10	24	7%
Vectren		11	4	15	4%
Hoosier			12	12	4%
Total	**129**	**84**	**123**	**335**	

Table 6-2: Total installed Indiana PV capacity (Data source: IURC [20]

The currently PV capacity in Indiana connected to the grid is as follows: 38 percent (129 MW) through feed-in tariffs, 15 percent (84 MW) through net metering tariffs, and 27 percent (123 MW) through direct utility ownership or a power purchase agreement.

Table 6-3 lists the PV installations in Indiana with a capacity greater than two MW. Three of the largest projects account for almost 17 percent of the total installed PV 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 17.25 MW project at the Crane Naval Support Activity (NSA) facility in Martin County.

Project	Utility Interconnected	Location (County)	Capacity (MW_{AC})
Indy Solar 1, 2 (Franklin Township)	IPL	Marion	20
Indianapolis Airport 1, 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
Crawfordsville 2 Solar Park	IMPA	Montgomery	7.93
Richmond Solar Farm 2	IMPA	Wayne	7.4
McDonald Solar	Duke	Vigo	5
Pastime Farm	Duke	Clay	5
Geres Energy	Duke	Howard	5
Sullivan Solar	Duke	Sullivan	5
Camp Atterbury	Duke	Bartholomew	5
Anderson I Solar Park	IMPA	Madison	5
Olive Solar	I&M	St. Joseph	5
Tipton Solar Park	IMPA	Tipton	5.26
Crawfordsville 2 Solar Park	IMPA	Montgomery	4.76
Lifeline Data Centers	IPL	Marion	4
Rensselaer Solar Farm 2	IMPA	Jasper	4
Washington Solar Park	IMPA	Daviess	4
CWA Authority	IPL	Marion	3.83
Rensselaer 2 Solar Farm	IMPA	Jasper	3.8
Duke Realty #129	IPL	Marion	3.4
Crawfordsville 1 Solar Park	IMPA	Montgomery	3
Peru Solar Park	IMPA	Miami	3
Tell City 2 Solar Park	IMPA	Spencer	3
Gas City Solar Park	IMPA	Grant	3
Greenfield Solar Park	IMPA	Madison	2.8
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

Table 6-3: PV systems in Indiana with capacity greater than 2 MW (Data sources: IURC [20], IMPA [21])

As mentioned earlier, Indiana's PV capacity is set to increase substantially if all the currently proposed solar projects are constructed. Table 6-4 is a list of the projects with a capacity of 1 MW or greater proposed in various counties in Indiana. If all the projects are completed as planned Indiana's grid connected PV capacity will grow from the current 335 MW to 1,840 MW at the end of 2024.

Project	Utility Owner or Buyer	County	Capacity (MW_{AC})	Planned In-service Date
Fairbanks Solar Energy Center	Merchant	Sullivan	250	2023
Riverstart Solar Park	Hoosier	Randolph	200	2022
Brickyard Solar Project	NIPSCO	Boone	200	2022
Elliott Solar Project	Merchant	Gibson	200	2023
Speedway Solar (Ranger)	WVPA	Shelby	199	2023
Ratts 2 Solar Project	Merchant	Knox	150	2023/2024
Lone Oak Solar Energy	Merchant	Madison	120	2023
Greensboro Solar Project	NIPSCO	Henry	100	2022
Vectren Spencer County Project	Vectren South	Spencer	50	2021
South Bend Solar Farm	IM Power	St. Joseph	20	2023
Richmond 4 Solar Park	IMPA	Wayne	8	2019
Scottsburg Solar Park	IMPA	Scott	8	2019
Centerville Solar Park	IMPA	Wayne	1	2020

Table 6-4: Proposed PV projects with a capacity 1 MW or greater (Data sources: IURC [20], IMPA [21], IIB [22])

As explained previously, the factors being credited with the rapid growth in the PV market in the last decade 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 residential installations and to allow electric utilities access to the investment tax credit. In more recent years the desire to insulate from potential carbon regulation has caused utilities to focus more on low and no carbon resources to meet new capacity needs. 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 309 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 be compensated at the full retail rate until July 1, 2032 [15, 23].

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 6-5.

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 6-5: Purchase rates under NIPSCO renewable feed-in tariff (Data source: NIPSCO [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 6-5 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 6-5.
- 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. As of the writing of this report, application for intermediate solar was closed.
- 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

- Business Energy Investment Tax Credit (ITC) is a corporate tax credit that credits up to 30 percent of expenditures, with no maximum credit limit, on solar PV installations. The credit scales down to 26 percent in 2020, 22 percent in 2021 and 10 percent in subsequent years [16].
- Residential Renewable Energy Tax Credit is a personal tax credit that credits up to 30 percent of expenditures, with no maximum credit, on solar PV installations on residential properties. The tax credit scales down to 26 percent in 2020, 22 percent in 2021 and expires at the end of 2021 [16].
- U.S. DOE Loan Guarantee Program (Section 1703, Title XVII of Energy Policy Act of 2005) provides loan guarantees for large scale innovative, high technology risk renewable energy projects that reduce the emission of pollutants [16].
- Modified Accelerated Cost-Recovery System (MACRS) allows businesses to recover investments in qualified renewable energy technologies through depreciation deductions. In its history, bonus first year deprecation has been made available sporadically. The latest of these is a 100 percent first year depreciation for projects placed in service between September 27, 2017 to December 31, 2023 provided for by the Tax Cuts and Jobs Act of 2017 [16].
- USDA Rural Energy for America Program (REAP) promotes energy efficiency and renewable energy for agricultural producers and rural small businesses through the use of grants and loan guarantees for energy efficiency improvements and renewable energy systems. The program covers up to 25 percent of costs [16, 25].
- High Energy Cost Grant Program administered by USDA is aimed at improving the electricity supply infrastructure in rural areas having extremely high per-household energy costs; that is, 275 percent of the national average and above. Eligible infrastructure includes renewable resources generation [26].
- Green Power Purchasing Goal requires that 7.5 percent of energy used by federal agencies must be obtained from renewable resources [16].
- 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 subsidizes these mortgages by insuring them through the Federal Housing Authority or the Department of Veterans Affairs [16].

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 Enrolled Act 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, 23].

- Renewable Energy Property Tax Exemption provides property tax exemptions for solar thermal, PV, wind, hydroelectric and geothermal systems [16].
- Community Conservation Challenge Grant provides $25,000-$100,000 in grants for community energy conservation projects that reduce energy consumption or displace the use of traditional energy sources [27].
- Solar Access Laws prevent planning and zoning authorities from prohibiting or unreasonably restricting the use of solar energy. Indiana's solar-easement provisions do not create an automatic right to sunlight; they allow parties to voluntarily enter into solar-easement contracts which are enforceable by law [16].
- Sales and Use Tax Exemption for Electrical Generating Equipment exempts transactions involving manufacturing machinery, tools, and equipment used for the production of tangible personal property, which includes electricity, from state gross retail tax. However, only wind energy has clearly specified rules from the Department of Revenue [16].
- Clean Energy Portfolio Goal sets a voluntary goal of obtaining 4 percent between 2013 and 2018, 7 percent between 2019 and 2024, and 10 percent by 2025, of electricity from clean energy sources based on 2010 retail sales. Participation in the goal makes utilities eligible for incentives that can be used to pay for the compliance projects. The deadline to apply for incentives in the 2013 to 2018 period has expired [16].
- 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* [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 7 percent of the total electricity generated in 2019. 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 41 percent of the renewable electricity generated in the U.S. in 2018 [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].

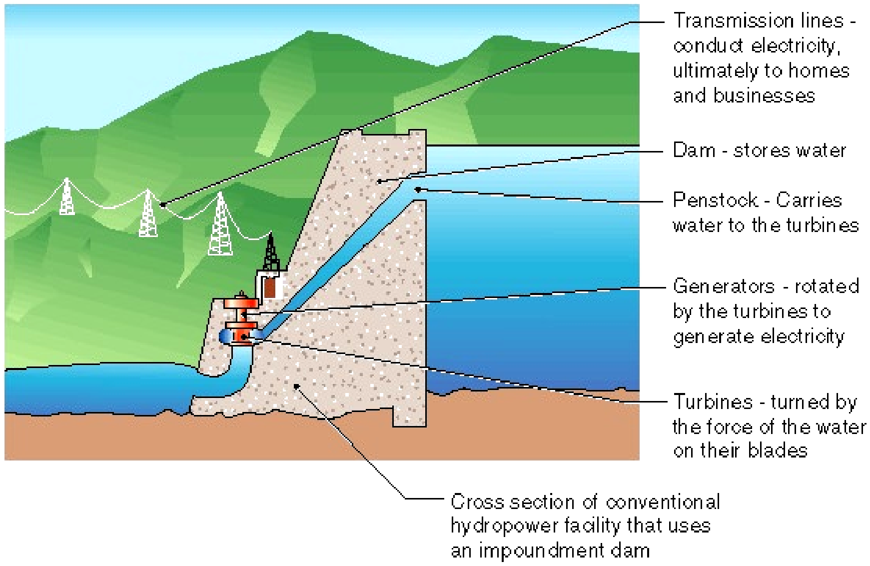

Figure 7-1: Schematic of impoundment hydropower facility (Source: DOE [6])

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.

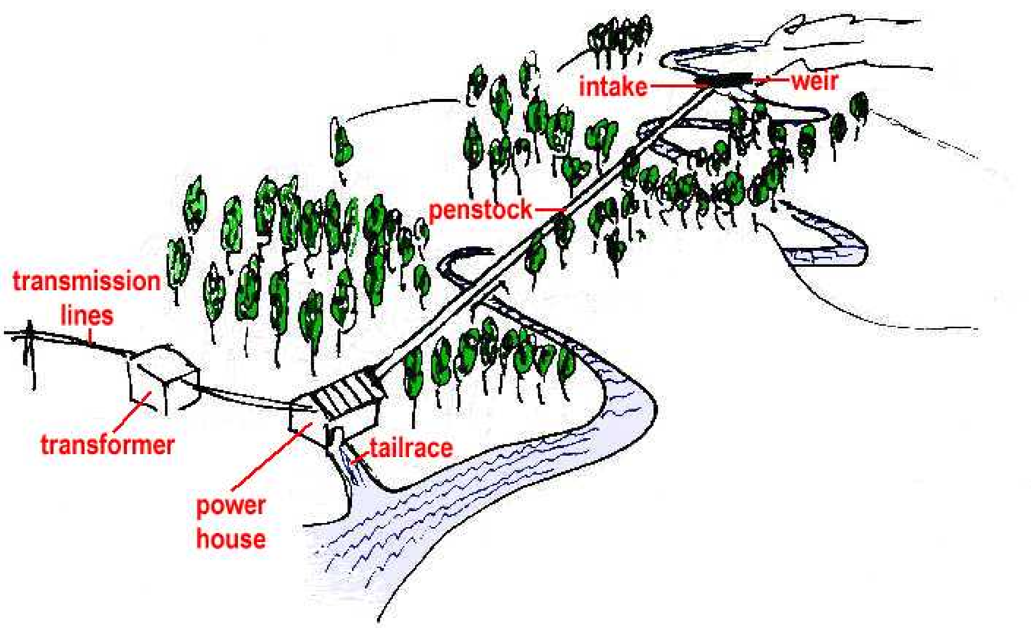

Figure 7-2: Schematic of a diversion hydropower facility (Source: wordpress [7])

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.

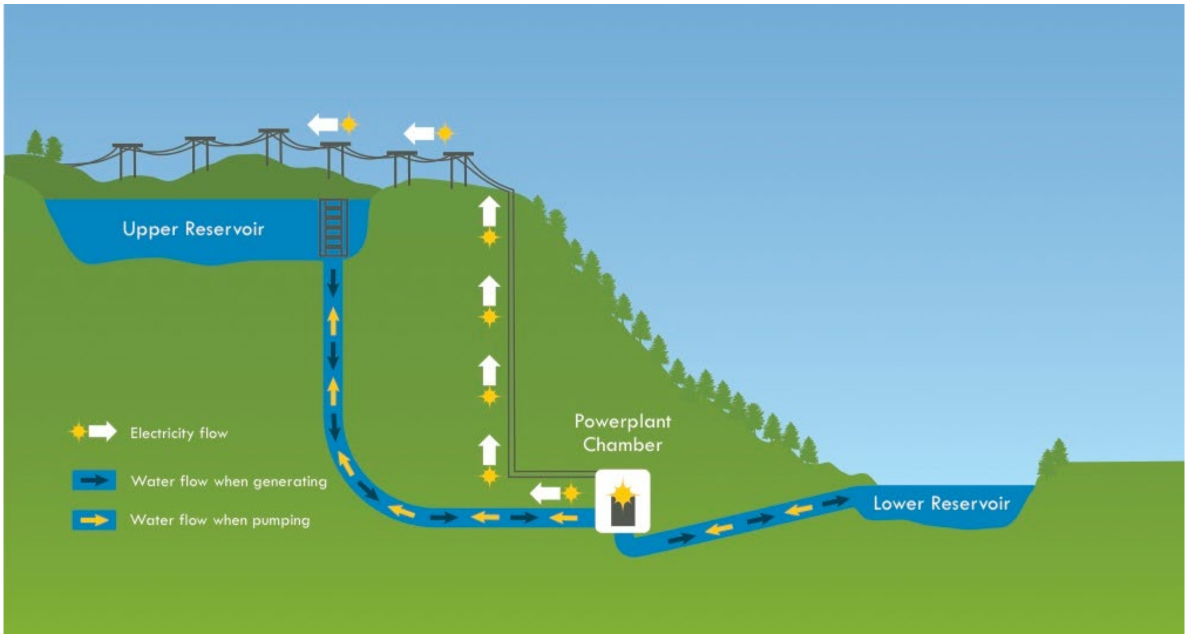

Figure 7-5: Schematic of a pumped hydro facility (Source: DC Thompson and Company [10])

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,[15] 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 expressed in 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

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

projects are those constructed on water conveyance conduits put in place primarily for irrigation or water supply. N*ew stream-reach development* projects are small capacity hydropower projects that can be built on streams with minimal environmental impact, while *non-powered dams* are exactly that, hydropower projects added to dams already in place for other purposes, such as water storage, irrigation or navigation [12].

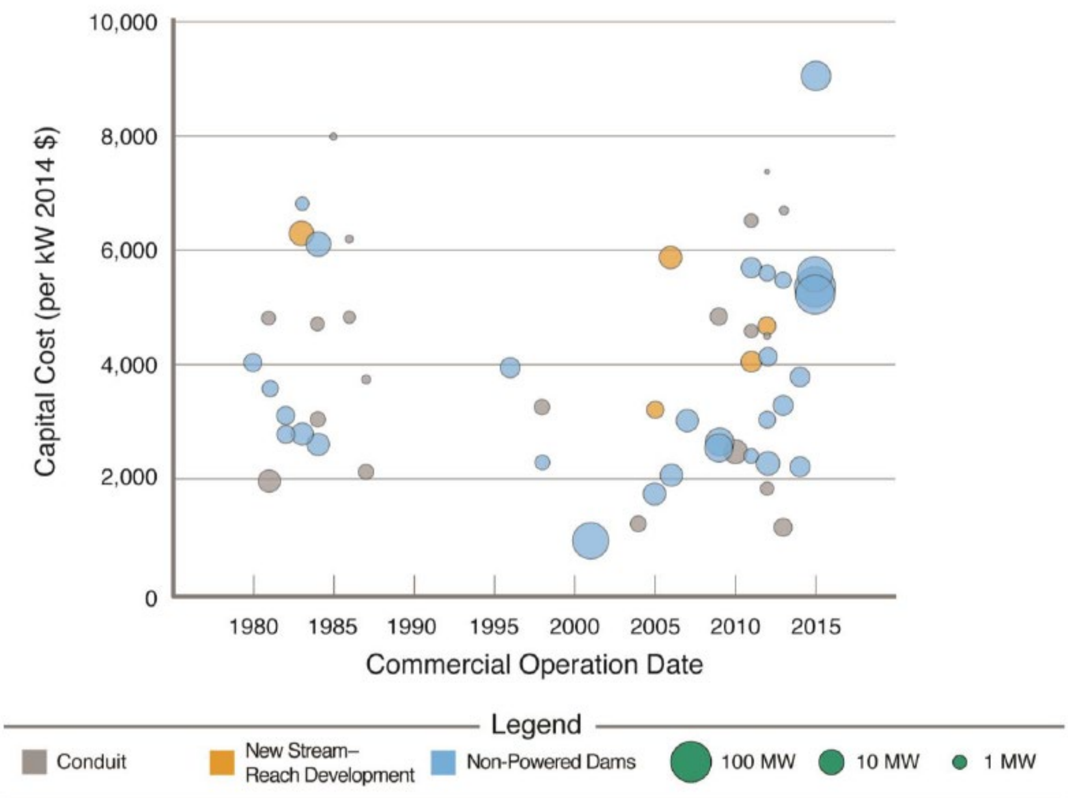

Figure 7-6: U.S. hydropower construction cost by project type and size (Source: DOE [12])

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/West Wailuaiki		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 2018 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 January 2019 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 $1.36/MWh and the fixed O&M cost of $41/kW/yr for a conventional hydroelectric plant. This is among the lowest O&M costs for 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.

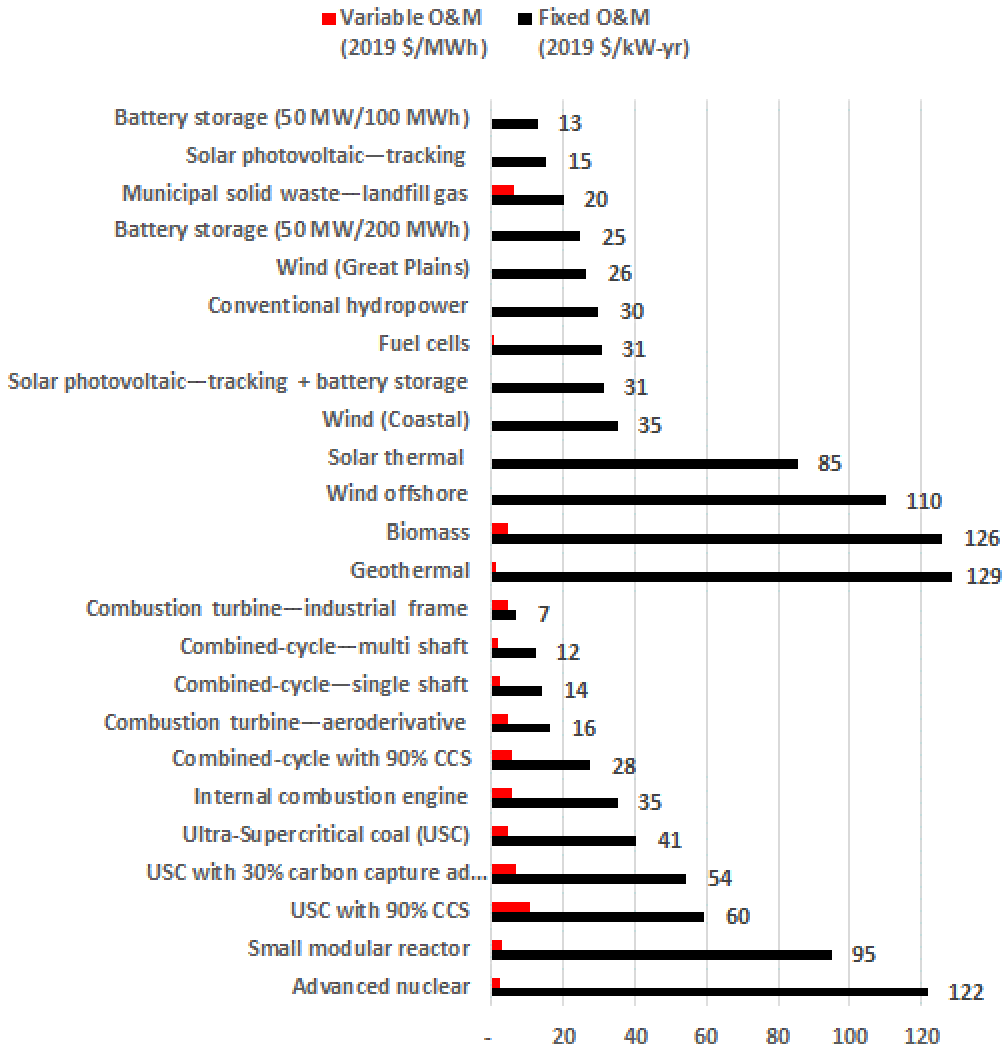

Figure 7-7: Variable and fixed O&M costs of generating technologies (Data source: EIA [13])

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 2018. 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 more than 40 percent of the renewable electricity generated and 23 percent of the renewable energy consumed in the U.S. in 2018.

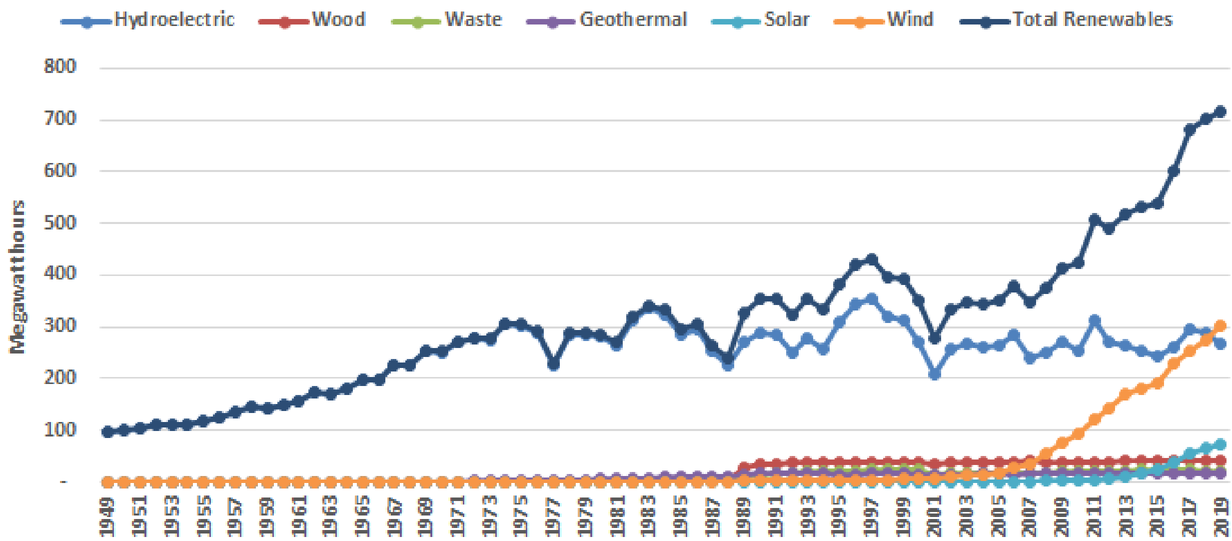

Figure 7-8: Net renewable electricity generation in the U.S. (1949-2019) (Data source: EIA [4])

The total installed hydropower capacity in the U.S. consists of 78.9 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	6,809	1942-1984
Bath County*	Little Back Creek	Virginia	2,862	1985
Chief Joseph	Columbia	Washington	2,456	1958-1979
Robert Moses - Niagara	Niagara	New York	2,429	1961-1962
John Day	Columbia	Oregon	2,160	1968-1971
Hoover	Colorado	Arizona/Nevada	2,079	1936-1961
Ludington*	Lake Michigan	Michigan	1,979	1973
The Dalles	Columbia	Oregon	1,820	1957-1973
Raccoon Mountain*	Tennessee River	Tennessee	1,714	1978-1979
Castaic*	California Aqueduct	California	1,682	1973-1978

*pumped hydropower stations

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

Table 7-3 shows the top ten hydro states ranked by their hydroelectricity output in 2018 and Table 7-4 shows the top ten hydro states ranked by installed hydro capacity at the end of 2018. Almost sixty percent of the hydroelectricity generation in 2018 was from the top four states of Washington, Oregon, New York and California and approximately half the summer hydro capacity in the U.S. in 2018 was in the top three states of Washington, California and Oregon.

State	2018 Generation (GWh)	percent of U.S. generation		State	2018 Generation (GWh)	percent of U.S. generation
Washington	80,883	28%		Alabama	11,143	4%
Oregon	35,443	12%		Idaho	11,024	4%
New York	29,630	10%		Tennessee	10,293	4%
California	26,331	9%		Arizona	6,982	2%
Montana	11,405	4%		North Carolina	6,605	2%

Table 7-3: Top ten U.S. hydropower generating states in 2018 (GWh) (Data source: EIA [19])

State	2018 Summer Capacity (MW)	Percent of U.S. Hydro Capacity		State	2018 Summer Capacity (MW)	Percent of U.S. Hydro Capacity
Washington	21,281	27%		Montana	2,768	3%
California	10,184	13%		Idaho	2,764	3%
Oregon	8,402	11%		Arizona	2,721	3%
New York	4,561	6%		Tennessee	2,617	3%
Alabama	3,292	4%		Georgia	2,047	3%

Table 7-4: Top ten U.S. hydropower capacity states at the end 2017 (MW) (Data source: EIA [20])

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 [21]. 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.

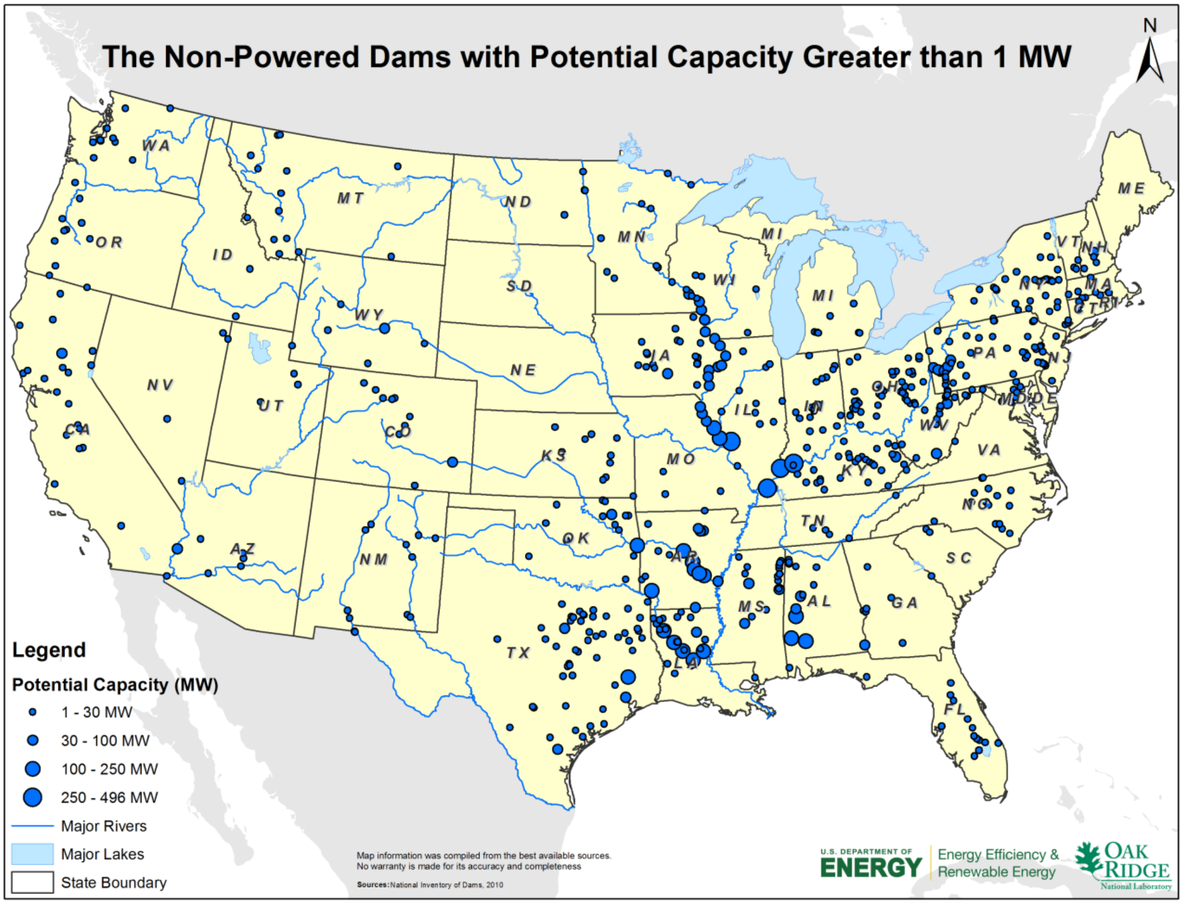

Figure 7-9: Non-powered dams with potential capacity over 1 MW (Source: DOE [21])

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

Table 7-5: Hydropower potential from non-powered dams by state (Data source: DOE [21])

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 [22].

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 2,314 MW of utility scale installed wind capacity at the end of 2019 compared to 69.4 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 335 MW of installed solar at the writing of this report.

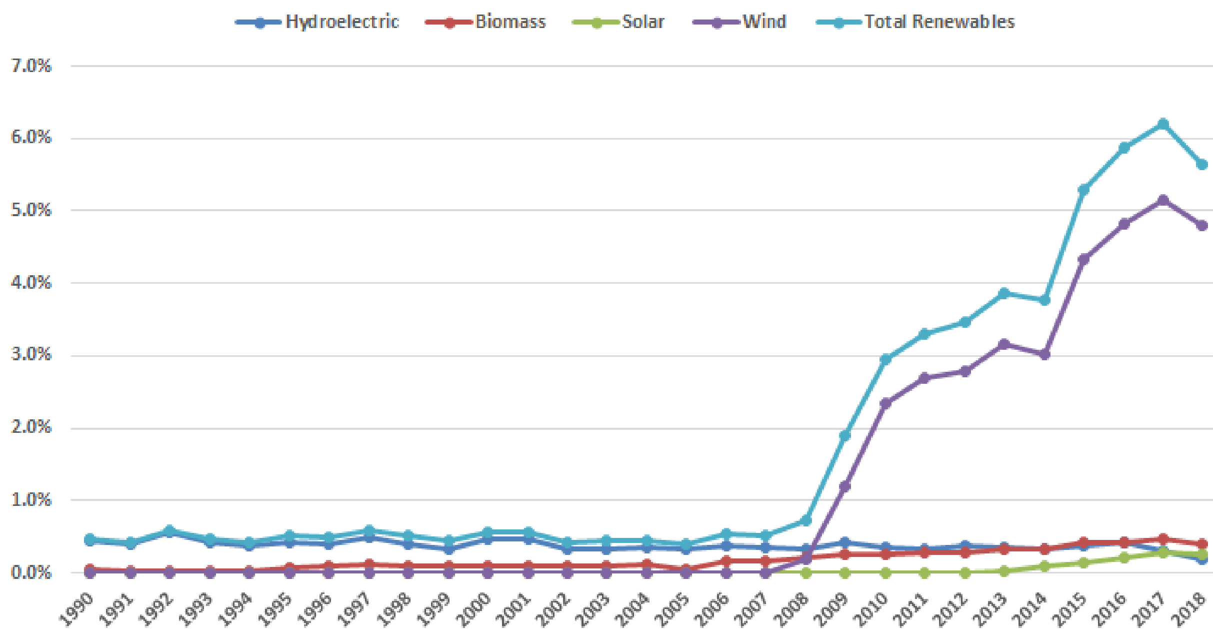

Figure 7-10: Renewables share of Indiana net electricity generation (1990-2018) (Data source: EIA [23])

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 [22]. 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 [22])

American Municipal Power (AMP), a wholesale electricity supplier to municipal utilities in Ohio, Pennsylvania, Michigan, Virginia, Kentucky and West Virginia has since 2016 been 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 was completed in 2017. One of the projects, the 50 MW Robert Byrd has since been abandoned with city of Wadsworth, Ohio giving up its FERC construction license in 2019. The Cannelton project is located on the Indiana/Kentucky section of the river [24, 25].

In August 2019 the University of Notre Dame broke ground on a project to construct a 2.5 MW hydroelectric plant on the Saint Joseph River in South Bend. Notre Dame and the City of South Bend has had an agreement since 2016 for the University to construct the hydroelectric project as part of improvements planned for the Seitz park in downtown South Bend where the hydroelectric project is located. The Hydroelectric project is expected to be completed in 2022 and is part of Notre Dame's goal to cut its carbon footprint by half by 2030 [26].

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 expires at the end of 2020. That is, facilities must begin construction before December 31, 2020 to qualify [27, 28].
- 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 [27].
- 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 [27, 29].
- High Energy Cost Grant Program administered by USDA is aimed at improving the electricity supply infrastructure in rural areas having extremely high per-household energy costs; that is, 275 percent of the national average and above. Eligible infrastructure includes renewable resources generation [30].
- Green Power Purchasing Goal requires that 7.5 percent of energy used by federal agencies must be obtained from renewable resources [27].

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. Indiana Senate Enrolled Act 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 [27, 31].
- Renewable Energy Property Tax Exemption provides property tax exemptions for solar, wind, hydroelectric and geothermal systems [27].
- 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 [27].
- 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 [27].

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