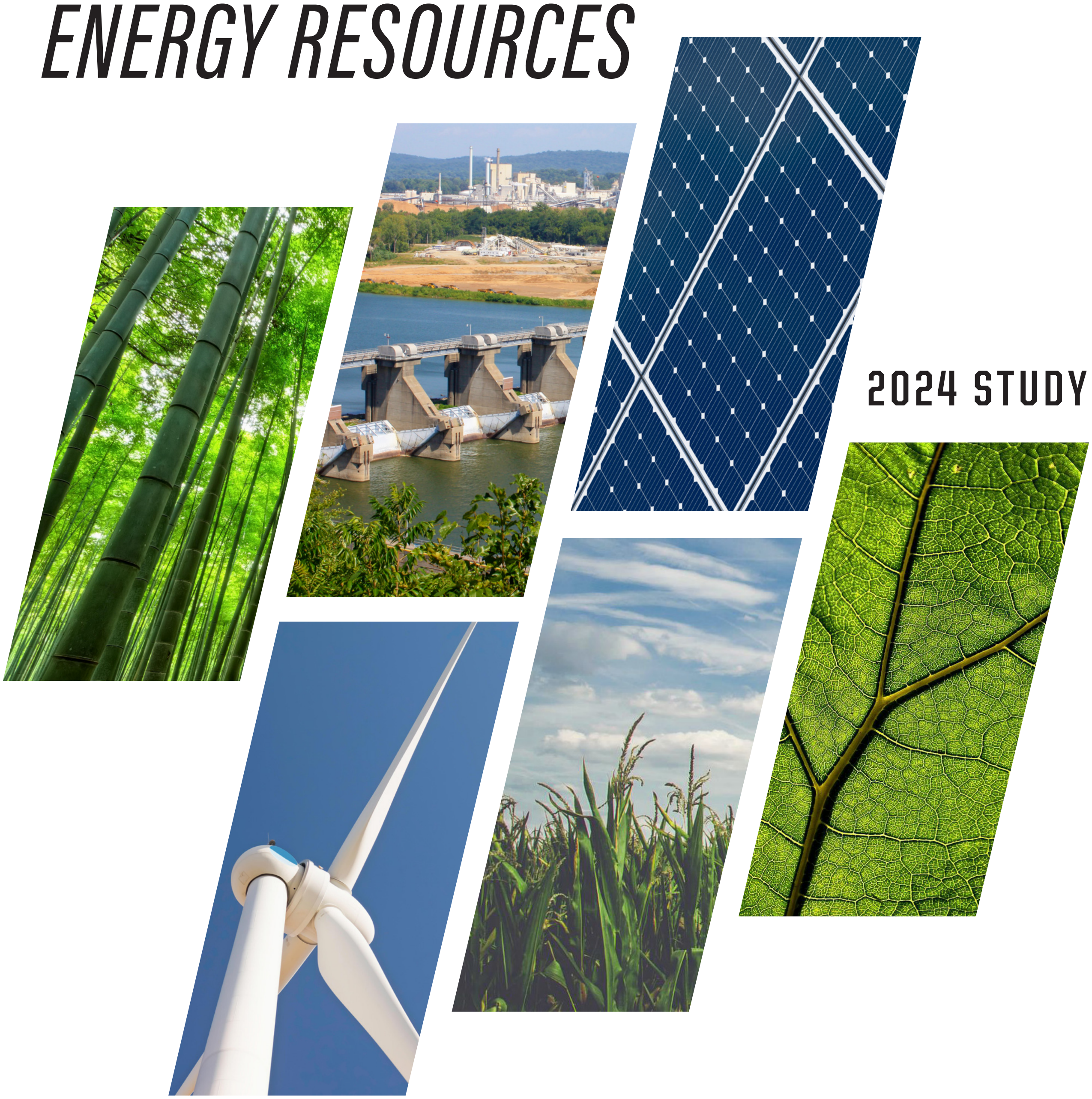
STATE UTILITY FORECASTING GROUP

INDIANA RENEWABLE ENERGY RESOURCES



2024 STUDY

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Purdue Policy Research Institute

2024 INDIANA RENEWABLE ENERGY RESOURCES STUDY

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Table of Contents

List of Figures ... iii
List of Tables ... vii
Acronyms and Abbreviations ... ix

1. Overview ... 1

1.1 Trends in renewable energy consumption in the United States ... 1
1.2 Trends in renewable energy consumption in Indiana ... 6
1.3 Cost of renewable resources ... 12
1.4 Renewable energy incentives in the Inflation Reduction Act of 2022 ... 16
1.5 References ... 18

2. Energy from Wind ... 21

2.1 Introduction ... 21
2.2 Economics of wind energy ... 23
2.3 State of wind energy nationally ... 29
2.4 Wind energy in Indiana ... 36
2.5 Incentives for wind energy ... 42
2.6 References ... 45

3. Dedicated Energy Crops ... 49

3.1 Introduction ... 49
3.2 Economics of energy crops ... 54
3.3 State of energy crops nationally ... 59
3.4 Energy crops in Indiana ... 61
3.5 Incentives for energy crops ... 64
3.6 References ... 66

4. Organic Waste Biomass ... 69

4.1 Introduction ... 69
4.2 Economics of organic waste biomass ... 71
4.3 State of organic waste biomass nationally ... 75
4.4 Organic waste biomass in Indiana ... 79
4.5 Incentives for organic waste biomass ... 86
4.6 References ... 88

5. Solar Energy 93

5.1 Introduction 93
5.2 Economics of solar technologies 96
5.3 State of solar energy nationally 100
5.4 Solar energy in Indiana 103
5.5 Incentives for solar energy 104
5.6 References 107

6. Photovoltaic Cells 109

6.1 Introduction 109
6.2 Economics of PV systems 112
6.3 State of PV systems nationally 117
6.4 PV systems in Indiana 119
6.5 Incentives for PV systems 123
6.6 References 126

7. Hydropower 129

7.1 Introduction 129
7.2 Economics of hydropower 132
7.3 State of hydropower nationally 135
7.4 Hydropower in Indiana 140
7.5 Incentives for hydropower 144
7.6 References 145

8. Underground Pumped Storage Hydropower 149

8.1 Introduction 149
8.2 Economics of underground pumped storage hydropower 151
8.3 State of underground pumped storage hydropower nationally 154
8.4 State of underground pumped storage hydropower in Indiana 156
8.5 Incentives for underground pumped storage hydropower 157
8.6 References 158

List of Figures

1-1 Renewable energy consumption in the United States (1949-2023) 1
1-2 U.S. energy consumption by source (1949-2023) 2
1-3 U.S. total energy consumption by energy source in 2023 3
1-4 Renewable electricity generation in the U.S. (1949-2023) 4
1-5 U.S. electricity generation by source (1949-2023)... 5
1-6 Net U.S. electricity generation by energy source in 2023 5
1-7 Renewables share of Indiana total energy consumption (1960-2022) 6
1-8 Renewables share of Indiana electricity generation (1990-2023) 7
1-9 Wind energy capacity in Indiana 8
1-10 Growth in Installed PV capacity in Indiana 9
1-11 Average construction cost of generation installed 2013 to 2022 13
1-12 Estimated generating technologies capital costs 14
1-13 Estimated generating technologies fixed and variable O&M costs................................... 15

2-1 Horizontal wind turbine configuration 21
2-2 Estimated capital costs of various electric generation options 24
2-3 Average construction cost of generators installed 2013 to 2022 in the U.S...................... 25
2-4 Installed wind power project costs 1982 to 2022 26
2-5 Estimated generating technologies fixed and variable O&M costs.................................... 27
2-6 Average O&M costs for available data years.. 28
2-7 Wholesale energy value of wind 29
2-8 U.S. wind capacity growth 30
2-9 Renewable portfolio standards across the U.S. 31
2-10 Wind power capacity by state at the end of 2023 (MW)... 32
2-11 100-meter U.S. wind resource map 34
2-12 Utility-scale wind farm capacity installed in Indiana 36
2-13 Indiana wind speed at 100 meters height 40
2-14 Indiana wind speed at 50 meters height 41

3-1 Energy crops included in the *2016 Billion-Ton Report*... 51
3-2 Schematic of steps in bioenergy conversion process 52
3-3 Production of energy crops at various farm-gate prices for select years........................... 55
3-4 Supply curves of potential herbaceous energy crop production for select years under base-case assumptions 56
3-5 Supply curves of potential woody energy crop production for select years under base-case assumptions 56
3-6 Bioenergy crop trial stations... 60
3-7 Estimated shares of energy crops and agricultural residues supplied at $60 per dry ton in 2030 61
3-8 Projected production of energy crops in Indiana in 2030.. 62

4-1 Supply curves of potential production from primary crop residues for select years under *2016 Billion-ton* study base-case assumptions 73
4-2 U.S. corn stover supply curve 74
4-3 U.S. renewable energy consumption 1949-2023 75
4-4 Landfill gas projects 77
4-5 Renewables share of Indiana total energy consumption (1960-2022) 80
4-6 Estimated biomass production potential in Indiana 86

5-1 The layout of a flat-plate collector 93
5-2 A parabolic trough CSP system 94
5-3 A linear Fresnel CSP system 95
5-4 A power tower CSP system 95
5-5 A dish/engine CSP system 96
5-6 Estimated capital cost of generating technologies 98
5-7 Operating and maintenance cost of generating technologies 99
5-8 Solar power resource in the U.S. 100
5-9 Solar thermal power capacity installed in the U.S. 101
5-10 Direct normal solar radiation (flat-plate collector) in Indiana 104

6-1 Photovoltaic cell operation 109
6-2 Illustration of a cell, module, panel and array of a PV power plant 110
6-3 Illustration of concentrating photovoltaic cell 111
6-4 Installed price trends among grid-connected, distributed PV systems 112
6-5 Installed price of utility-scale PV systems over time 113
6-6 Average construction cost of generation installed in the U.S. (2013-2022) 114
6-7 Estimated generating technologies capital costs 115
6-8 Estimated generating technologies fixed and variable O&M costs 116
6-9 Installed U.S. PV capacity 117
6-10 Renewable portfolio standards and goals 118
6-11 Growth in Installed PV capacity in Indiana 120

7-1 Schematic of an impoundment hydropower facility 130
7-2 Schematic of a diversion hydropower facility 130
7-3 Oakdale run-of-river hydropower plant in Carroll County 131
7-4 Micro hydropower facility 131
7-5 Schematic of a pumped hydro facility 132
7-6 Capital cost of new U.S. hydropower plants constructed (1980-2020) 133
7-7 Estimated generating technologies fixed and variable O&M costs 135
7-8 Net renewable electricity generation in the U.S. (1949-2023) 136
7-9 Non-powered dams with potential capacity over 1 MW 138
7-10 Renewables share of Indiana net electricity generation (1990-2023) 141

8-1 Schematic of a pumped storage hydropower plant 149
8-2 Schematic of an underground pumped storage hydropower plant 150
8-3 Capital cost of underground pumped storage hydropower plant in an abandoned coal mine in Germany 152
8-4 Location of inactive mines in Indiana 156

List of Tables

1-1 Operating large-scale Solar farms in Indiana 10
1-2 Utility-scale PV projects under construction in Indiana 10
1-3 Approved utility-scale PV projects in Indiana not yet under construction 11

2-1 Wind resource classification 22
2-2 U.S. wind power rankings: top 25 states 33
2-3 Off-shore wind capacity targets and mandates 35
2-4 Indiana wind farms; operating and proposed 37
2-5 Wind energy purchase agreements by Indiana utilities 38
2-6 Wind energy virtual purchase agreements from Indiana wind farms 39

3-1 Integrated biorefinery projects 53
3-2 Commercial integrated biorefinery projects 54
3-3 Ethanol plants in Indiana 58
3-4 Average farm-gate cost ($/ton) for producing switchgrass in Indiana 62
3-5 Cost by category for producing corn stover, switchgrass and miscanthus in Wildcat Creek Watershed 63

4-1 Summary of secondary agricultural wastes potential at select prices and years under *2016 Billion-ton* study base-case assumptions 73
4-2 Location of the 75 municipal solid waste to energy plants in the U.S. 76
4-3 Top ten states for potential electricity generation from swine and dairy farms 78
4-4 Wastewater treatment combined heat and power systems in the U.S. 79
4-5 Electricity generating plants at Indiana landfills 81
4-6 Wabash Valley Power Association landfill electricity projects 81
4-7 Potential electricity generating capacity at Indiana landfills 82
4-8 Operational anaerobic digesters in Indiana 83
4-9 Potential electricity generating capacity at Indiana concentrated animal feeding operations 84
4-10 Potential electricity generating capacity at Indiana wastewater treatment plants 85

5-1 Estimated capital cost of CSP plants in the U.S. 97
5-2 Operating concentrating solar power plants in the U.S. 101
5-3 Concentrating solar power plants in the U.S. that are no longer operating... 102
5-4 Concentrating solar power plants under construction outside the U.S.... 103

6-1 Operating large-scale Solar farms in Indiana 121
6-2 Utility-scale PV projects under construction in Indiana 121
6-3 Approved utility-scale PV projects in Indiana not yet under construction 122

7-1 Initial capital costs of hydropower projects 134
7-2 Ten largest hydropower plants in the U.S.. 136
7-3 Top ten U.S. hydropower generating states in 2022 (GWh)..................................... 137
7-4 Top ten U.S. hydropower capacity states at the end of 2022..................................... 137
7-5 Hydropower potential from non-powered dams by state... 139
7-6 Potential Capacity from non-powered dams owned by the U.S. Army Corps of Engineers….. 140
7-7 Indiana non-powered dams with potential capacity over 1 MW 142
7-8 Potential Capacity from non-powered dams owned by the U.S. Army Corps of Engineers in Indiana… 143

Acronyms and Abbreviations

AC	Alternating current
AES	AES Indiana (formerly Indianapolis Power and Light)
AgSTAR	A joint program of EPA and USDA that promotes the use of biogas recovery systems to reduce methane emissions from livestock waste
AMP	American Municipal Power
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
CEITC	Clean Energy Investment Tax Credit
CEPTC	Clean Energy Production Tax Credit
CHP	Combined heat and power plant
CNG	Compressed natural gas
CO_2	Carbon dioxide
CPV	Concentrating photovoltaic
CRP	Conservation Reserve Program
CSP	Concentrating solar power
DC	Direct current
DOC	U.S. Department of Commerce
DOE	U.S. Department of Energy
DNR	Indiana Department of Natural Resources
DSIRE	Database of state incentives for renewables and efficiency
EDPR	EDP Renewables Corporation
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
FERC	Federal Energy Regulatory Commission
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
IRA	Inflation Reduction Act 2022
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
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
NPD	Non-powered dams

NREL	National Renewable Energy Laboratory, U.S. Department of Energy
NSD	New stream-reach development
NYISO	New York Independent System Operator
O&M	Operation and maintenance
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
RFS	Renewable Fuel Standard
RPS	Renewable portfolio standard
SAE	Indiana Senate Enrolled Act
SEGS	Solar electric generation system
SEIA	Solar Energy Industries Association
SOx	Sulfur oxides
SPP	Southwest Power Pool
SUFG	State Utility Forecasting Group
USACE	United State Army Corps of Engineers
USDA	U.S. Department of Agriculture
VEETC	Volumetric ethanol tax credit
W	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 twenty-second 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 and 2022, clarifying the topics to be covered in the report.

The report consists of eight 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. It also includes a discussion of the incentives in the Inflation Reduction Act of 2022 for renewable and clean energy resources. The next 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. The final section covers underground pumped storage, which was added to the list in Senate Enrolled Act 147 (2022). The sections 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 2024 Indiana Renewable Energy Resources Study report presents overviews of the trends in renewable energy penetration in the U.S. and in Indiana, the cost of renewable resources, and incentives in the Inflation Reduction Act of 2022.

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 2023 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. Since then, biofuels (mainly corn-based ethanol), wind and solar have increased rapidly as sources of renewable energy with biofuels becoming the main source of renewable energy starting in 2016. In 2023, biofuels, wind, and solar combined to contribute 61 percent of the 8.2 quadrillion Btu of renewable energy consumed in the U.S., reducing the combined contribution of hydroelectricity and wood to 28 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 *methyl tertiary-butyl ether* (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.

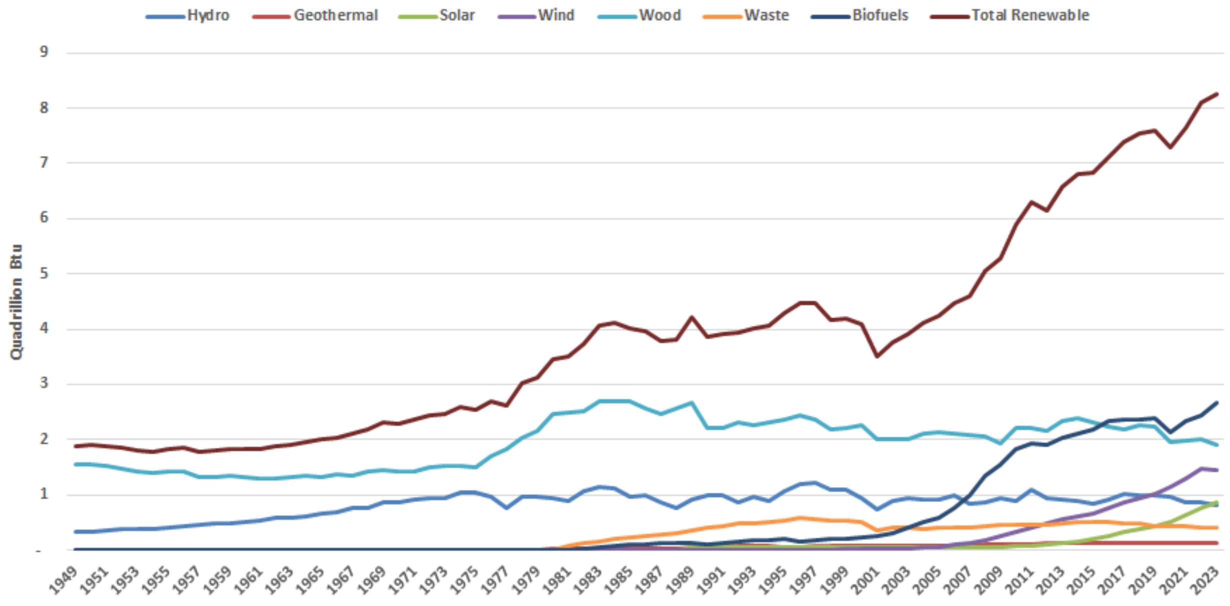

Figure 1-1: Renewable energy consumption in the U.S. (1949-2023) (Data source: EIA [1])

The rapid increase in wind energy started with the introduction of the federal Production Tax Credit (PTC) in 1992 and continued with the enacting 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 and the federal government 30 percent Investment Tax Credit (ITC). Renewable energy resources were given a major boost in August 2022 when the federal government Inflation Reduction Act (IRA) was signed into law. The IRA extended the PTC and the ITC to the end of 2032 [2, 3]. Reductions in the cost of constructing wind and solar have also contributed to the increase in those types of generation.

Despite the rapid growth in the amount of energy from renewable resources in the last two decades as shown in figure 1-1 above, renewable resources contribution remains quite small. Figure 1-2 shows the sources of total energy consumed in the U.S. from 1949 t0 2023. In 2023 renewables share of total energy consumed nationally was 8.8[1] percent. Fossil fuels continue to dominate the energy landscape contributing 82.5 percent of total energy consumed in 2023. Nuclear energy contribution was in the same range (8.7 percent) with renewable resources.

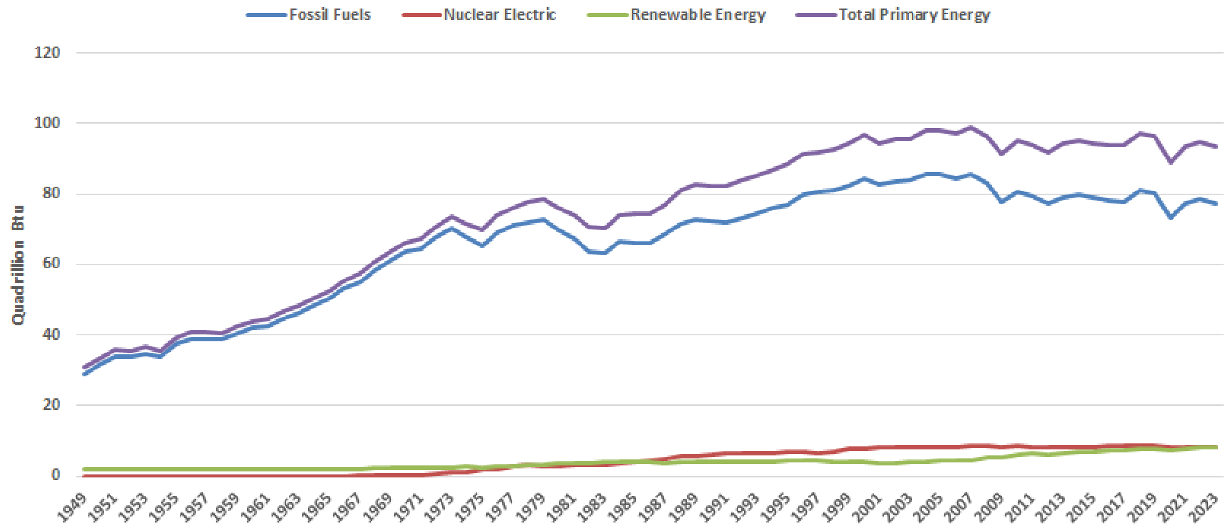

Figure 1-2: U.S. energy consumption by source (1949-2023) (Data source: EIA [4])

Figure 1-3 shows the contribution of the various energy sources to the total energy consumed in the U.S. in 2023. Petroleum (38 percent) and natural gas (36 percent) continue to be the largest sources of energy. Coal's share dropped from 10 percent in 2022 to 9 percent in 2023, while the total renewable energy share increased from 8.5 percent in 2022 to 8.8 percent in 2023. Among renewable resources, biomass (including wood, biofuels, municipal solid waste, landfill gas, and

---

[1] Starting in the September 2023 Monthly Energy Review [5, 6], EIA changed its method of converting electricity generated by non-combustible renewable resources (kWh) into equivalent heat content (Btu) from the "*fossil fuel equivalency*" approach to the "*capture energy*" approach. The net effect was to reduce the Btu equivalent contribution of renewables substantially. By the *fossil fuel equivalency* approach renewables contribution in 2023 would have been 13.4 percent of total energy consumed in the U.S.

others) comprised 60 percent of the total renewable energy. Wind energy's contribution remained at 18 percent of the renewable energy in 2023 compared to hydroelectricity's 10 percent. Solar energy's contribution rose to 11 percent, and geothermal's share stayed at 1 percent.

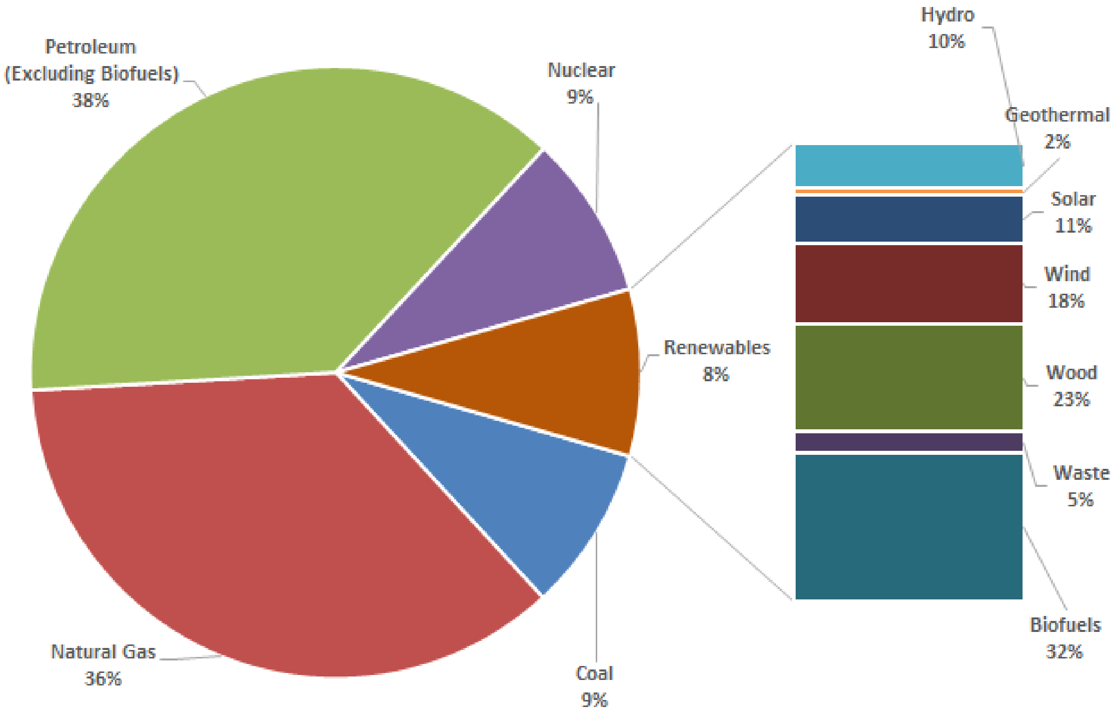

Figure 1-3: U.S. total energy consumption by energy source in 2023 (Data source: EIA [1, 7])

Figure 1-4 shows the growth of renewable resources in electricity generation in the U.S. from 1949 to 2023. Through the late 1980s, hydroelectricity was the sole significant source of renewable electricity generation, at which point wood started gaining prominence, contributing approximately 10 percent of the annual renewable generation. In the early 2000s, wind energy's share of electricity generation started rising rapidly. In 2023, wind accounted for 48 percent of the renewable electricity generated, for the fifth-year surpassing hydroelectricity, whose share of the total renewable electricity generated had dropped to 27 percent. Solar electricity generation has risen rapidly in the last ten years contributing 19 percent of the U.S. renewable electricity generation in 2023. The other sources (geothermal, wood, and waste biomass) contributed a combined total of 7 percent.

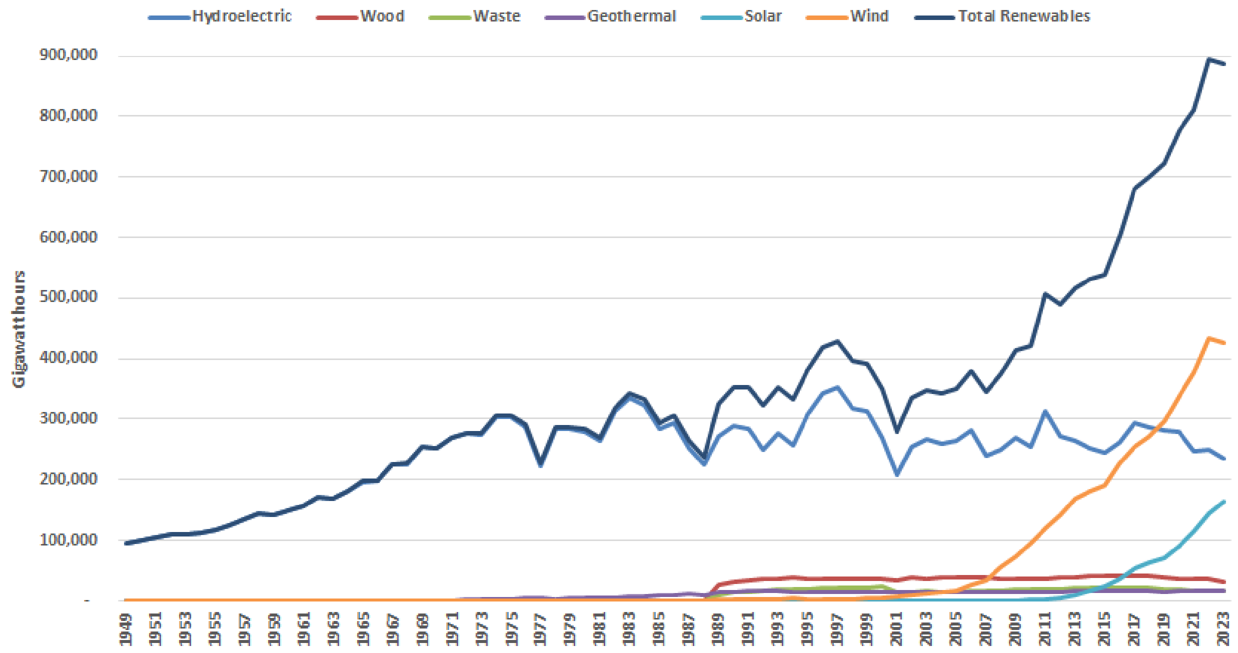

Figure 1-4: Renewable electricity generation in the U.S. (1949-2023) (Data source: EIA [8])

Although the amount of electricity generated from renewable resources in the U.S. has increased rapidly in the last twenty years, fossil fuels continue to be the main source of electricity. Figure 1-5 shows the amount of electricity generated from all sources from 1949 to 2023, while Figure 1-6 shows the share of electricity generated from various energy sources in the U.S. in 2023. Natural gas, coal and nuclear energy still comprise most electricity generation, jointly accounting for 79 percent of the electricity generated in 2023. Renewable resources jointly contributed 21 percent and petroleum less than half a percent. Among renewable resources hydroelectricity and wind played the dominant roles, jointly contributing 76 percent of the renewable electricity generated (48 percent from wind and 28 percent from hydro). Solar contributed 16 percent, wood 4 percent, geothermal and waste biomass 2 percent each. As expected, pumped hydroelectricity's net energy contribution was negative.[2]

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

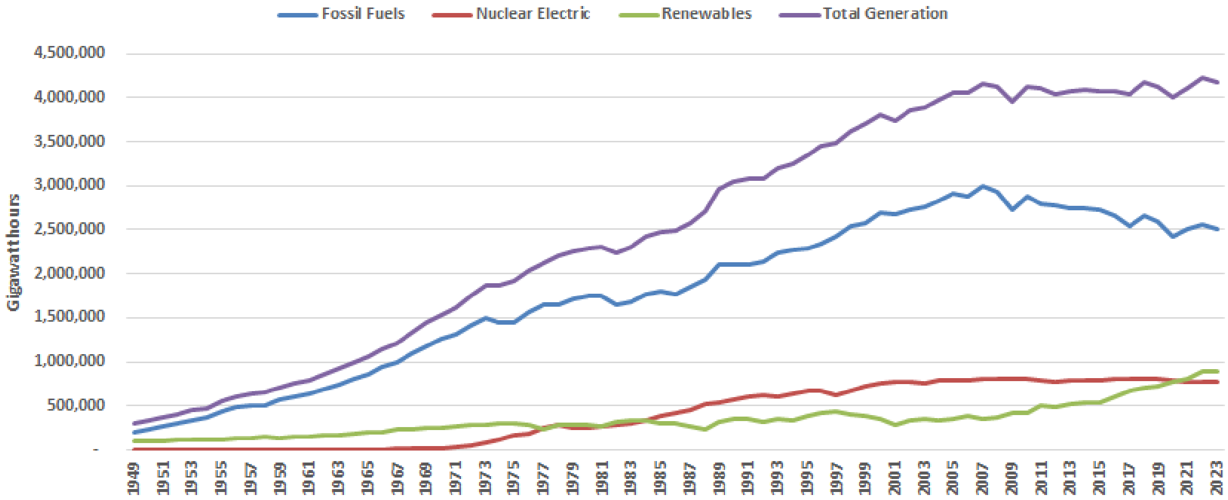

Figure 1-5: U.S. electricity generation by source (1949-2023) (Data source: EIA [8])

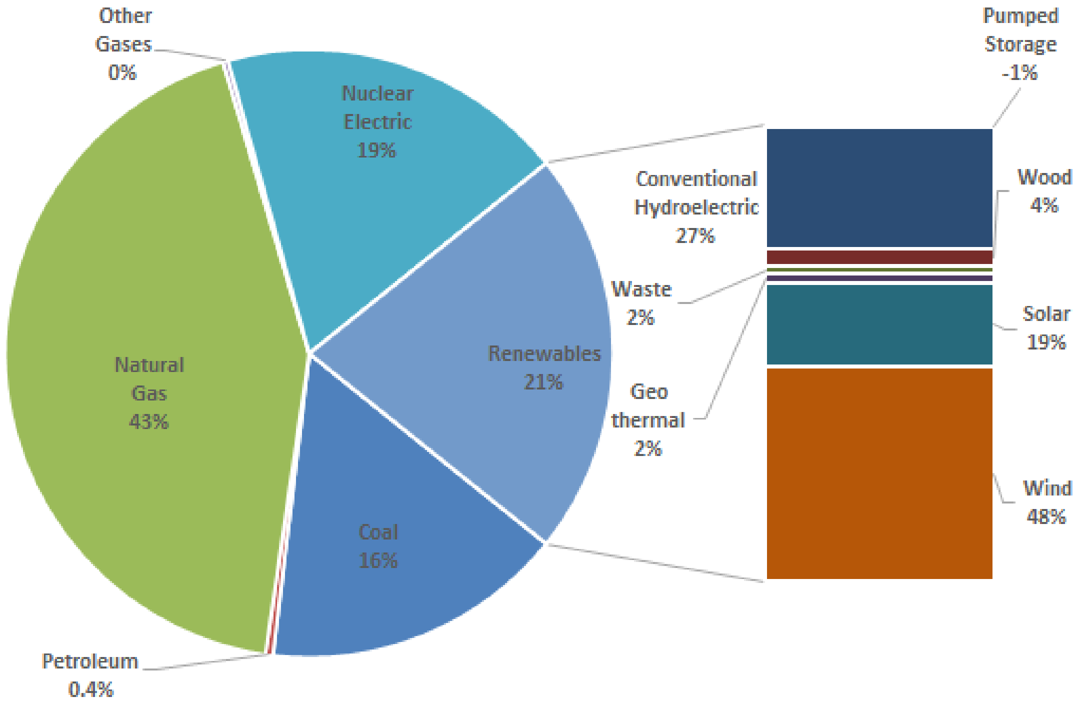

Figure 1-6: Net U.S. electricity generation by energy source in 2023 (Data source: EIA [8])

1.2 Trends in renewable energy consumption in Indiana

Figure 1-7 shows renewable energy consumption in Indiana from 1960 to 2022. 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 beginning in the 2000s increased renewable resources' share to 6.5 percent in 2022. 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 55 percent of the renewable energy consumed in 2022, followed by wind energy contributing 20 percent. Wood and wood waste contributed 19 percent, solar and geothermal each contributed 3 percent.

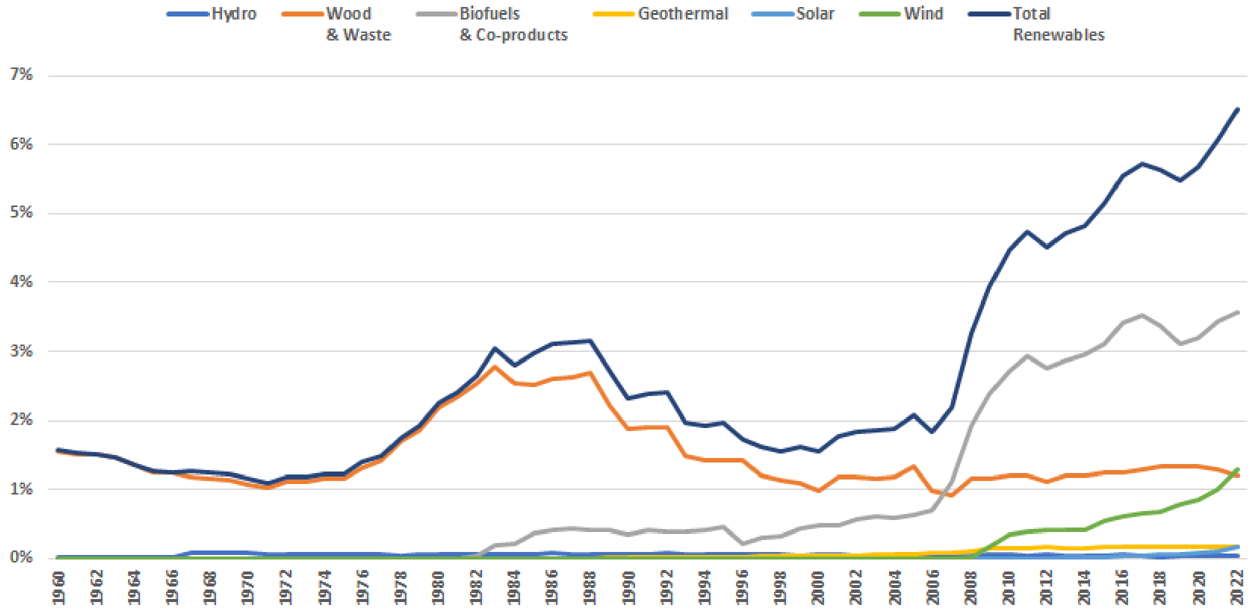

Figure 1-7: Renewables share of Indiana total energy consumption (1960-2022) (Data source: EIA [9])

Figure 1-8 shows the contribution of renewable energy to Indiana's net electricity generation from 1990 to 2022. The construction of utility-scale wind energy projects beginning in 2008 marked the beginning of 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 13.3 percent in 2023. The share of hydroelectricity, which until 2007 was the primary source of renewable electricity, dropped to 0.4 percent of the net electricity generated in Indiana in 2023. Wind energy has become the dominant source of renewable electricity in Indiana, contributing 78 percent of the renewable electricity generated and 10.4 percent of the net electricity generated in 2023. Solar generation has grown from virtually none in 2011 to 1,880 GWh in 2023 which was approximately two percent of Indiana's total net generation, surpassing hydroelectricity as the second largest source of electricity from renewable resources after wind.

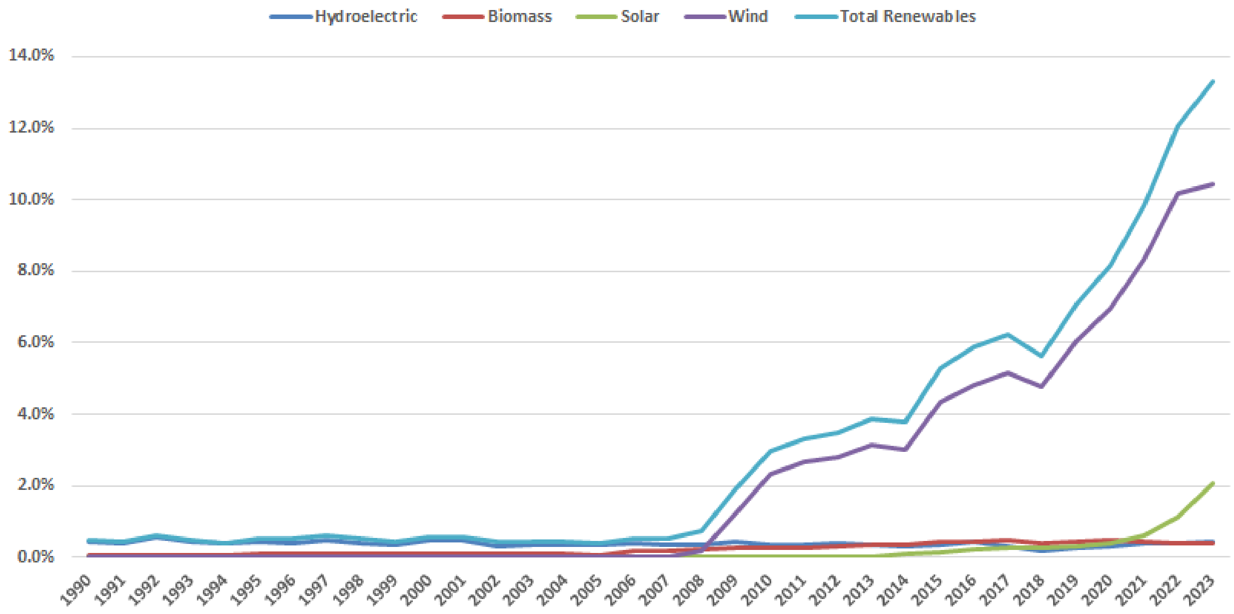

Figure 1-8: Renewables share of Indiana electricity generation (1990-2023) (Data source: EIA [10])

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 2023, the installed utility-scale wind generating capacity stood at 3,668 MW.

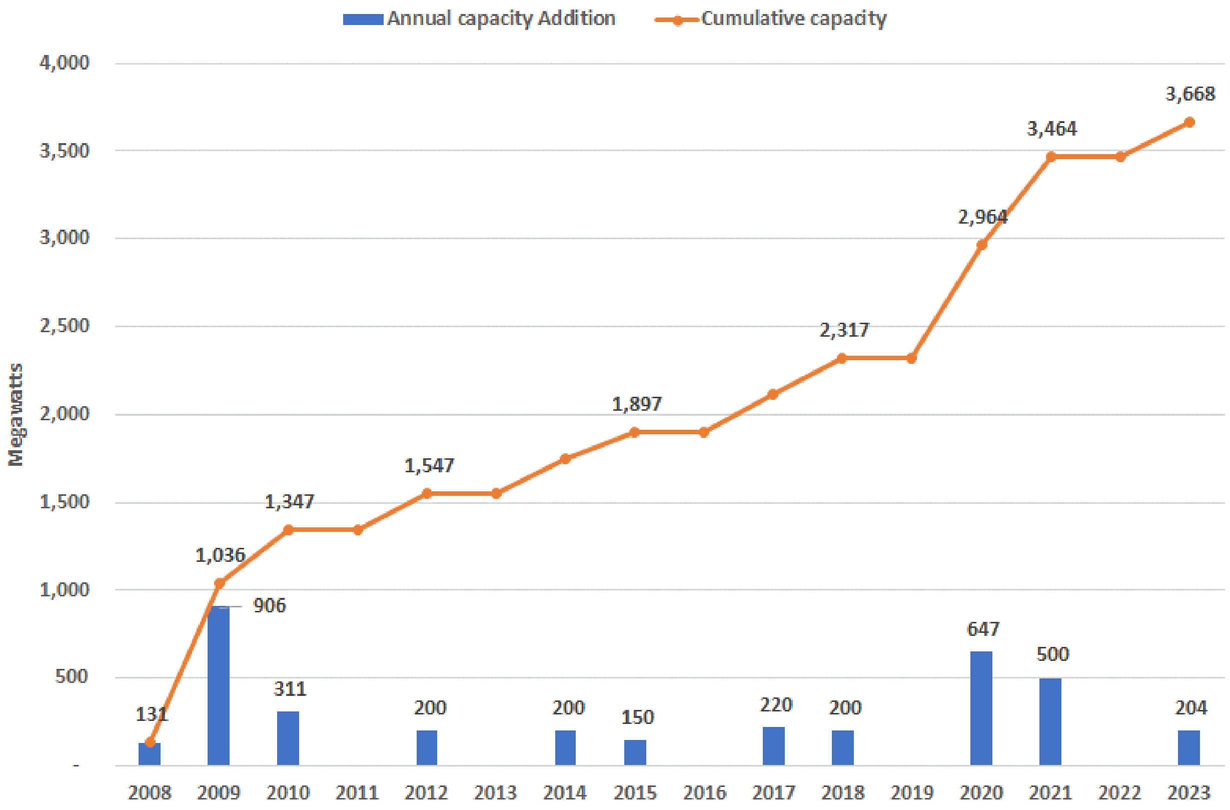

Figure 1-9: Wind energy capacity in Indiana (Data source: IURC [11])

The other renewable resource that has been experiencing rapid growth in Indiana in the last decade is solar photovoltaic. The installation of multi-megawatt PV power plants started in 2013 in Indianapolis and in Northern Indiana with the enactment of feed-in tariffs offered by AES Indiana and NIPSCO with such notable projects as the 10 MW solar farm at the Indianapolis International Airport. 96 MW of PV capacity was installed in the AES service territory between 2013 and 2018 through this tariff. At the end of 2023 23 MW of PV capacity had been interconnected to the NIPSCSO system under their feed-in tariff. The other driver for the multimegawatt-sized PV systems was the expansion of the Indiana net metering rule in 2011 to include systems up to 1 MW in capacity. Approximately 188 MW of PV capacity has been installed across the state under the net metering tariff.

With the commissioning of the 200 MW Riverstart Solar Park in Randolph County at the beginning of 2022, the scale of solar farms has entered a new phase where the utilities are now including utility-scale solar farms as part of their generating portfolio, rather than the customer-side net-metered and feed-in tariff previous phase in the previous phase. Figure 1-10 shows the growth in installed PV capacity in Indiana.

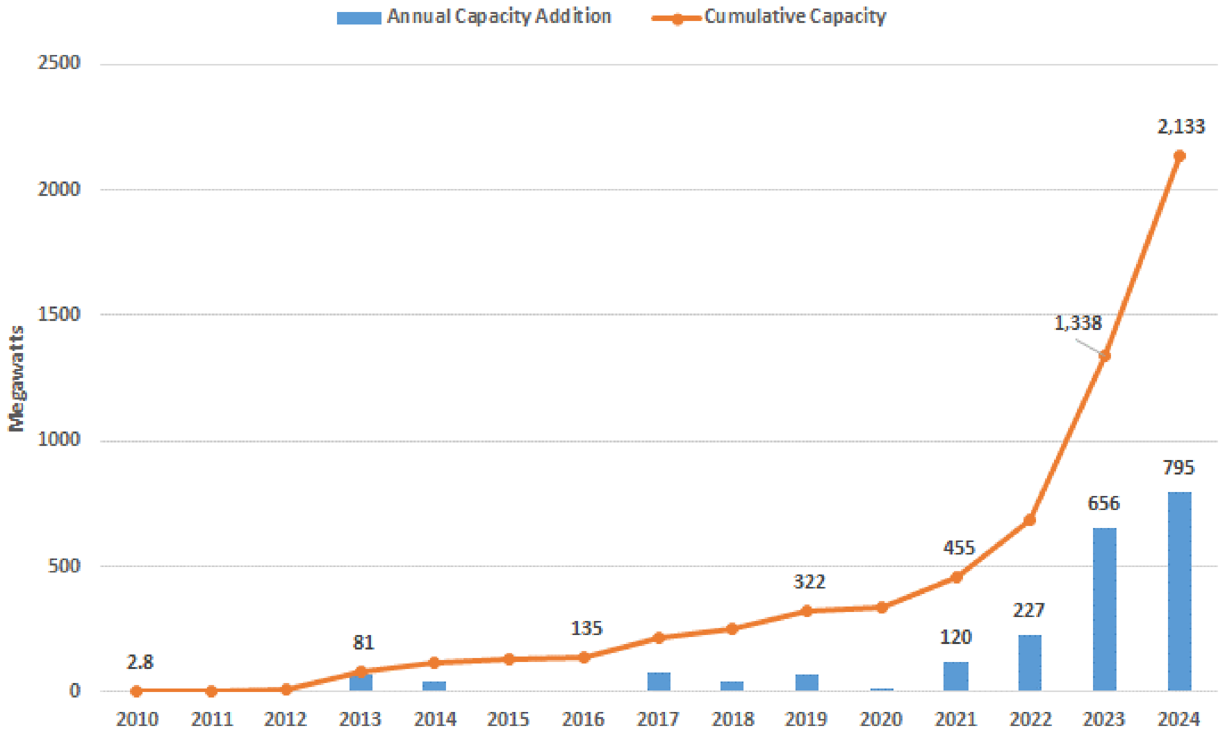

Figure 1-10: Growth in Installed PV capacity in Indiana (Data source: IURC [11, 12], NREL [13])

As of the writing of this report, seven utility-scale projects with a combined capacity of 1,613 MW have been commissioned in Indiana, bringing the installed solar PV capacity total to 2,133 MW. Table 1-1 is a list of these utility-scale projects currently operating in Indiana. Another eleven projects with a combined capacity of 2,471 MW were under construction with the expectation to come online in 2024 and 2025. Table 1-2 is a list of the utility-scale solar farms that were under construction at the writing of this report.

Project	Utility Interconnected	County	Capacity (MW_{AC})	In-service Year
Riverstart Solar Park	Hoosier	Randolph	200	2022
Bellflower Solar Project	Verizon#	Rush & Henry	153	2023
Dunns Bridge Solar Center Phase I	NIPSCO	Jasper	265	2023
Indiana Crossroads Solar	NIPSCO	White	200	2023
Cavalry Energy Center	NIPSCO	White	200	2024
Mammoth Solar Phase I (North)	AEP	Starke & Pulaski	400	2024
Hardy Hills Solar	AES Indiana	Clinton	195	2024

#Bellflower Solar selling its output in a PPA to Verizon Communications

Table 1-1: Operating large-scale Solar farms in Indiana (Data source: IURC [11])

Project	County	Developer	Utility Buyer	Capacity (MW_{AC})	Planned In-service Year
Dunns Bridge Solar/Storage Phase II	Jasper	NextEra	NIPSCO	435	2024
Honeysuckle Solar	St. Joseph	Lightsource	Unknown	150	2024
Mammoth Solar Phase I (North)	Starke & Pulaski	Doral	Unknown	400	2024
Riverstart Solar Park III	Randolph	EDPR	Unknown	100	2024
Twin Lakes Solar	White	ENGIE	Unknown	150	2024
Appleseed Solar	Cass	NextEra	NIPSCO	200	2025
Fairbanks Solar Energy Center	Sullivan	Invenergy	NIPSCO	250	2025
Petersburg Energy Center	Pike	NextEra	AES Indiana	250	2025
Posey County Solar	Posey	Capital Dynamics	CenterPoint	191	2025
Ratts 1 Solar	Pike	Arevon Energy	IMPA	150	2025
Speedway Solar	Shelby	Ranger Power	Duke	199	2025
			Total under construction	**2,471**	

Table 1-2: Utility-scale PV projects under construction in Indiana (Data source: IURC [11])

In addition to the eleven projects under construction at the time this report was written, there was a further thirty five projects with a total combined capacity of 5,993 MW which had received approval from the Indiana Utility Regulatory Commission (IURC) whose construction had not yet started. Table 1-3 is a list of the thirty five projects that had received approval by the IURC but whose construction had not begun as of the writing of this report.

Project	**County**	**Capacity (MW_{AC})**	**Planned In-service date**
Blackford Solar	150	Blackford	2025
Elkhart Solar	100	Elkhart	2025
Gibson Solar Ph1	200	Gibson	2025
Lone Oak Solar Energy	120	Madison	2025
Riverstart Solar Park IV	150	Randolph	2025
Sun Chief Solar	100	Jay	2025
Thalassa Solar***	116.4	Dekalb	2025
Vermillion Rise Solar	185	Vermillion	2025
Cherry Hill Solar Energy	100	LaGrange	2026
Emerald Green Solar	200	Howard	2026
Honey Creek Solar Phase I	200	White	2026
Honey Creek Solar Phase II	180	White	2026
IN Solar 1/Wheatland Solar	150	Knox	2026
Locomotive Solar	200	Howard	2026
Mammoth Solar Phase II (South)	300	Pulaski	2026
Mammoth Solar Phase III (Central)	600	Pulaski	2026
Ratts 2 Solar	150	Knox	2026
Rose Gold Solar	150	Jay	2026
Skycrest Solar	155	Jay	2026
Trade Post Solar	200	Sullivan	2026
Crosstrack Solar	130	Pike	2027
Crossvine Solar	100	Dubois	2027
Foundry Works	200	Lake	2027
Gibson Solar Ph 2	80	Gibson	2027
Honey Creek Solar Phase III	200	White	2027
Lake Trout Solar	245	Blackford	2027
Mayapple Solar	224	Pulaski	2027
Merrillville Solar	57.5	Lake	2027
Moss Creek	200	Pulaski	2027
Reclamation Solar Energy++	150	Gibson	2027
Elliott Solar~	200	Gibson	2028
Crossroads Solar	200	Fountain	NA
Greensboro Solar Center	100	Henry	NA
Rustic Hills Solar	100	Warrick	NA
Rustic Hills Solar II/Warrick Co Solar Project	100	Warrick	NA

Total approved but not started construction **5,993**

Table 1-3: Approved utility-scale PV projects in Indiana not yet under construction (Data source: IURC [11])

Unlike the growth in PV capacity in the 2013 – 2020 period that was driven by favorable incentive rates, the more recent growth of utility-scale PV solar capacity is driven by more fundamental industry-wide issues of the need for replacement capacity for aging generating fleet working in combination with the pressure to lower the carbon emissions of the electricity industry.

In addition, the Federal government has provided a generous incentive package through the Inflation Reduction Act (IRA) signed into law in 2022. In the IRA, the investment tax credit (ITC) available to PV power plants was extended to 2032 in two stages. In the first stage, the ITC was extended to include projects beginning construction before the end of 2024. From 2025 a new 30 percent Clean Electricity Investment Tax Credit (CEITC) kicks in and continues to include projects starting construction in 2032 or until greenhouse gas emissions from the electricity sector fall to 75 percent below the 2022 level. The CEITC is identical to the ITC, except it is expanded to include other non-carbon emitting technologies such as nuclear.

In addition, the Inflation Reduction Act made provision for PV projects to qualify for the 1.5 cents/kWh (1993 dollars) production tax credit, which was extended, like the ITC, to the end of 2024, and also for the new Clean Electricity Production Tax Credit (CEPTC) that runs from the beginning of 2025 to the end of 2032 or until greenhouse gas emissions from the electricity sector fall to 75 percent below the 2022 level. A more detailed presentation of the CEITC, CEPTC, and other incentives in the Inflation Reduction Act is given in Section 1.4 of this report.

1.3 Cost of renewable resources

Figure 1-11 shows the average construction cost of wind and solar photovoltaic facilities installed in the U.S. from 2013 to 2022. Included also for comparison is the cost of combustion turbine and combined cycle power plants installed in the same time period. As can be seen in the figure, the capital cost of PV has dropped by 57 percent from $3,705 in 2013 to $1,588 in 2021. Onshore wind generation capital cost has fallen by 23 percent in the same time period from $1,895/kW in 2013 to $1,451/kW in 2022.

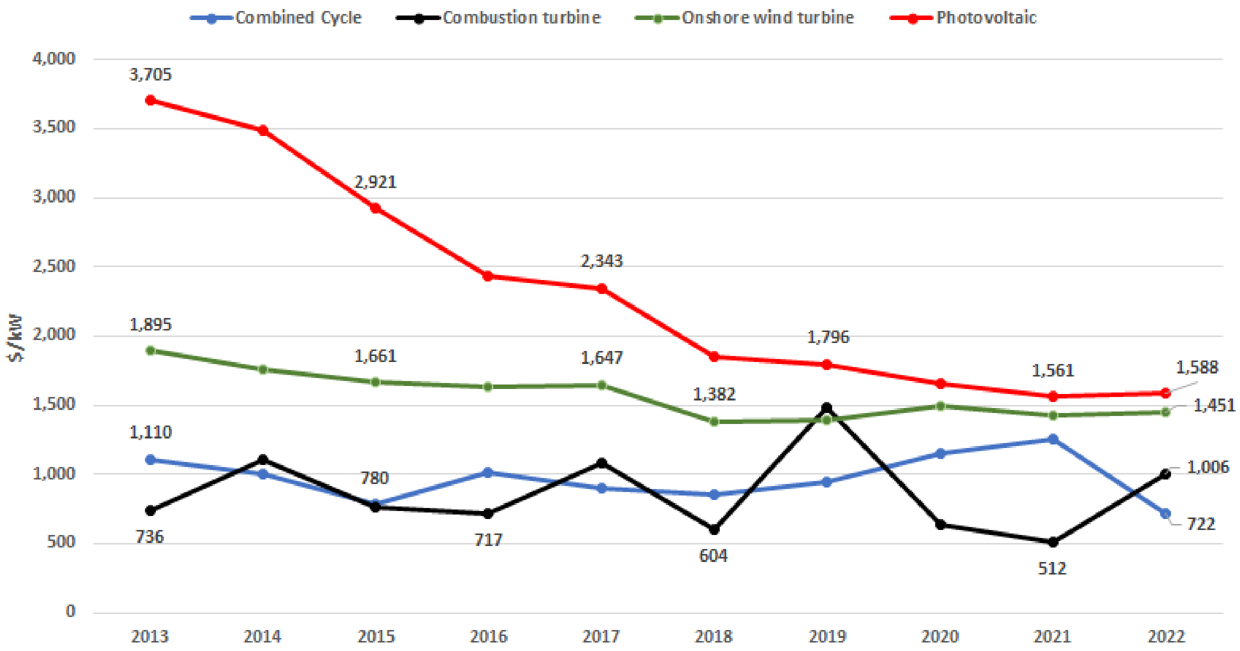

Figure 1-11: Average construction cost of generation installed 2013 to 2020 (Data source: EIA [14])

Figure 1-12 shows the estimated cost of future generating plants modeled in the 2023 EIA Annual Energy Outlook. Since the 2021 Annual Energy Outlook, EIA estimated the cost of a PV plant to be lower than the cost of a wind power plant. The capital cost of a PV plant is estimated at $1,448/kW as compared with $2,098/kW for an onshore wind power plant.

The estimated cost of renewable generators is still, for the most part, higher than that of fossil fuel generators that would be considered for installation currently. For example, the capital cost of PV with tracking is 9 percent higher than that of a single-shaft combined cycle plant, 23 percent higher than that of a multi-shaft combined cycle plant, and 67 percent higher than that of an industrial frame combustion turbine.

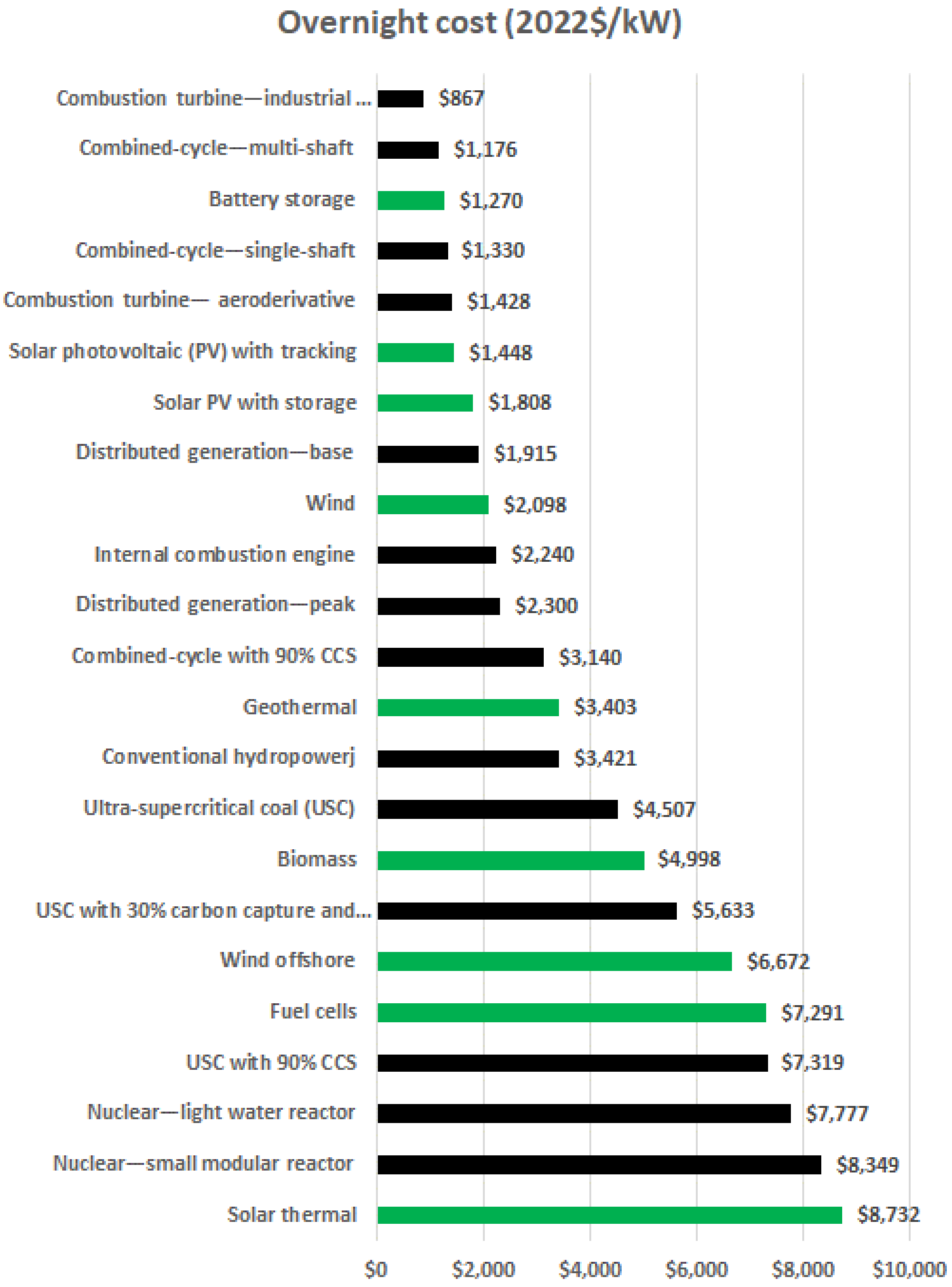

Figure 1-12: Estimated generating technologies capital costs (Data source: EIA [15])

Figure 1-13 shows the EIA estimated fixed and variable operating and maintenance (O&M) costs of the future generating technologies modeled in the 2023 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 when it comes to variable O&M costs, renewable resource generators, except for biomass-based ones, have a clear advantage;

renewable generators such as wind and solar have virtually no variable O&M costs. In addition, most renewable generators have no fuel cost since their fuel (sunlight and wind) is free.

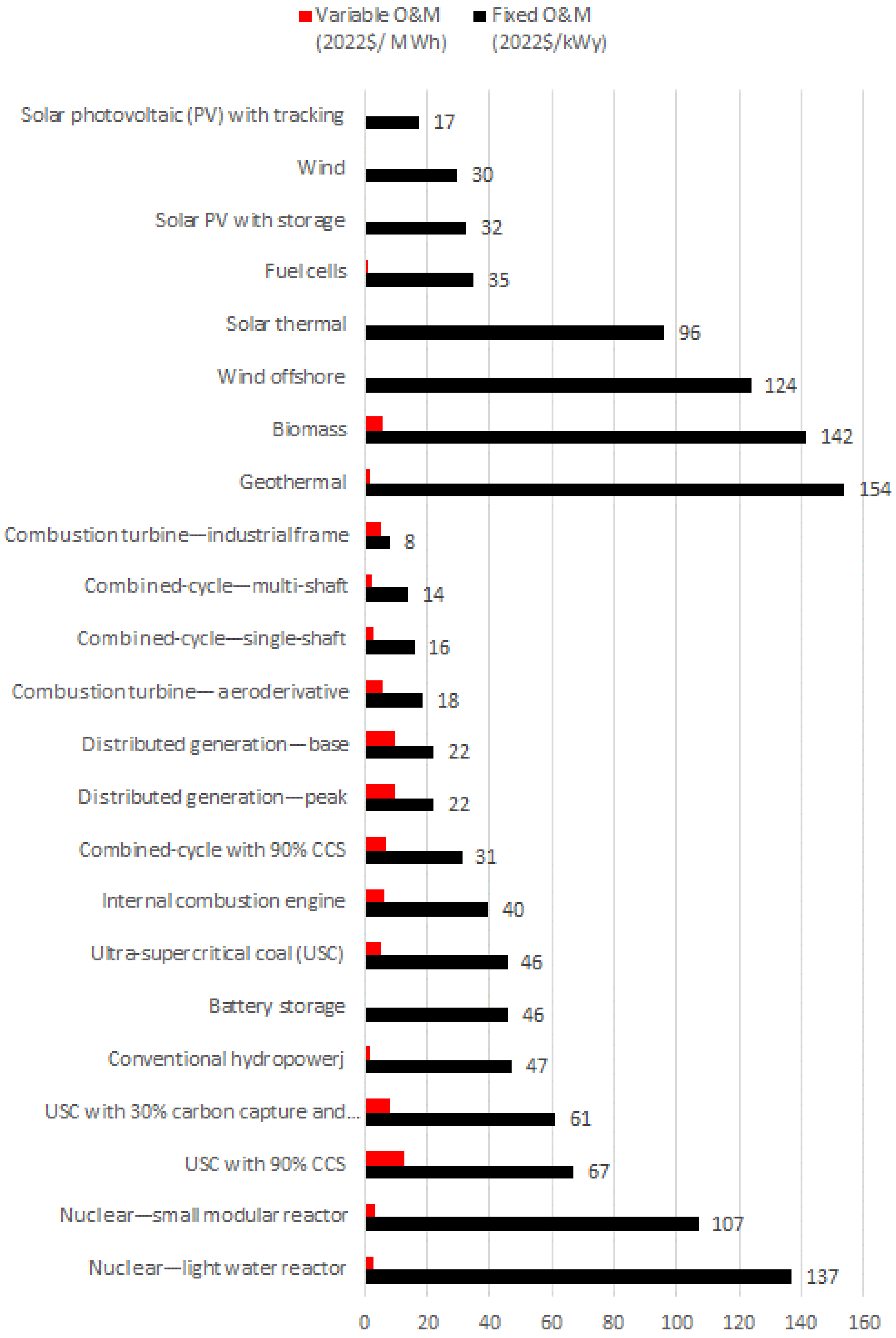

Figure 1-13: Estimated generating technologies fixed and variable O&M costs (Data source: EIA [15])

1.4 Renewable Energy Incentives in the Inflation Reduction Act of 2022

The Inflation Reduction Act 2022 (IRA), signed into law in August 2022, extended and expanded the tax incentives available to renewable resources as follows [3, 16, 17].

Extended the production tax credit (PTC) and investment tax credit (ITC)

- The PTC has been extended to include projects beginning construction before the end of 2024 at its full value of 1.5 cents/kWh in 1993 dollars. The PTC for wind had expired at the end of 2021.
- The investment tax credit (ITC) has been extended at its full 30 percent value to include projects starting construction before the end of 2024. The ITC for solar, before this extension, had started scaling down and had been set at 26 percent for projects starting construction in 2022.
- The ability to draw the full value of the PTC or the ITC is subject to a project meeting the prevailing wage and apprenticeship conditions explained in more detail later in this sub-section of the report.

Expanded the PTC and ITC to other generating technologies

- The IRA expands the PTC to include solar generating technology. Previously, solar energy projects had access only to the ITC.
- The ITC has been expanded to include stand-alone energy storage equipment. Until this change, energy storage could only qualify for the ITC if it was coupled with a renewable generating resource such as solar or wind.
- The PTC was expanded to include electricity generated from existing nuclear power plants. The PTC for nuclear generation starts applying to electricity produced and sold from January 2024 to the end of 2032.
- The credits in this set are also subject to the prevailing wage requirement mentioned earlier.

IRA introduced new Clean Electricity Tax Credits (production tax credit and investment tax credit) which come into effect in 2025. That is, after the expiration date of the traditional PTC and the ITC. The two Clean Electricity credits are

- The Clean Electricity Production Tax Credit (CEPTC) is similar to the traditional PTC, except it expands eligibility for the 1.5 cents/kWh (1993 dollars) to include, in addition to the traditional renewable generating technologies, all other net-zero greenhouse emission technologies. A nuclear power plant would qualify under this category. The CEPTC expires at the end of 2032 or when greenhouse gas emissions from the electricity industry are reduced to 75 percent below 2022 levels.

- The Clean Electricity Investment Tax Credit (CEITC) is similar to the current ITC, except it expands to include all net-zero greenhouse gas emitting technologies such as nuclear. Like the CEPTC, the CEITC phases out at the end of 2032 or when the greenhouse gas emissions from the electricity industry target of 75 percent below 2022 levels is reached.

Prevailing wage and apprenticeship condition. The IRA requires that before a project can draw the full value of any of the above tax credits, all the employees in the project must be paid a wage that is no less than the prevailing wage for their profession at the locality hosting the project. In addition, a specified amount of the labor for the project must be performed by workers participating in an apprenticeship program as defined by the National Apprenticeship Act. A project that does not meet the prevailing wage requirement will be eligible for a much-reduced credit as follows.

- PTC and CEPTC – start at a base rate of 0.3 cents/kWh (1993 dollars) and only go up to 1.5 cents/kWh (1993 dollars) for projects that meet the prevailing wage and apprenticeship requirements.
- ITC and CEITC – start at a base rate of 6 percent and only go up to 30 percent for projects that meet the prevailing wage and apprenticeship requirement.

Projects can earn bonus tax credits if they satisfy the following conditions.

- A project meeting the domestic content condition can earn a 10 percent extra tax credit. To meet the domestic content condition a project has to do the following: use 100 percent U.S. steel or iron, use a specified percentage of its manufactured components using products made or mined in the U.S.
- A project located in an "energy community qualifies for an extra 10 credits." An energy community is defined as a brownfield site, an area that has had significant employment in the fossil fuel industry, or an area that has had a coal mine close or a coal-fired power plant retire.
- A project located in "an environmental justice community" qualifies for a 10 percent extra tax credit. An environmental justice community is defined as a low-income community or Native American land.
- A project located in a low-income economic development project or residential building is eligible for a 20 percent extra tax credit.
- These extra tax credits also apply to the production tax credits, except that for the production tax credits, the 10 percent extra credit is calculated as a percentage of the underlying production tax credit. That is, as a percentage of the 1.5 cents/kWh (1993 dollars).

Direct pay option for non-profit organizations, including local and state governments. The IRA now provides that non-profit organizations can receive cash payment for the tax credit that they would have qualified for if they had been a tax-paying entity.

Tax credits can now be transferred (sold) without attracting a tax liability on the revenue received by the selling entity.

Other clean energy incentives in the IRA that don't directly apply to the renewable resources covered in this report but will have an impact on the broader clean energy industry include.

- An investment tax credit for electric and hydrogen-fueled vehicles: $7,500 tax credit for a new electric or hydrogen-fueled vehicle and $4,000 for a used electric or hydrogen-fueled vehicle.
- Alternative Fuel Refueling Property Credit: Up to 30 percent investment tax credit for electric charger stations.
- A production tax credit for clean hydrogen production projects of up to $3/kg.
- A carbon capture and sequestration credit of up to $85/ton for carbon dioxide that is captured and sequestered geologically and up to $60/ton for carbon dioxide that is reused.
- Advanced Energy Project Credit: up to 30 percent investment tax credit for projects that contribute to domestic manufacture of renewable energy technologies.
- Advanced Manufacturing Production Tax Credit: a production tax credit for domestic production of certain solar and wind components such as inverters, battery components, and critical minerals needed to manufacture them.
- Clean Fuel Production Credit; a production tax credit for clean transportation fuels.

The year 2032 and the "*continuity safe harbor*" effect. Projects that satisfy the IRS-defined "*commence construction*" criteria and hence are eligible for the IRA tax credits have a four-calendar year "*continuity safe harbor*" period for which a project continues to be eligible for the tax credits as long as it satisfies the IRS that it is making continuous progress towards completion. There are two alternative ways of meeting the commence construction criteria.

1. Incur at least 5 percent of IRS qualifying project costs, or
2. Significant physical work be commenced on the project site or on project equipment [18].

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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. Vertical wind turbines are more suitable for smaller urban applications where space is limited, and safety is a 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 wind speed and less turbulent winds [1]. Figure 2-1 shows the basic parts of a modern horizontal axis wind turbine used for electricity generation.

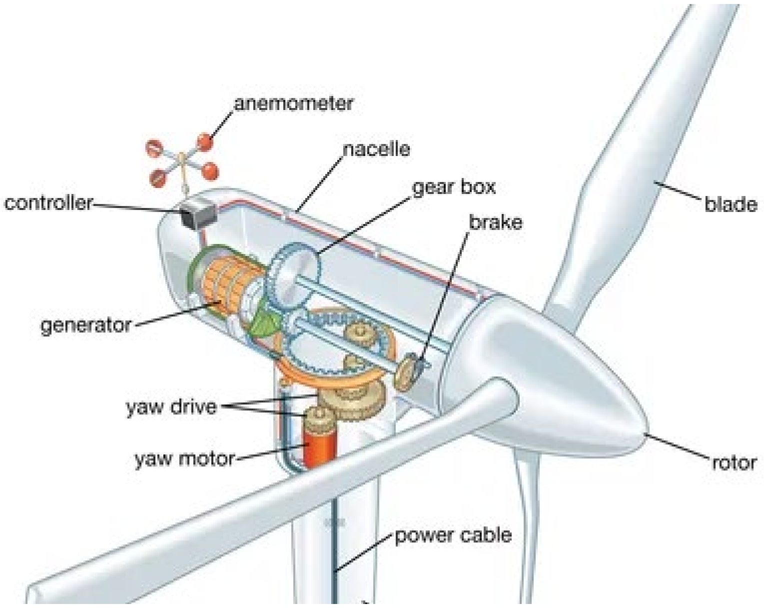

Figure 2-1: Horizontal wind turbine configuration (Source: Alternative Energy News [2])

Although utility-scale wind farms were not installed in the U.S. until the 1980s, windmills were a source of energy for pumping water on farms and ranches in the 19th century and into the early 20th century. Until the rural electrification efforts of the federal government 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 kilowatts (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].

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 nameplate capacity. A baseload coal or nuclear power plant in the U.S. may have an annual capacity factor[3] of over 80 percent, while typically, the capacity factors of wind farms are estimated to range between 20 and 40 percent, depending on the average annual wind speed at their location [5].

Wind speeds are important in determining a wind turbine's performance. Generally, annual average wind speeds of greater than 9 miles per hour (mph) are required for small electric wind turbines, 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. According to the National Renewable Resources Laboratory (NREL), the wind resources available in the continental U.S. can be arranged into ten wind classes, as shown in Table 2-1. Wind class 1 is the highest wind resource level and wind class 10 is the lowest wind resource level. According to NREL, the moderate wind resource class 4 is the representative resource level for a majority of wind projects installed in the U.S.

Wind Class	Wind Speed Range (m/s)	Weighted Average Wind Speed (m/s)
1	> 9.0	9.5
2	8.8 - 9.0	8.9
3	8.6 - 8.8	8.7
4	8.4 - 8.6	8.5
5	8.1 - 8.4	8.2
6	7.6 - 8.1	7.8
7	7.1 - 7.6	7.4
8	6.5 - 7.1	6.8
9	5.9 - 6.5	6.2
10	1.7 - 5.9	5.2

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

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 is 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

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

farm is determined by the level of the wind blowing at the moment and is not under the control of the grid operator. The only control the grid operator can assert is to curtail the output from the wind farm 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 expect from a generator at a future planning date. Since the wind speeds on a particular day many years into the future are unknown, it is difficult to quantify how much power one can expect from the wind farm at any future planning date. 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 the potential adverse effects of the shadow flicker[4] on people living in close proximity to the wind turbine.

2.2 Economics of wind energy

Figure 2-2 shows capital cost estimates for electricity generating plants modeled by the EIA in the 2023 Annual Energy Outlook. The national average cost for a wind farm on land is estimated at $2,098/kW, while the national average for offshore wind is estimated at $6,672/kW. In these estimates, EIA observes that the capital cost of wind (and solar) plants varies widely across the United States. The estimated capital cost of wind varies from a low of $1,566/kW in regions such as Indiana to a high of $3,458/kW in such regions as Northern California. According to EIA, the locational factors affecting the regional variation in wind plant capital costs include such things as the quality of the wind in the region, proximity to existing transmission lines, access to a road network, and availability of lower development cost land.

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

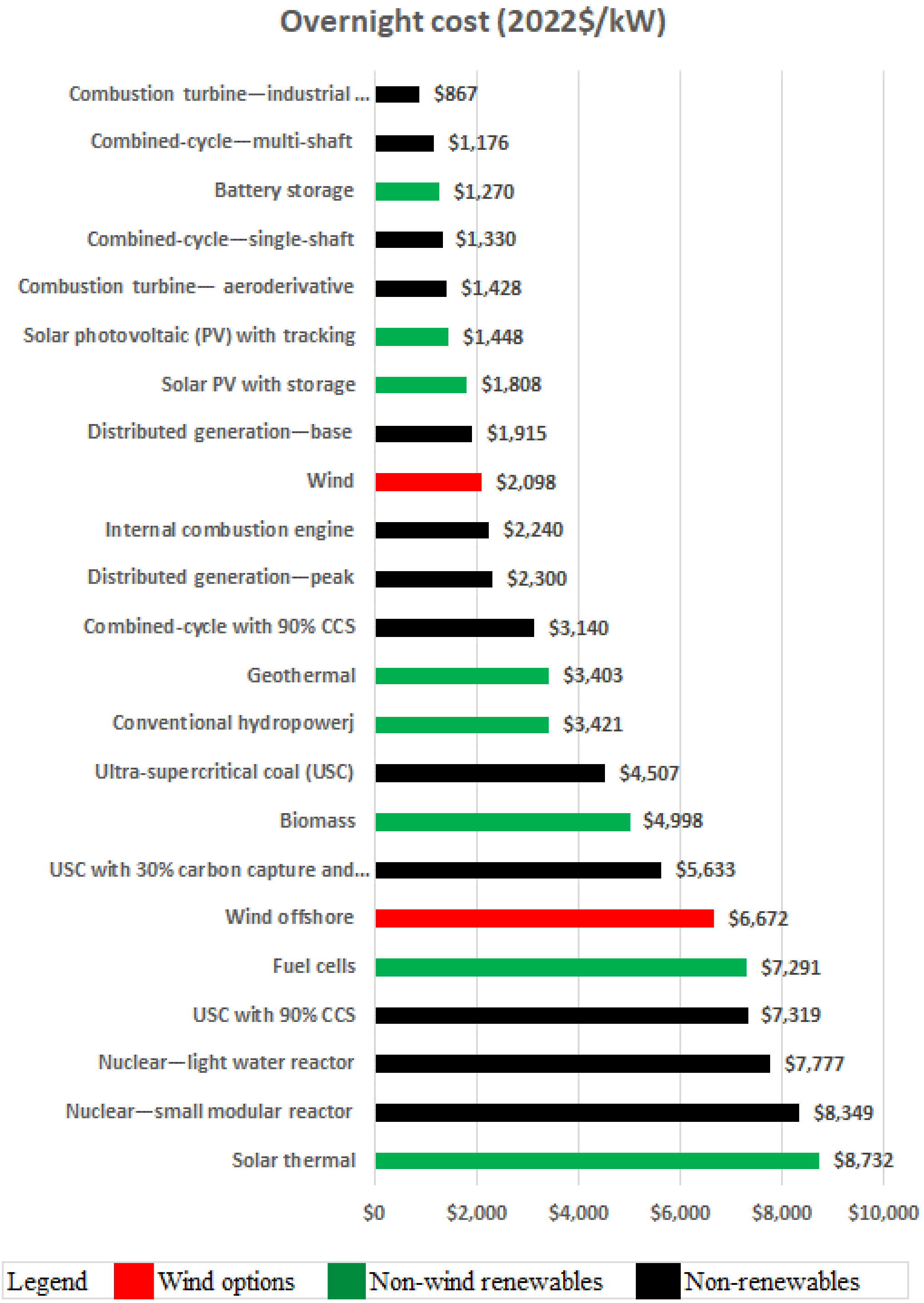


Figure 2-2: Estimated capital costs of various electric generation options (Data source: EIA [7])

Figure 2-3 shows the capacity-weighted average construction cost for wind and other generation technologies installed in the U.S. from 2013 to 2022. As can be seen from the figure, the capital cost of wind has decreased by 23 percent from $1,895/kW in 2013 to $1,451/kW in 2022.

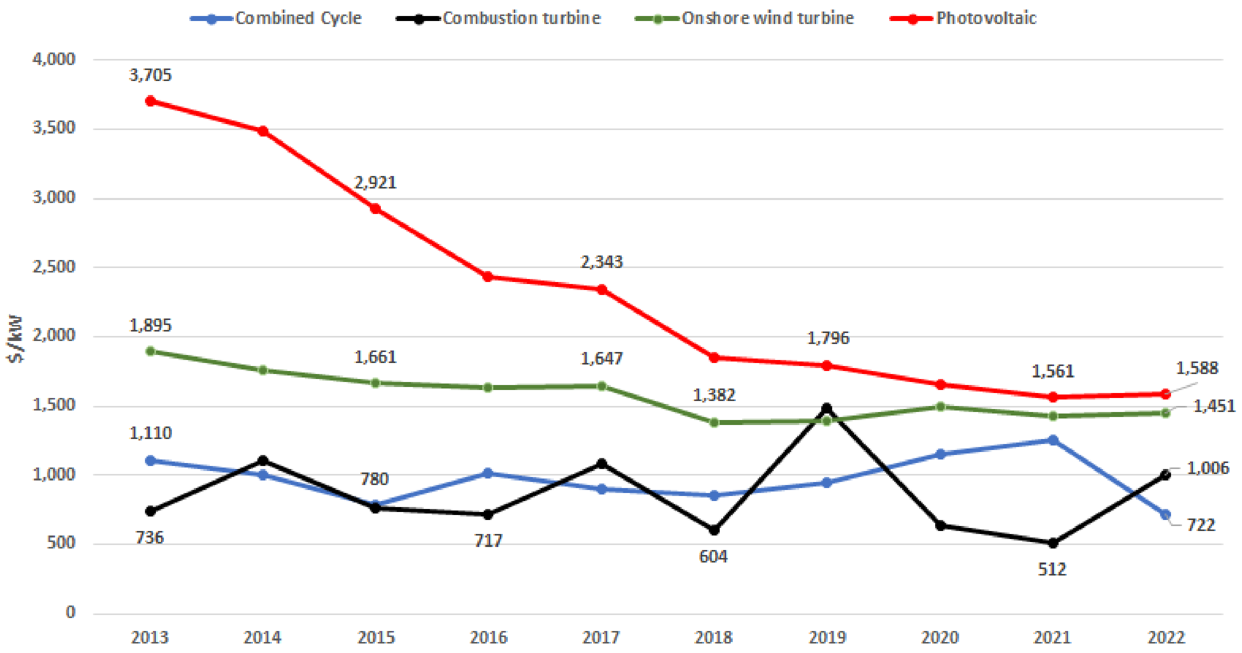


Figure 2-3: Average construction cost of generators installed from 2013 to 2022 in the U.S. (Data source: EIA [8, 9])

Figure 2-4 shows the trend in installed wind power plant costs for the projects from 1982 to 2022 contained in the *2023 Land-Based Wind Market Report* from Lawrence Berkeley National Laboratory (LBNL). As can be seen in the figure, after a period of increasing project costs between 2005 and 2009, the costs have been declining. The 2022 capacity-weighted average installed project cost of $1,367/kW was 52 percent lower than the peak of $2,841/kW reported in 2009.

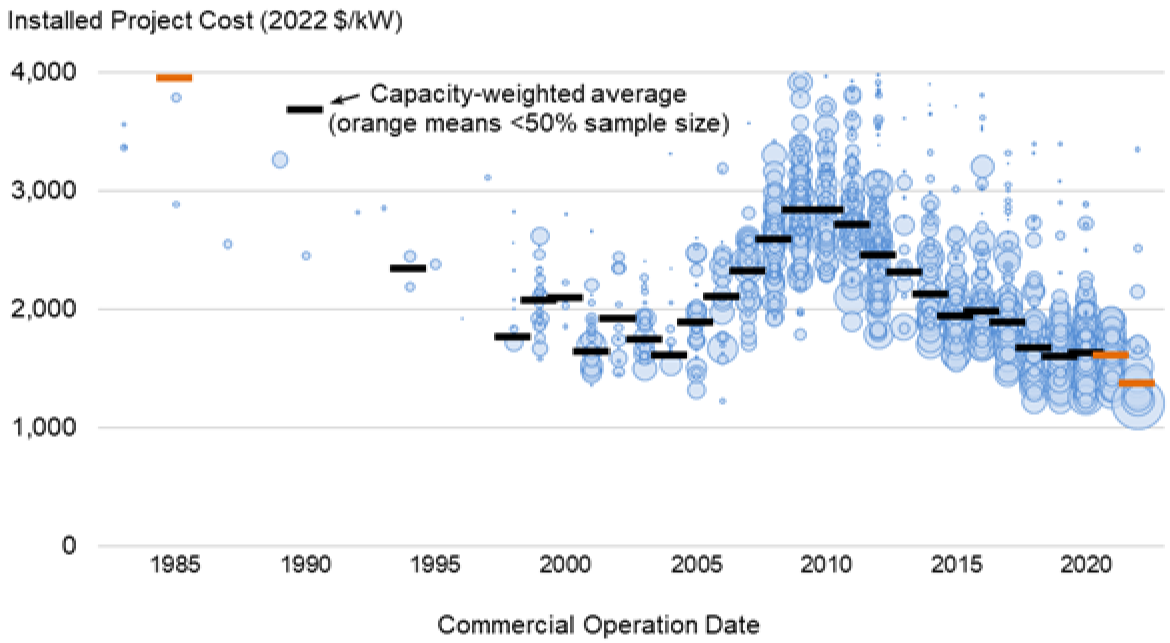


Figure 2-4: Installed wind power project costs 1982 to 2022 (Source: LBNL [10])

Figure 2-5 shows the operating and maintenance (O&M) costs of electricity generating plants according to the EIA March 2023 estimates. EIA estimates the variable O&M to be zero for both land-based and offshore wind farms. The fixed O&M cost is estimated at $30/kW-yr for land-based wind farms and $124/kW-yr for offshore wind farms.

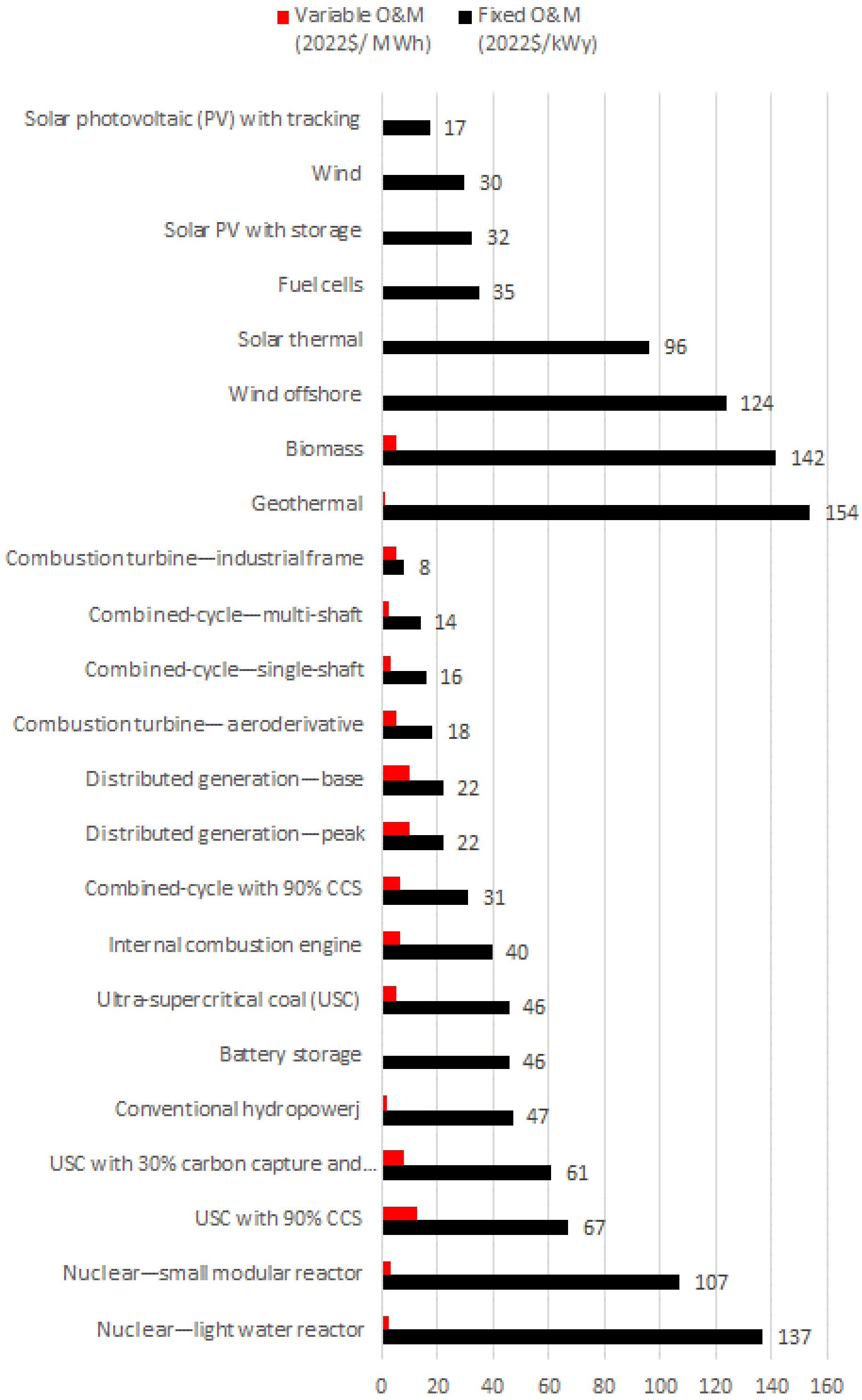


Figure 2-5: Estimated generating technologies fixed and variable O&M costs (Data source: EIA [7])

Figure 2-6 shows the median annual O&M costs by commercial operation date in the 2023 LBNL land-based wind market report. The chart groups the projects into three sets by their commercial operation date, that is, those commissioned from 1998 to 2005, those commissioned from 2006 to 2013 and those commissioned from 2014 to 2021. According to LBNL, the O&M cost data shown should be read with caution because consistent O&M data is not readily available, and even where it is, the costs included as O&M costs may not be consistent among projects. As one would expect, projects commissioned from 1998 to 2005 have a higher median annual O&M cost ($35-84/kW-year) than newly commissioned projects, $26-36/kW-year for projects commissioned between 2014-2021.

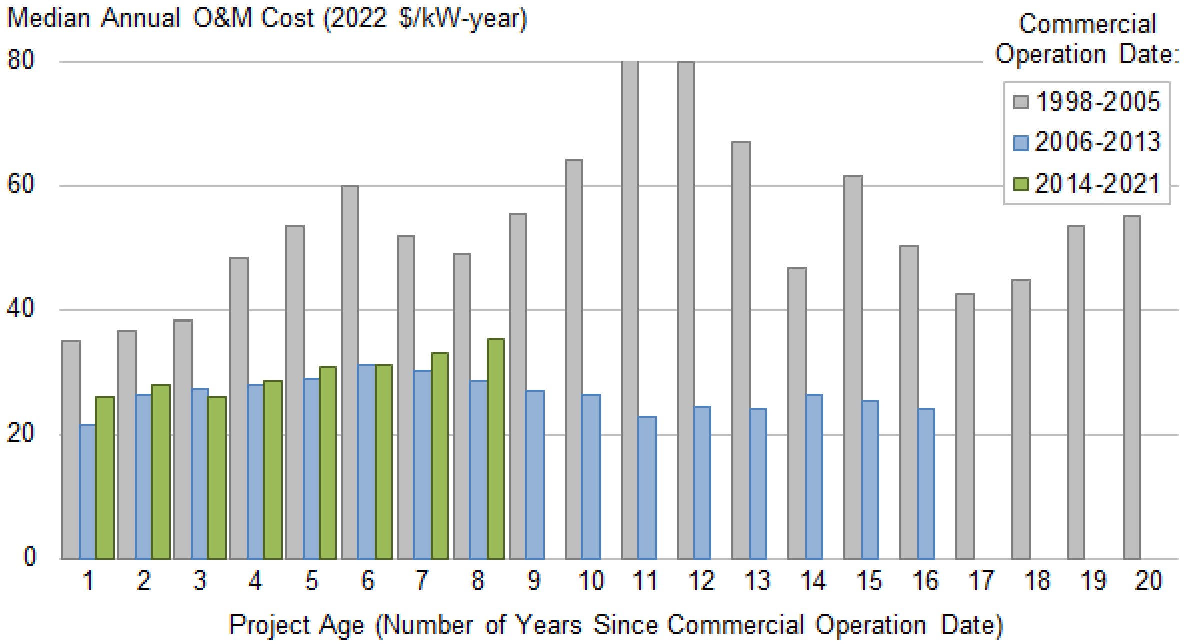


Figure 2-6: Average O&M costs for available data years (Source: LBNL [10])

Figure 2-7 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, falling to its lowest level in 2017, after which it has risen in the last three years but not to the highs of the 2008-2012 period.

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 have mainly remained that way to date. The upward trend in wind's market value in 2017, 2018, and 2022 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.

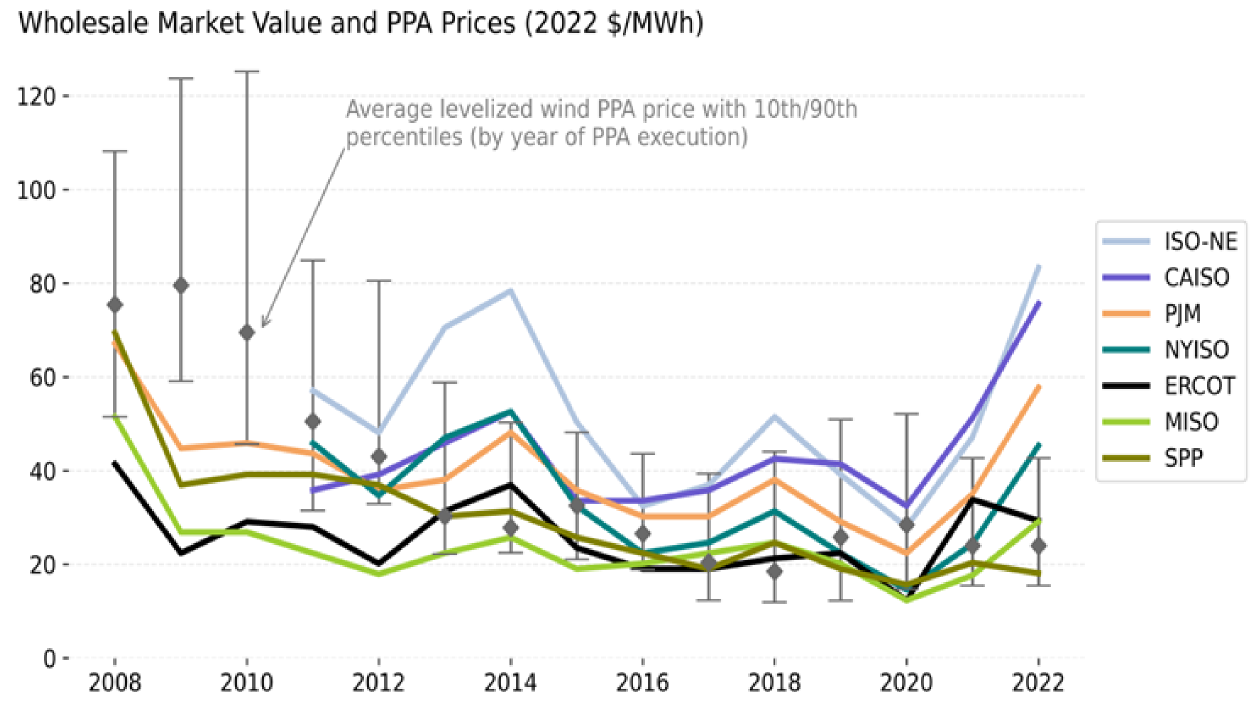


Figure 2-7: Wholesale energy value of wind (Source: LBNL [10])

2.3 State of wind energy nationally

As can be seen in Figure 2-8, U.S. installed wind energy capacity has increased steadily from 1,512 MW total installed capacity at the end of 1998 to 150,427 MW total installed capacity at the end of 2023. In that period wind energy has grown to rival hydroelectricity as the nation's main source of renewable electricity. In 2019 wind energy for the first time overtook hydroelectricity as the largest source of renewable electricity generation in the U.S. The 425,000 GWh of electricity generated from wind in 2023 constituted 48 percent of renewable generation in that year.

The 6,254 MW of wind generating capacity added in 2023 was almost 27 percent lower than the 8,511 MW installed in 2022 and 64 percent lower than the all-time high of 17,213 MW installed in 2020. This slowdown in wind capacity installation was likely due to the supply chain and other disruptions associated with the COVID-19 pandemic, combined with the expiry of the production tax credit at the end of 2021. The production tax credit has since been extended to the end of 2032 by the Inflation Reduction Act (IRA) of 2022.

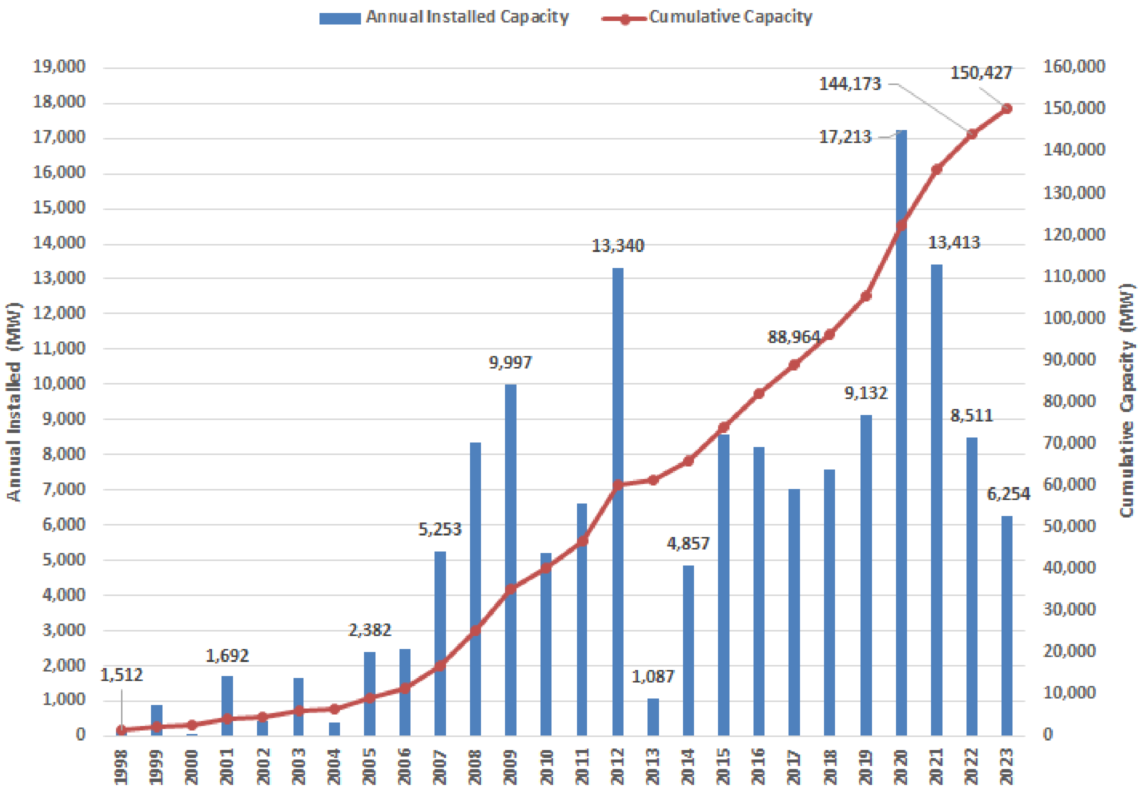


Figure 2-8: U.S. wind capacity growth (Sources: LBNL [10], DOE [11])

Federal and state incentives and renewable portfolio standards continue to play key roles in the growth of the wind energy industry. The various surges and sudden drops in capacity additions seen in Figure 2-8 are associated with the years when the production tax credit was heading to expiration. 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, by 60 percent for projects commencing construction in 2019 and to expire at the end of 2021. In its most recent extension, the credit was extended at its full value (1.5 cents/kWh in 1993 dollars) for ten years by the Inflation Reduction Act signed into law in August 2022 to include projects beginning construction in 2032.

Figure 2-9 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-eight states and Washington, DC, have binding renewable portfolio standards, while seven states, including Indiana, have non-binding renewable portfolio goals. Eleven states have binding clean energy standards, while seven states have non-binding clean energy goals. Clean energy standards differ from renewable portfolio standards in that they also include low-carbon resources such as nuclear energy and coal-bed methane that are deemed to contribute to a reduction in net greenhouse gas emissions.

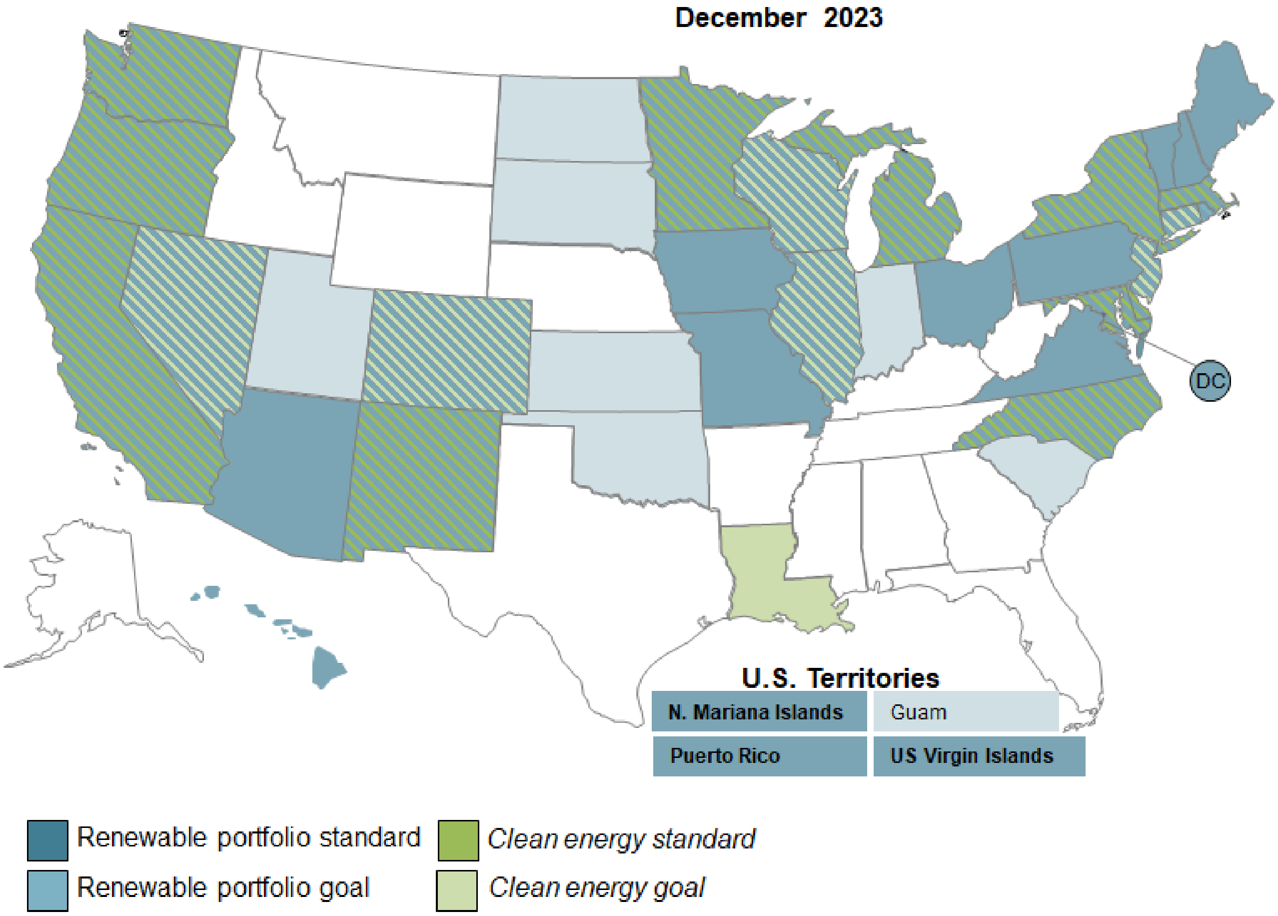


Figure 2-9: Renewable portfolio standards across the U.S. (Source: DSIRE [12])

Figure 2-10 shows the distribution of the 150,427 MW cumulative capacity of utility-scale wind farms installed in the U.S. by state at the end of 2023. Texas continued to lead with a total capacity of 41,577 MW installed, over three times the installed capacity of its closest follower Iowa, which had 13,007 installed. Oklahoma is third with 12,624 MW installed. Indiana ranked 12th overall with 3,658 MW of wind capacity installed.

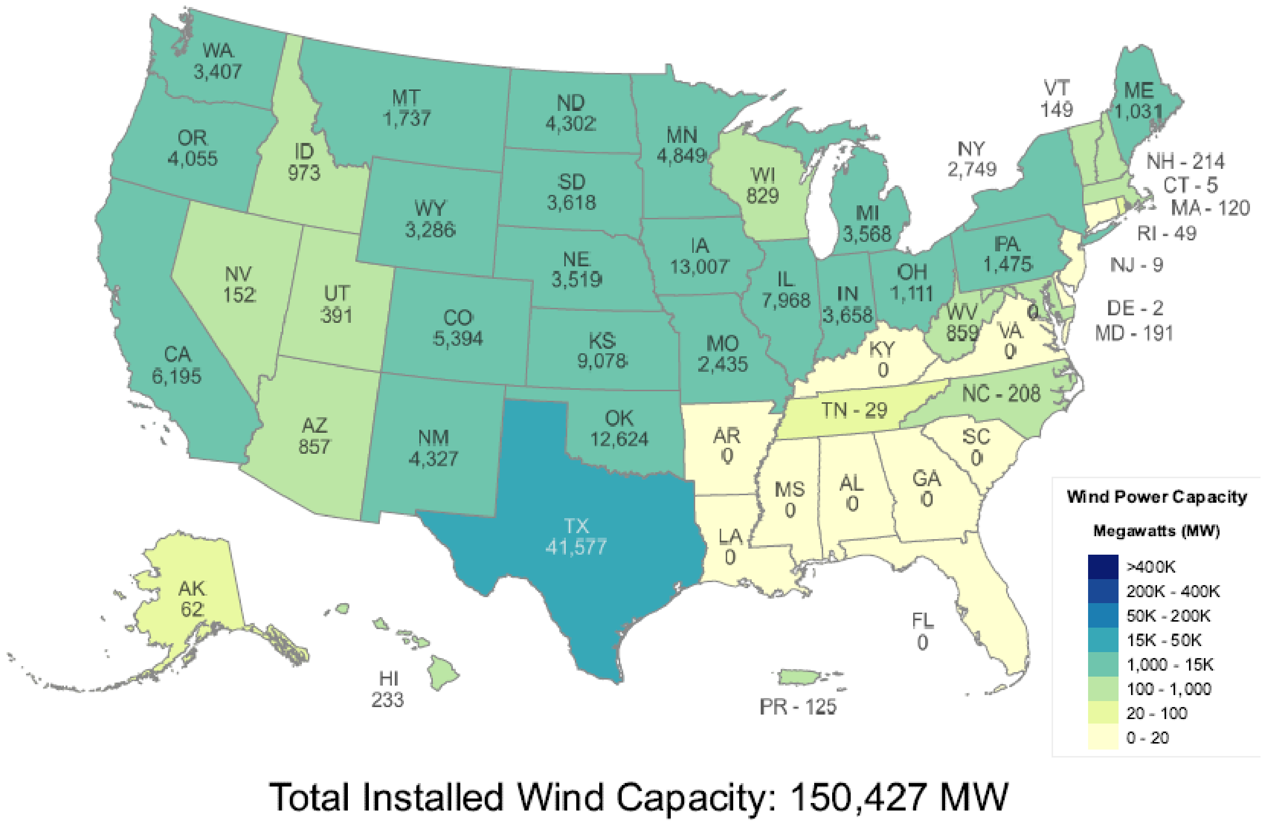


Figure 2-10: Wind power capacity by state at the end of 2023 (MW) (Source: DOE [11])

While Texas led in total capacity installed, Iowa led in the percentage of electricity generated by wind in 2023, at 60 percent. South Dakota followed, with a wind contribution to electricity generated of 55 percent. Indiana ranked 18th overall in the share of wind in electricity generation in 2023, at 10 percent, which was equal to the percent wind contribution to the national electricity generation. Table 2-2 shows the top twenty rankings in wind energy capacity installed and wind electricity generation share of in-state electricity generation in 2023.

State	Installed Wind Capacity December 2023 (MW)		State	Wind Share of Electricity Generation 2023
Texas	41,577		Iowa	60%
Iowa	13,007		South Dakota	55%
Oklahoma	12,624		Kansas	46%
Kansas	9,078		Oklahoma	42%
Illinois	7,968		New Mexico	39%
California	6,195		North Dakota	36%
Colorado	5,394		Nebraska	30%
Minnesota	4,849		Colorado	28%
New Mexico	4,327		Minnesota	25%
North Dakota	4,302		Texas	22%
Oregon	4,055		Maine	22%
Indiana	**3,658**		WY	21%
South Dakota	3,618		Montana	18%
Michigan	3,568		Vermont	16%
Nebraska	3,519		Idaho	15%
Washington	3,407		Oregon	15%
Wyoming	3,286		Illinois	12%
New York	2,749		**Indiana**	**10%**
Missouri	2,435		Missouri	10%
Montana	1,737		Washington	8%
U.S. Total	**150,427**		**US-Total**	**10%**

Table 2-2: U.S. wind power rankings: top 25 states (EIA [13])

The U.S. has significant wind energy potential. NREL estimates the potential onshore wind 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 this potential capacity is approximately 31 million gigawatt hours (GWh). This is approximately seven times the 4,178,171 GWh of electricity generated from all sources in the U.S. in 2023 [14, 15]. Figure 2-11 shows the distribution of the wind resource.

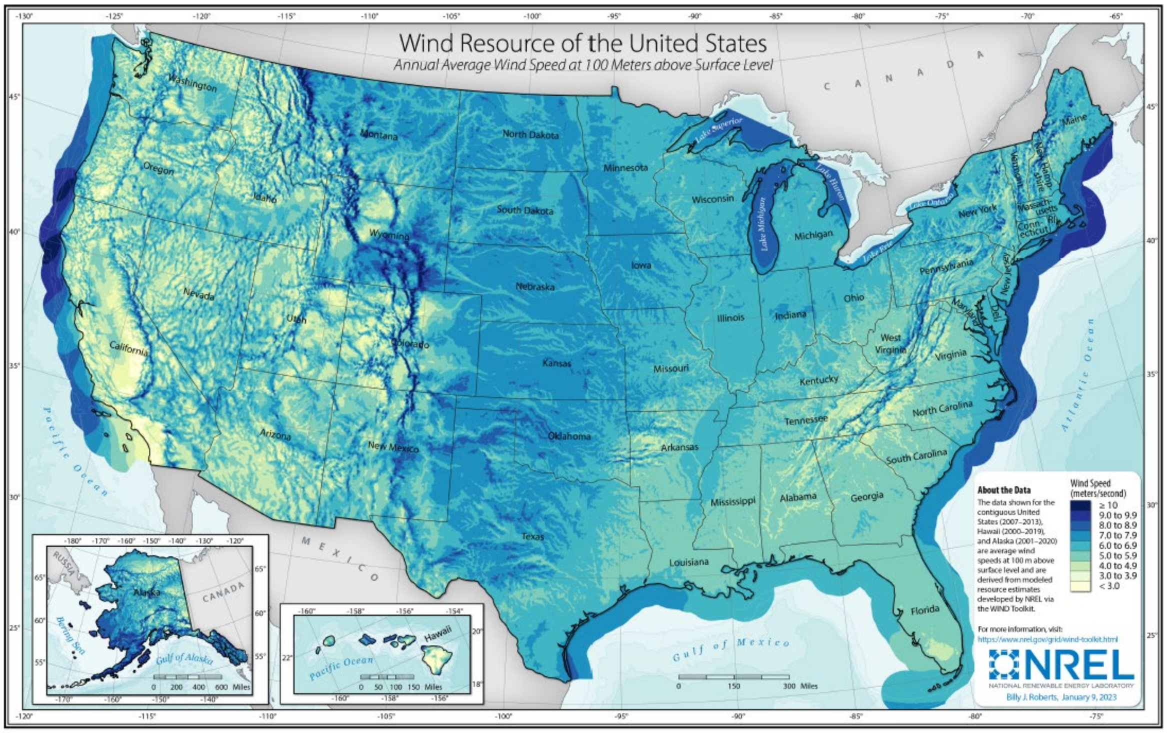


Figure 2-11: <u>100-meter U.S. wind resource map</u> (Source: DOE [16])

As can be seen in Figure 2-11 there is an abundance of wind energy resources along the U.S. coastlines 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 of electricity in a year. This is more than one and a half times the 4,178,171 GWh of electricity generated from all generation resources in the U.S. in 2023 [17].

The first U.S. offshore wind farm, the 30 MW Block Island Wind farm off the coast of Rhode Island, was commissioned by the developer Deepwater Wind in 2016. The second one was the 12 MW Coastal Virginia Offshore Wind project by Dominion Energy completed in 2020. This two-turbine project is a pilot in preparation for a much larger (2,600 MW) proposed offshore wind farm. The third one is the 132 MW South Folk Wind Farm off the coast of New York, commissioned in March 2024 [18].

In a major boost to the offshore wind industry, President Biden set a goal to install 30 GW of offshore wind generating capacity by 2030 in March 2021. In May 2021, the state of California signed an agreement with the federal government to advance offshore wind farms off the coast of California [19, 20].

Even before these recent federal government efforts, several states on the East Coast had set targets and mandates for major offshore wind farm installations to meet their renewable energy and climate mitigation goals. These include 112,286 MW of goals, 42,730 MW of mandated capacity, and 17,546 MW that had power purchase agreements in place for their generation. The targets and mandates are shown in Tables 2-3.

State	**Planning Goal**		**Mandated Procurement**		**Offtake Contracts Awarded (MW)**
	Planning Target (MW)	**Planning Target** Year	**Mandated Capacity (MW)**	**Target Mandate Year**	
California	25,000	2045			-
Connecticut	2,000	2030	2,000	2030	1,104
Louisiana	5,000	2035			
Maryland	8,500	2031	8,500	2031	2,045
Massachusetts	23,000	2050	5,600	2035	3,236
Maine	156	2030			12
New Jersey	11,000	2040	11,000	2040	3,758
New York	20,000	2050	9,000	2035	4,362
North Carolina	8,000	2040			
Oregon	3,000	2030			
Rhode Island	1,430	2030	1,430	2030	430
Virginia	5,200	2034	5,200	2034	2,599
Total	**112,286**		**42,730**		**17,546**

Table 2-3: Off-shore wind capacity targets and mandates (Data Source: DOE [20, 21])

The construction of the first large-scale offshore wind farm, the 800 MW Vineyard Wind Farm located off the coast of Massachusetts, started in 2021 after much resistance from residents of the adjacent coastal area. The project reached a milestone in January 2024 when the first turbine was commissioned and delivered 5 MW of power into the New England electricity grid. Unfortunately, the commissioning process experienced a major setback in July when one of the turbines fell apart, scattering debris into the sea and the adjacent beaches [22].

Towards the end of 2023, the momentum of offshore wind farm development on the U.S. eastern seaboard suffered a major setback as several major projects were canceled, citing the effect of inflation having so increased their capital cost that the projects were no longer financially viable without a big increase in the prices they had agreed to in their power purchase agreements. These include the 804 MW Park City Wind project off the coast of Connecticut, the 2,400 MW Ocean Winds North America project off the coast of Massachusetts, and the 1,232-MW Commonwealth Wind off the coast of Massachusetts [23]

The lone proposed project in the Great Lakes, the 21 MW Icebreaker for Lake Erie near Cleveland, Ohio, has since been abandoned. Even the initial proponents, Lake Erie Energy Development, have come out in opposition to the project. The project had been intended as an experimental one to study the challenges unique to offshore wind projects in freshwater bodies such as freshwater ice and interaction with migratory birds [24, 25].

2.4 Wind energy in Indiana

Since the installation of the first utility-scale wind farm in Benton County in 2008, Indiana's utility-scale wind generating capacity has grown steadily, increasing from 131 MW in 2008 to 3,668 MW at the end of 2023. As of the writing of this report, SUFG was not aware of any wind farms currently under construction. Construction on two wind farms with a combined capacity of 403 MW that had received commission approval had not yet started. Figure 2-12 shows the utility-scale wind capacity installed in Indiana.

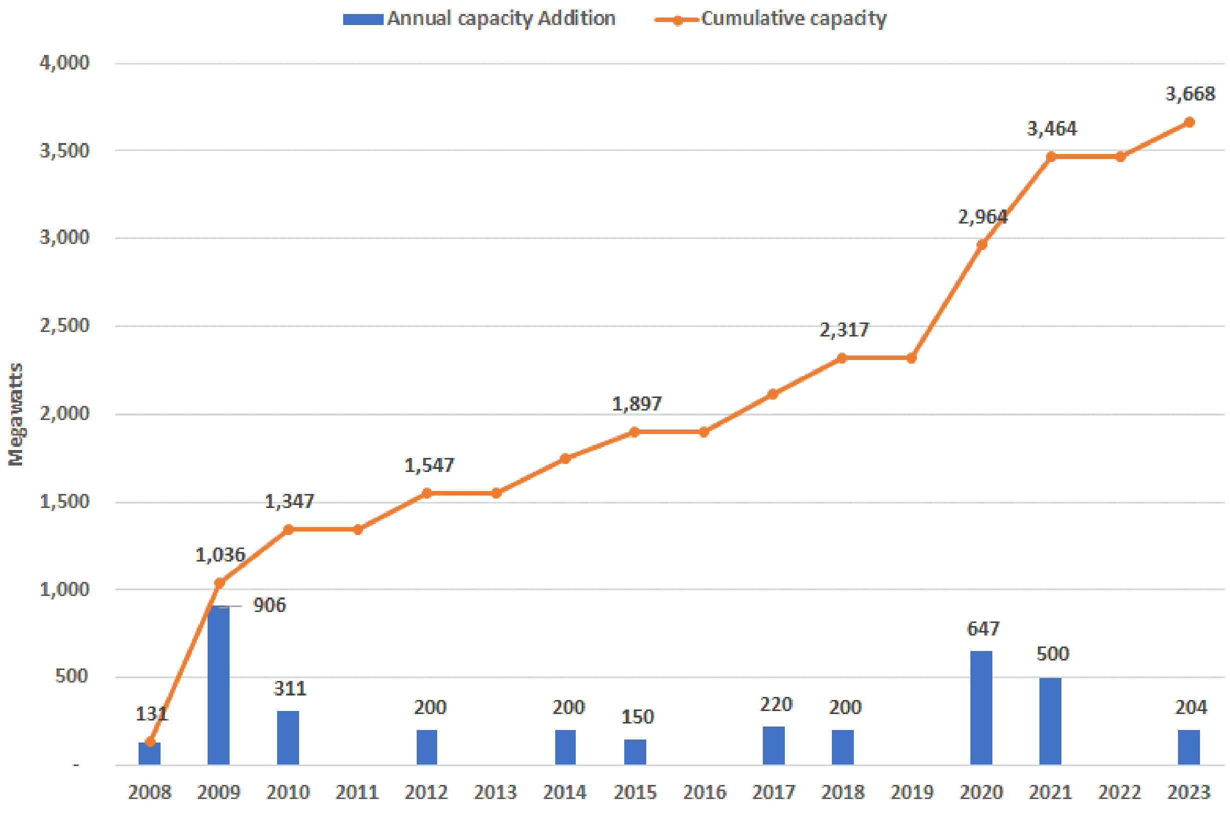


Figure 2-12: Utility-scale wind farm capacity installed in Indiana (Data source: IURC [26]).

Table 2-4 is a list of utility-scale wind farms in Indiana. As of the writing of this report, there were 20 operational wind farms with a combined capacity of 3,866 MW. Two wind farms with a combined capacity of 403 MW had been proposed for Blackford County but construction had not yet started at the writing of this report.

Wind Farm Name	County	Capacity (MW)	In-Service Date
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	102.3	2010
Meadow Lake Wind Farm III	White	110.4	2010
Meadow Lake Wind Farm IV	White	98.7	2010
Wildcat Wind Farm I	Madison/Tipton	200	2012
Headwaters Wind Farm	Randolph	200	2014
Fowler Ridge IV Wind Farm (Amazon)	Benton	149.5	2015
Meadow Lake Wind Farm V	White	100	2017
Bluff Point Wind Farm	Jay/Randolph	119.7	2017
Meadow Lake Wind Farm VI	White	200.4	2018
Bitter Ridge Wind Farm	Jay	146.5	2020
Rosewater Wind Farm	White	102	2020
Jordan Creek Wind Farm	Warren	398.6	2020
Headwaters II Wind Farm	Randolph	198	2021
Indiana Crossroads Wind Farm I	White	302.4	2021
Sweet Acres Wind Farm (previously Indiana Crossroads Wind Farm II)	White	201.6	2023
	Total operating	**3,668**	

Approved but construction not started

Prairie Creek Wind	Blackford	202.5	
Blackford Wind Farm	Blackford	200	

Table 2-4: Indiana wind farms; operating and proposed (Data source: IURC [26])

SUFG is aware of 2,026 MW of wind power contracted in power purchase agreements (PPAs) by Indiana utilities. Out of the total, 1,509 MW (75 percent) is with wind farms located in Indiana and 516 MW (25 percent) with wind farms in Iowa, Illinois, Minnesota, and South Dakota. Table 2-5 shows the wind capacity contracted to Indiana utilities. Two wind farms in White County, the 102 MW Rosewater Wind Farm and the 302 MW Indiana Crossroads Wind Farm I were built for NIPSCO by EDP Renewables on a build-transfer agreement. A build-transfer agreement is where an experienced developer handles the pre-construction permitting and construction process and hands over the project at commissioning.

Utility	Wind Farm Name	State	Power Purchase Agreement (MW)
Duke Indiana	Benton County	Indiana	100
I&M	Fowler Ridge I	Indiana	100
I&M	Fowler Ridge II	Indiana	50
CenterPoint	Benton County	Indiana	30
CenterPoint	Fowler Ridge II	Indiana	50
I&M	Headwaters I	Indiana	200
I&M	Wildcat I	Indiana	100
AES Indiana	Hoosier	Indiana	100
NIPSCO	Jordan Creek	Indiana	400
NIPSCO	Sweet Acres Wind Farm (formerly Indiana Crossroads II)	Indiana	204
WVPA	Meadow Lake V	Indiana	25
WVPA	Meadow Lake VI	Indiana	75.4
Hoosier	Meadow Lake V	Indiana	75
Hoosier	Rail Splitter Wind Farm	Illinois	25
NIPSCO	Barton	Iowa	50
NIPSCO	Buffalo Ridge	South Dakota	50
AES Indiana	Lakefield	Minnesota	200
WVPA	Agriwind	Illinois	6.4
WVPA	Pioneer Trail	Illinois	10
WVPA	Harvest Ridge	Illinois	100
IMPA	Alta Farms II	Illinois	75
		Total Power Purchase Agreements	**2,026**

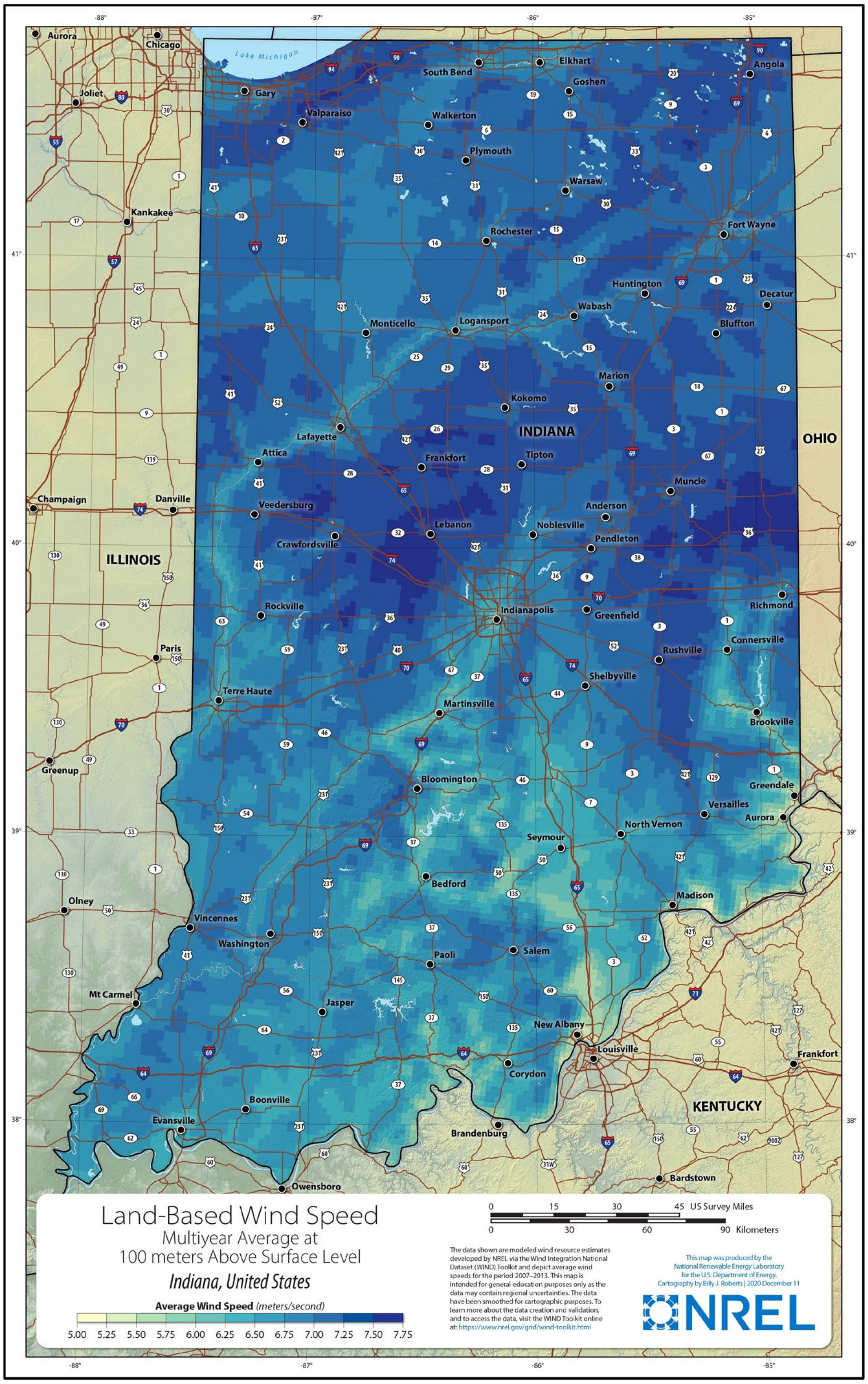
Table 2-5: Wind energy purchase agreements by Indiana utilities (Data sources: AES [27], CenterPoint [28], Duke [29], Hoosier [30], IMPA [31], I&M [32], NIPSCO [33], WVPA [34])

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 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 PPA (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 from Indiana wind farms (Data sources: IURC [35])

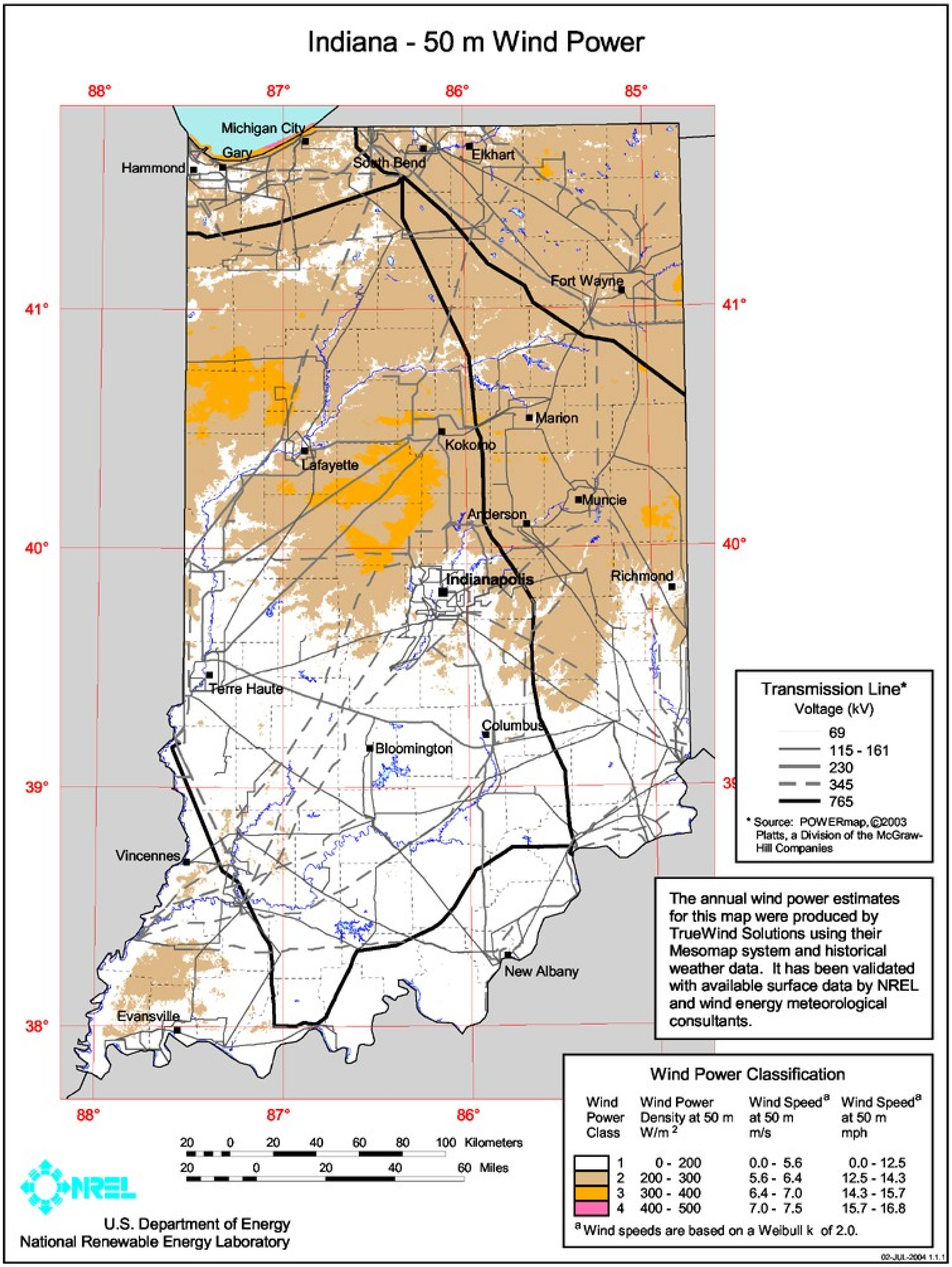
Figure 2-13 shows the distribution of Indiana wind energy resources at 100 meters, the height at which utility-scale wind turbines typically operate, while Figure 2-14 shows the distribution of the wind resource at 50 meters, a height at which smaller-scale community wind projects operate.



The data shown are modeled wind resource estimates developed by NREL via the Wind Integration National Dataset (WIND) Toolkit and depict average wind speeds for the period 2007–2013. This map is intended for general education purposes only as the data may contain regional uncertainties. The data have been smoothed for cartographic purposes. To learn more about the data creation and validation, and to access the data, visit the WIND Toolkit online at: https://www.nrel.gov/grid/wind-toolkit.html

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy. Cartography by Billy J. Roberts | 2020 December 11

Figure 2-13: Indiana wind speed at 100 meters height (Source: DOE/NREL [36])



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

Wind Power Classification

	Wind Power Class	Wind Power Density at 50 m W/m ^{2}	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
⬜	1	0 - 200	0.0 - 5.6	0.0 - 12.5
🟫	2	200 - 300	5.6 - 6.4	12.5 - 14.3
🟧	3	300 - 400	6.4 - 7.0	14.3 - 15.7
🟪	4	400 - 500	7.0 - 7.5	15.7 - 16.8

[a] Wind speeds are based on a Weibull k of 2.0.

Figure 2-14: Indiana wind speed at 50 meters height (Source: DOE/NREL [36])

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 ordinances 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 wind farms in the county since the typical utility-scale wind turbine tower ranges anywhere from 300 to 600 feet. According to the IndyStar more than 30 Indiana Counties had passed ordinances to restrict installation of utility-scale wind turbines [37, 38].

In April 2023, Senate Enrolled Act 390 (SEA 390) was signed into law with the goal to incentivize counties and municipalities to put in place regulations that make it easier for commercial solar and wind developers to get through the permitting process. The law provides that the Indiana Office of Energy Development shall set up a mechanism to certify Indiana counties and municipalities as *commercial solar energy-ready communities and wind energy-ready communities*. A county will be certified as a commercial solar energy ready community and wind energy ready community if, among other things, their commercial solar and wind regulations are not more restrictive than the state-wide default standard set by Indiana law. SAE 390 also stipulated that an incentive fund may be established that would pay a $1/MWh production tax credit for ten years paid to the counties or municipalities that meet the solar energy ready communities and wind energy ready communities certification for a commercial solar or wind project installed in the county/municipality whenever funds are available [39].

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. The PTC has been extended by the Inflation Reduction Act of 2022 (IRA) to include projects that begin construction before the end of 2024. For a project to qualify for the full credit, it has to meet the prevailing wage and apprenticeship conditions. Details about the prevailing wage and apprenticeship conditions and other definitions in the IRA are given in Section 1.4 of this report. A project that does not meet the prevailing wages and apprenticeship conditions only qualifies for a credit of 0.3 cents/kWh (1993 dollars). Projects can also qualify for an extra 10 percent credit if they have the specified level of domestic content in the power plants or a located in an energy “community.” A project located in a low-income community economic development project or residential building is eligible for a 20 percent extra tax credit. The percentages given here are percentages of the base 1.5 cents/kWh (1993 dollars) [40, 41]

- Clean Electricity Production Tax Credit (CEPTC) is similar to the PTC above, except, in addition to renewable generating technologies like wind, it is available to all zero-carbon emitting technologies. The CEPTC goes into effect on January 1, 2025, and ends at the end of 2032, or when the carbon emissions from the electricity industry fall by 25 percent below the 2022 level [40, 41]

- Clean Electricity Investment Tax Credit (CEITC) is a new investment tax credit included in the Inflation Reduction Act of 2022 that comes into effect in January 2025 and is available for all technologies that have zero greenhouse gas emissions. The CEITC credits wind projects with 30 percent of their construction cost in lieu of the production tax credit. The CEITC expires at the end of 2032 or when greenhouse gas emissions from the electricity industry drop by 25 percent below the 2022 level [40, 41].

- 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 [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, and 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, 42].

- High Energy Cost Grant Program, administered by USDA, is aimed at improving the electricity supply infrastructure in rural areas with extremely high per-household energy costs—that is, 275 percent of the national average and above. Eligible infrastructure includes renewable resource generation [43].

- 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

- Senate Enrolled Act 390 (SEA 390), the Indiana Commercial Solar and Wind Energy Ready Communities Act provides for a mechanism to incentivize counties and municipalities to make solar and wind-friendly regulations. It provides for the Indiana Office of Energy Development to certify counties and municipalities as commercial solar energy ready communities and wind energy ready communities if their commercial solar and wind regulations are not more restrictive than the state-wide default standard set by Indiana law. Although funds had not been appropriated for the purpose, SAE 390 also provides for \$1/MWh production tax credit for ten years paid to the counties that meet the solar energy ready communities and wind energy ready communities certification for a commercial solar or wind project installed in the county/municipality [39, 44].

- 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. 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 continue to receive the full retail credit until July 1, 2047, and those installed from 2018 until either 2022 or when the utility's total net metering load reaches 1.5 percent of their peak demand will receive full retail credit for their generation until June 30, 2032 [12, 45].

- 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 [12].

- Sales and Use Tax Exemption for Electrical Generating Equipment exempts transactions involving manufacturing machinery, tools, and equipment used for the production of tangible personal property, which includes electricity, from state gross retail tax. However, only wind energy has clearly specified rules from the Department of Revenue [12].

- Clean Energy Portfolio Goal sets a voluntary goal of obtaining 4 percent of electricity from clean energy sources between 2013 and 2018, 7 percent between 2019 and 2024, and 10 percent by 2025 based on 2010 retail sales. Participation in the goal makes utilities eligible for incentives that can be used to pay for the compliance projects [12].

- NIPSCO offers feed-in tariff incentive rates for electricity generated from renewable resources for up to 15 years. The payment for wind turbines between 3kW and 10kW is \$0.23/kW and \$0.13/kWh for wind turbines larger than 10kW up to 200kW [46].

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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 Section 4 of this report and also differs from bioenergy from dual-use crops such as corn and soybeans, which are currently used 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. There are still significant technical and financial hurdles to be overcome before energy crops can be widely used as a commercially viable source of energy [1].

A substantial coordinated research and development effort across the federal government, led by the U.S. Department of Agriculture (USDA) and the U.S. Department of Energy (DOE), has been underway to build a national bioenergy industry with the objective to use non-food biomass to produce fuels, electricity, and other products currently produced using fossil fuels [2].

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. The current state of this research effort is detailed in the DOE *2016 Billion Ton Study Update*. The crops being considered and developed as dedicated energy crops can be grouped into three main categories – perennial grasses, woody crops and annual crops [3].

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

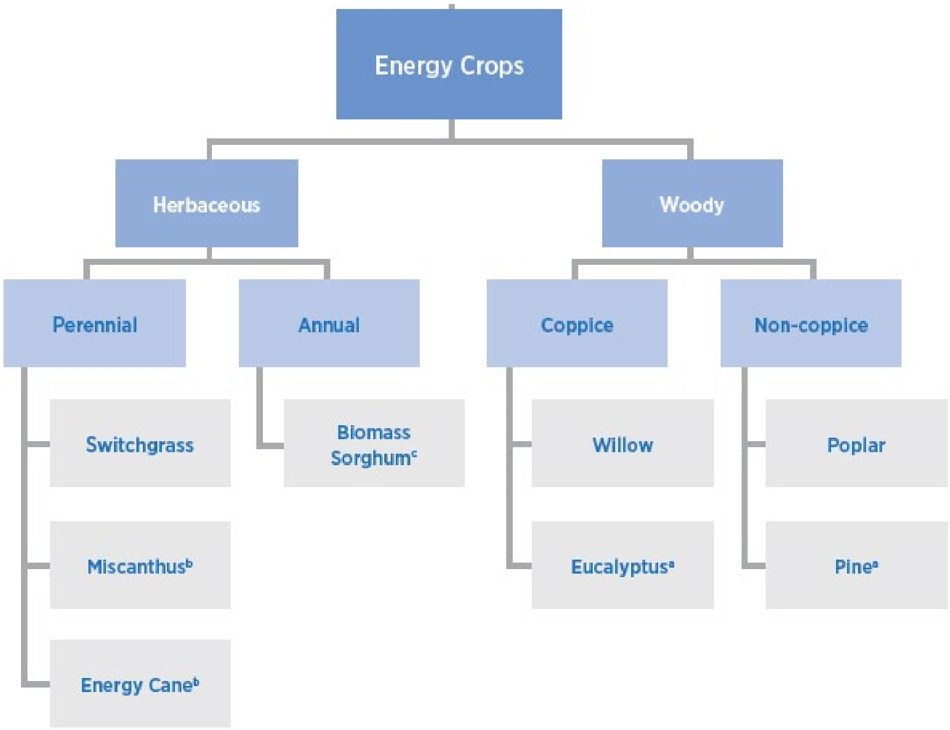
The Giant Miscanthus hybrid was developed in Japan and introduced to the U.S. as a landscape plant. The main attraction of Giant Miscanthus as an energy crop is its high level of biomass production. While a great deal of research has been done establishing its potential as an energy crop, there are still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

Sugarcane is attractive as an energy crop primarily due to its ability to store sugar 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 needed 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 main 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 [3])

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. 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].

In recognition of the integrated nature of the processes involved in converting biomass to a biofuel or related products, the DOE Bioenergy Technology Office organizes its research funding effort into the following two broad areas in the conversion process - deconstruction and fractionation, and synthesis and upgrading as shown in Figure 3-2 below. The deconstruction and fractionating processes break down biomass, including energy crops, into its component chemicals (sugars, bio-oils, etc.), while the synthesis and upgrading processes take these intermediate component chemicals and convert them into finished products such as fuel and chemicals.

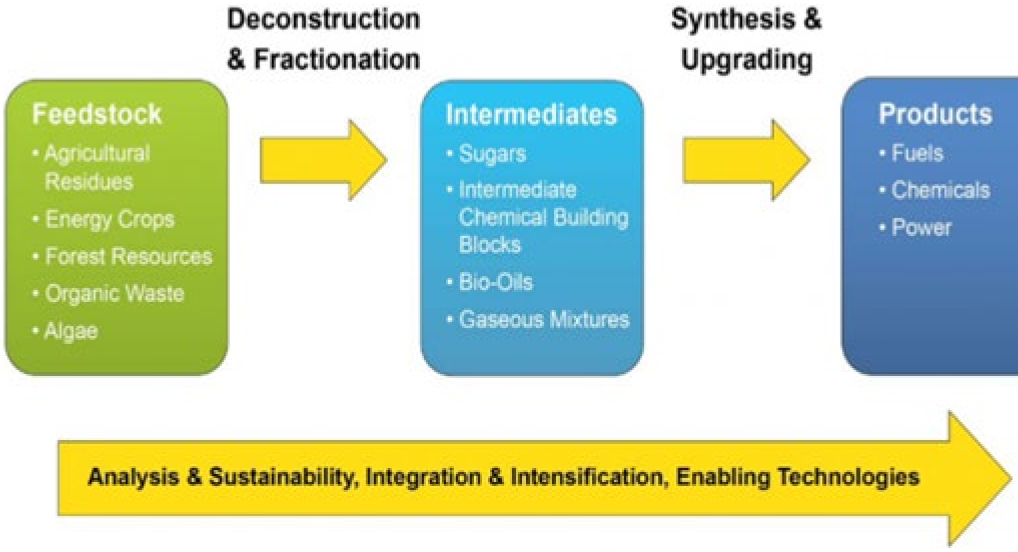


Figure 3-2: Schematic of steps in the bioenergy conversion process (Source: DOE [8])

To take full advantage of the strengths of the different biomass-to-energy conversion processes, the DOE Bioenergy Technologies Office 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. As of the writing of this report, there were 85 active DOE-funded integrated biorefinery-related projects spread across the United States working to develop the various bio-processing technologies needed as follows.

Project Scale	Number of Projects
Modeling	4
Engineering scale	10
Industrial relevant/Pre-pilot	26
Pilot scale	20
Demonstration	15
Commercial	8

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

At the pilot-scale projects, the technologies developed at the much smaller engineering and pre-pilot scales 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 [10]. The eight DOE-funded projects that are at the final commercial production scale are listed in Table 3-2.

Company	Location	Feedstock	Conversion Technology	Primary Product
Fulcrum	McCarran, Nevada	Municipal Solid Waste	Thermo-chemical	Renewable Hydrocarbons (jet fuel, diesel)
Red Rock Biofuels	Lakeview, Oregon	Woody Biomass	Thermo-chemical	Renewable Hydrocarbons
Emerald Biofuels	Plaquemine, Louisiana	Fats; Oils; Greases	Thermo-chemical	Renewable Hydrocarbons
INEOS New Planet Bioenergy	Vero Beach, Florida	Municipal Solid Waste; Agricultural Residue	Thermo-chemical	Ethanol
BlueFire	Fulton, Mississippi	Woody Biomass	Biochemical	Ethanol
RangeFuels	Soperton, Georgia	Woody Biomass	Biochemical	Mixed Alcohols
Abengoa	Hugoton, Kansas	Agricultural Residue; Algae; Woody Biomass; Energy Crops; Municipal Solid Waste; Vegetative Waste; Yard Waste	Biochemical	Ethanol
POET	Emmetsburg, Iowa	Agricultural Residue	Biochemical	Ethanol

Table 3-2: Commercial integrated biorefinery projects (Data source: DOE [9])

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 has not yet been realized. This is mainly because the economics of large-scale farming of energy crops are not yet favorable. For such 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 currently in use (e.g., petroleum and natural gas). 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 four types of short rotation woody crops, two that are rotated by coppicing[5] (willow and eucalyptus) and two 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 3-3 shows the production of herbaceous and woody energy crops under the Billion-Ton study base-case scenario[6] 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 amount of biomass from energy crops enters the market. 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.

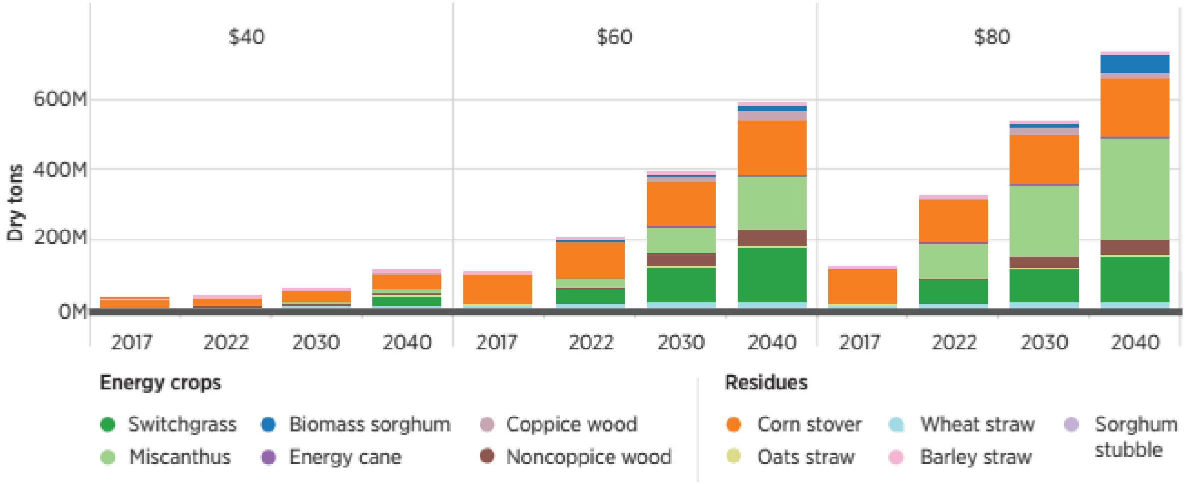


Figure 3-3: Production of energy crops at various farm-gate prices for select years (Source: DOE [3])

Figures 3-4 and 3-5 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.

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[5] 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.

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

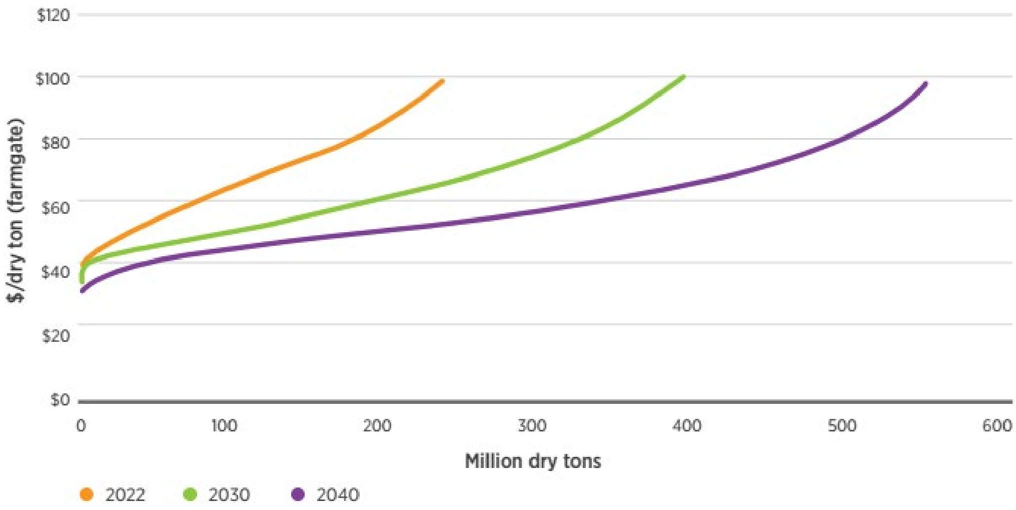

Figure 3-4: Supply curves of potential herbaceous energy crop production for select years under base-case assumptions (Source: DOE [3])

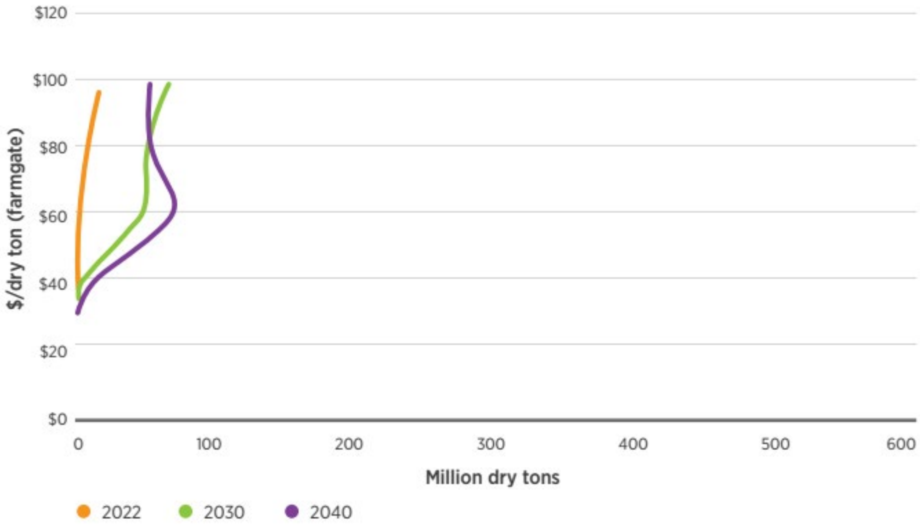

Figure 3-5: Supply curves of potential woody energy crop production for select years under base-case assumptions[7] (Source: DOE [3])

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

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[7] 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 3-4) than woody energy crops.

from the various DOE-supported bioenergy research efforts across the U.S. [11]. The research projects whose data is integrated into the KDF include:

- Biomass Resource Potential research prepared by the Oak Ridge National Laboratory whose results are presented in the 2016 *Billion-Ton Update* report 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,
- 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 are not dedicated energy crops but rather mainly grown as food crops, they are included in this section since they currently constitute 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 production plant with a capacity of 100 million gallons per year (MMGY). Since then the capacity has grown to 1,430 MMGY in sixteen 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 3-3 shows the location and capacities of operating ethanol plants in Indiana. There is currently one operating biodiesel plant in Indiana, the 88 MMGY Dreyfus plant in Claypool [12].

Company	Location	Capacity (MMGY*)
Cardinal Ethanol LLC	Union City	140
CIE - Marion Distillery	Marion	60
Grain Processing Corp. - Washington (wet mill)	Washington	35
Green Plains - Mt. Vernon	Mt. Vernon	90
Iroquois Bio-Energy Company LLC (Harvestone)	Rensselaer	50
MGP	Lawrenceburg	35
POET Biorefining - Alexandria	Alexandria	80
POET Biorefining - Cloverdale	Cloverdale	95
POET Biorefining - North Manchester	North Manchester	80
POET Biorefining - Portland	Portland	80
POET Biorefining - Shelbyville	Shelbyville	80
South Bend Ethanol LLC	South Bend	100
The Andersons - Clymers Ethanol LLC	Clymers	135
Valero Renewable Fuels - Bluffton	Bluffton	135
Valero Renewable Fuels - Linden	Linden	135
Valero Renewable Fuels - Mount Vernon	Mount Vernon	100

*MMGY denotes million gallons per year

Table 3-3: Ethanol plants in Indiana (Data source: Ethanol Producers Magazine [13], Renewable Fuels Association [14])

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 groundwater pollution. The replacement of MTBE was mandated both by states and the 2005 Energy Policy Act [15].

- The renewable fuel standard (RFS), 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. Although the minimum volumes of biofuels to be blended into transportation fuels in the RFS were only specified up to 2022, the RFS did not expire at the end of 2022. Beyond 2022 the Energy Independence and Security Act of 2007 mandates the Environmental Protection Agency to set the volumetric minimums [16, 17, 18]. On June 21, 2023, EPA announced the volume targets for the next three years. The total renewable targets in billion ethanol equivalent gallons are 20.94 for 2023, 21.54 for 2024, and 22.33 for 2025. According to some industry sources these volumes will not have a significant market impact in the renewable fuels industry because they are lower than the existing production capacity [16, 19].

- 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 that produce the mixture of gasoline and ethanol. This tax credit expired at the end of 2011 [20].

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 underway led by the U.S. Department of Energy to establish a sustainable supply of biomass to satisfy the Renewable Fuel Standard mandate of blending a specified amount of biofuels into the gasoline used for the transportation industry and also to increase electricity generation from biomass. The fossil fuel substitution goals include the Sustainable Aviation Fuel Grand Challenge which targets the production of 35 billion gallons per year of sustainable aviation fuel by 2050. 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 3-6 shows the biomass feedstock field trial locations established by the *Regional Biomass Feedstock Partnership*.

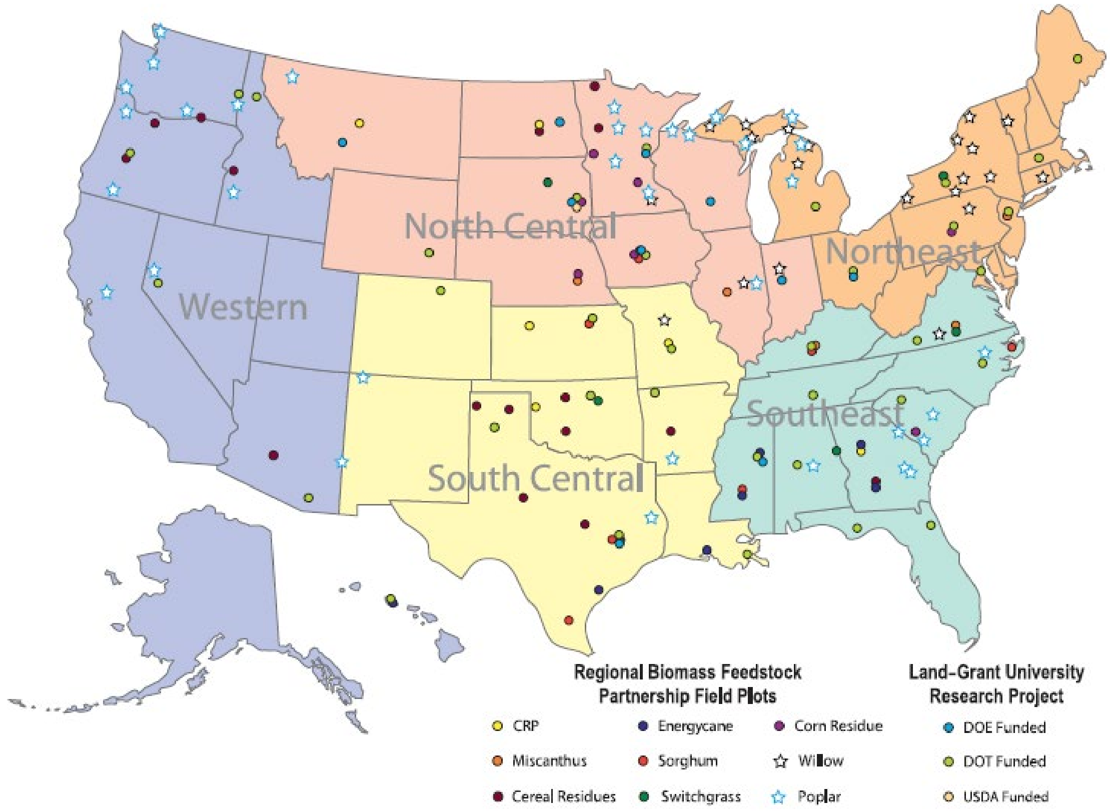


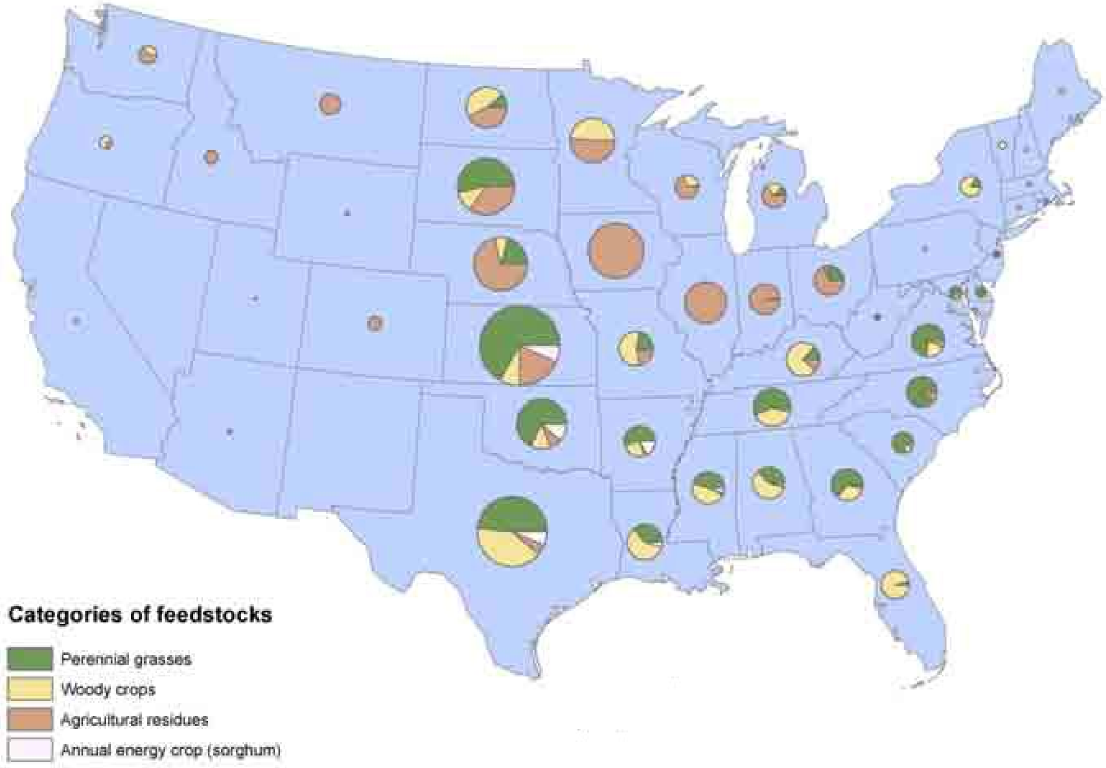
Figure 3-6: Bioenergy crop trial stations (Source DOE [21])

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 [22]. At the March 2015 project peer review conference, the following progress was reported on the feedstock research [23]:

- 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 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 of 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 3-7 shows the projected pattern of biomass feedstock production by the year 2030 at a biomass farm-gate price of $60 per dry ton.



<u>**Figure 3-7:** Estimated shares of energy crops and agricultural residues supplied at $60 per dry ton in 2030</u> (Source: DOE [4])

Figure 3-8 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.

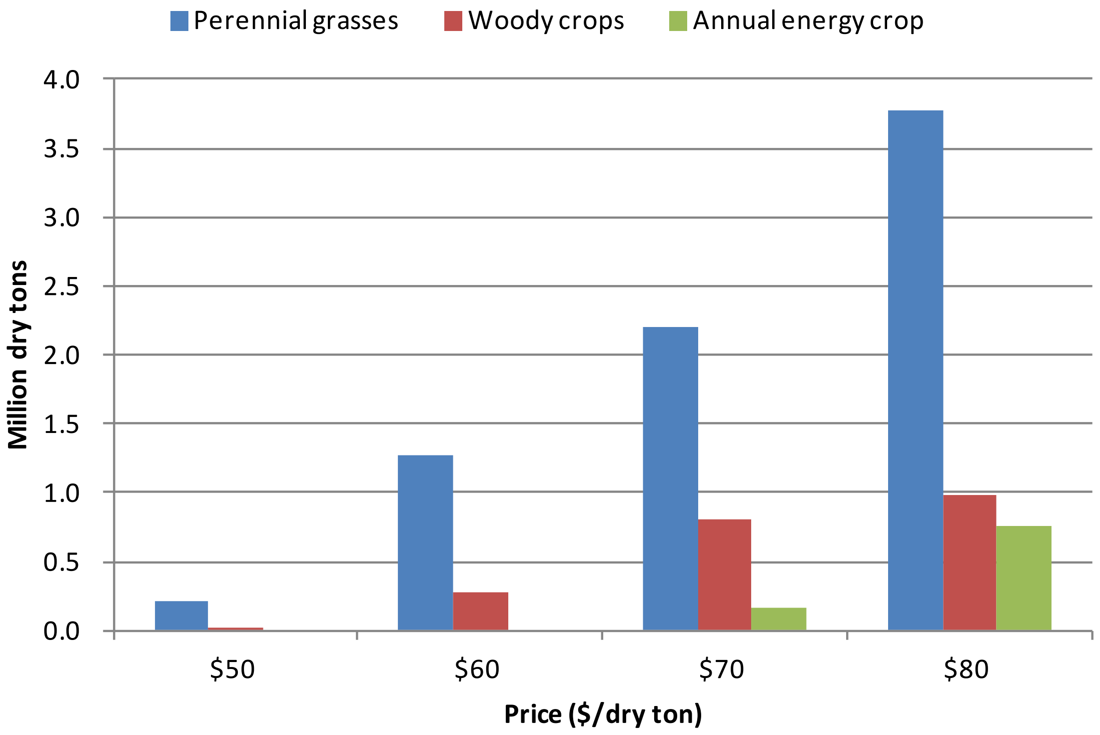


Figure 3-8: Projected production of energy crops in Indiana in 2030 (Data source: DOE [24])

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 3-4 shows the average cost of producing switchgrass given in this study [25]. 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 [26].

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

Table 3-4: Average farm-gate cost ($/ton) for producing switchgrass in Indiana (Data source: Brechbill, Tyner & Ileleji [25])

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 3-5. 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 3-5 are considered in order to compare candidate feedstocks and corn stover removal rates [27, 28].

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 3-5: Cost by category for producing corn stover, switchgrass and miscanthus in Wildcat Creek Watershed (Data source: Song et al. [28])

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. The PTC was extended to the end of 2024 at its full value for projects that meet the prevailing wage and apprenticeship requirements. Details about the prevailing wage and apprenticeship conditions and other definitions in the Inflation Reduction Act (IRA) are given in Section 1.4 of this report. A project that does not meet the prevailing wages and apprenticeship conditions only qualifies for a credit of 0.3 cents/kWh (1993 dollars). Projects can also qualify for an extra 10 percent credit if they have the specified level of domestic content in the power plants or a located in an energy "community." A project located in a low-income community economic development project or residential building is eligible for a 20 percent extra tax credit. The percentages given here are percentages of the base 1.5 cents/kWh (1993 dollars) [29, 30].

- Clean Electricity Production Tax Credit (CEPTC) is similar to the PTC above, except, in addition to renewable generating technologies, it is available to all zero-carbon emitting technologies. The CEPTC goes into effect on January 1, 2025 and ends at the end of 2032, or when the carbon emissions from the electricity industry fall by 25 percent below the 2022 level [29, 30]

- U.S. DOE Loan Guarantee Program (Section 1703, Title IV of Energy Policy Act of 2005) provides loan guarantees for large-scale innovative, high-technology risk renewable energy projects that reduce the emission of pollutants [31].

- 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 [31].

- 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 [31, 32].

- 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 [33].

- 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 [31].

- Green Power Purchasing Goal requires that 7.5 percent of energy used by federal agencies must be obtained from renewable resources [31].

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 of 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 continue to receive the full retail credit until July 1, 2047 and those installed from 2018 until either 2022 or when the utility's total net metering load reaches 1.5 percent of their peak demand will receive full retail credit for their generation until June 30, 2032 [31, 34].

- Community Conservation Challenge Grant provides $20,000-$80,000 in grants for community energy conservation projects that reduce energy consumption or displace the use of traditional energy sources [31].

- Sales and Use Tax Exemption for Electrical Generating Equipment exempts transactions involving manufacturing machinery, tools, and equipment used for the production of tangible personal property, which includes electricity, from state gross retail tax. However, only wind energy has clearly specified rules from the Department of Revenue [31].

- 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 [31].

- NIPSCO offers feed-in tariff incentive rates for electricity generated from renewable resources for up to 15 years. The payment for biomass projects is negotiated with maximum possible payment set at $0.0918/kWh. The size of biomass projects eligible for the feed-in tariff is between 100 and 1,000 kW [35].

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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), which presented biomass energy feedstock in the form of dedicated energy crops. Unlike the dedicated energy crops industry, organic waste biomass is and has been for a long time in widespread use as a source of renewable energy. Historically, organic waste biomass, mainly wood-derived, has been the leading source of renewable energy consumed in the U.S., only being overtaken by biofuels as the largest source of renewable energy in 2016. 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 an expanded renewable energy 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 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 biodigesters; and
- Municipal wastewater, or sewage, which is used to produce gas in biodigesters.

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 food crops such as corn are harvested; and
- Aquatic plants, such as algae that have high oil content that can be converted to biofuel such as 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 either used directly for heat or steam used to drive a turbine to generate electricity.

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 anaerobic digestion.

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. Like traditional fossil fuels, biogas can be used as a transportation fuel through an internal combustion engine or to generate electricity through a combustion or steam turbine. An additional benefit to converting biogas to energy is that it prevents methane from being emitted into the atmosphere. Because methane has a greenhouse gas heat-trapping effect 27 to 30 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 of this report, have shown that substantial energy resources in the form of biomass from crop residues could be harvested under appropriate economic conditions. Agricultural residues, unlike dedicated energy crops, have the added advantage that they do not require any further cultivation or the use of additional cropland, and therefore present a potential near-term feedstock into the bioenergy industry before a viable dedicated energy crop industry takes root.

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 seaweeds such as giant kelp, which can grow to over 150 feet long. They are fast growing organisms that 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, including [2, 3].

- Algae has a high biomass yield per acre, as much as 50 times more than crops such as soybeans,
- 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 has the potential for recycling of carbon dioxide from fossil-fueled power plants and other industrial carbon dioxide emitters, and
- Algae is relatively easy, compared to other biomass material, to convert into fuels and products compatible with current transportation industry uses.

Algae can be grown in either open ponds or in enclosed bioreactors. Open pond algae farms are much more cost competitive, but 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. Enclosed bioreactors' main disadvantage is cost; they 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 such that the power plant provides 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 through the open transmission access associated with wholesale electricity markets provides a market for those times when the plants' generation exceeds their internal demand.

In the case of municipal solid waste, the need to reduce the amount of material going into landfills is the main motivation for building municipal solid waste-based energy conversion facilities. Without this motivation, municipal solid waste power plants would be hard to justify financially since they are some of the most expensive plants to build and operate. In the 2019 EIA plant cost estimates, the municipal solid waste 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]. EIA has not included MSW power plants that burn solid waste in subsequent annual power plant cost estimates.

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 municipal solid waste 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 since the biogas is a byproduct of the decomposing waste. As a result, their capital costs are much lower than those of municipal solid waste energy conversion facilities since they primarily consist of the cost of the combustion engine and generator set.

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 a major benefit of the process of converting the biogas to energy. Further, except for landfill gas, the energy conversion efficiency, and therefore economics, are improved by the 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 of the biomass. In addition, in most places the treatment of the waste is required by local ordinances for the purpose of maintaining the environmental health of the watersheds where these facilities are located.

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.

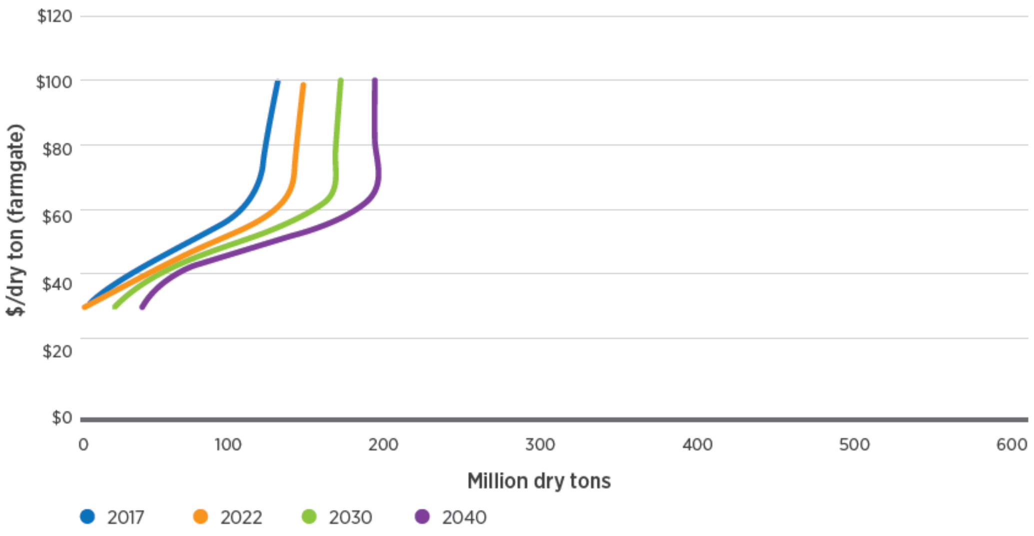
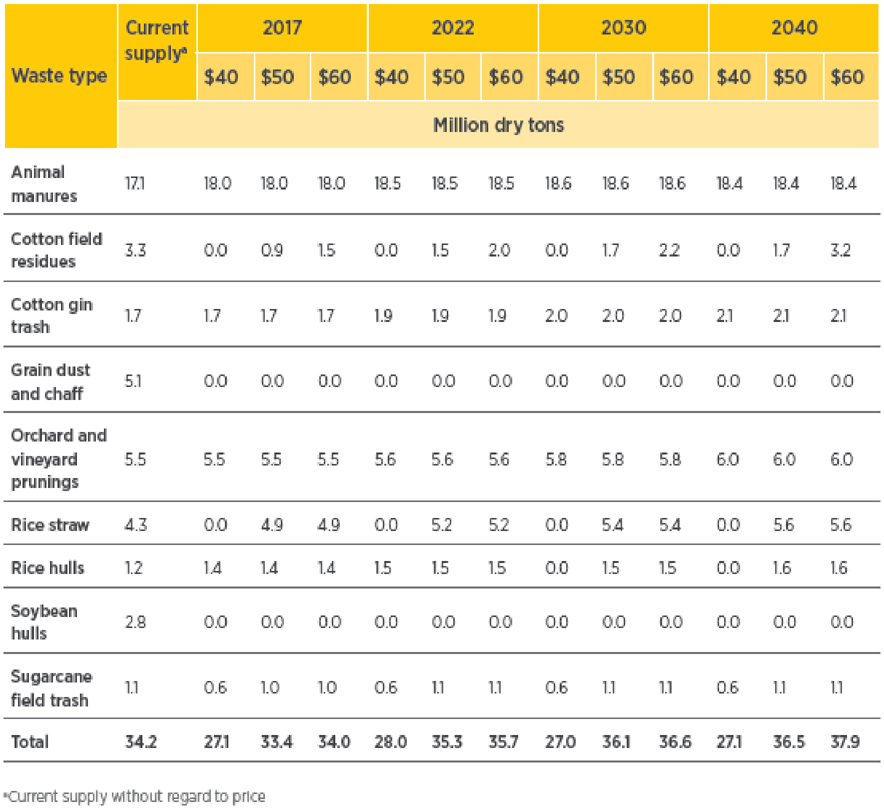


Figure 4-1 Supply curves of potential production from primary crop residues for select years under *2016 Billion-ton* study base-case assumptions[8] (Source: DOE [8])



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])

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[8] 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.

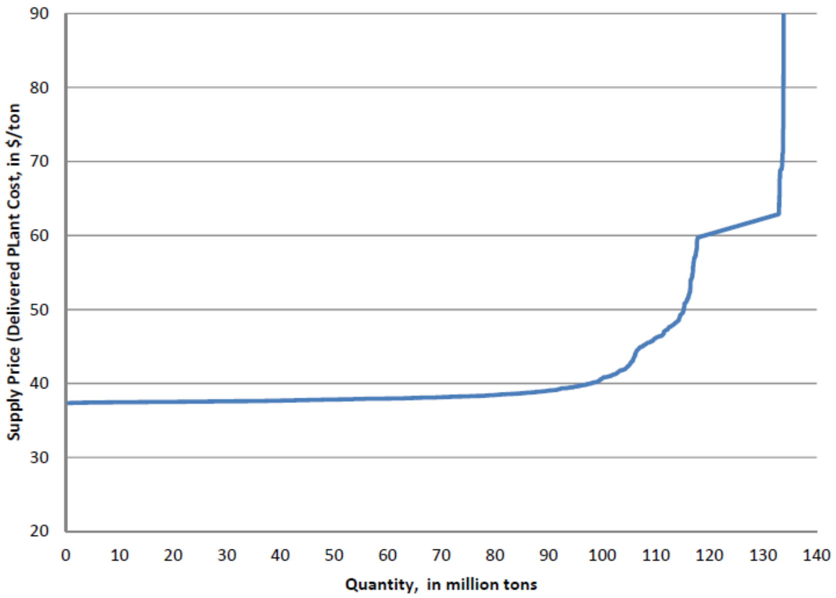


Figure 4-2: U.S. corn stover supply curve (Source: USDA [9])

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 established the National Alliance for Advanced Biofuels and Bioproducts (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. Until recently, as can be seen in Figure 4-3, wood and wood-derived were the main sources of renewable energy. Until the increase in wind and biofuels in the last twenty years, wood and wood-derived fuels comprised over half of the renewable energy consumed in the U.S. Recently wood was relegated to second place as biofuels have become the largest source of renewable energy. In 2023 wood contributed 23 percent of the renewable energy consumed, behind biofuel energy's 32 percent.

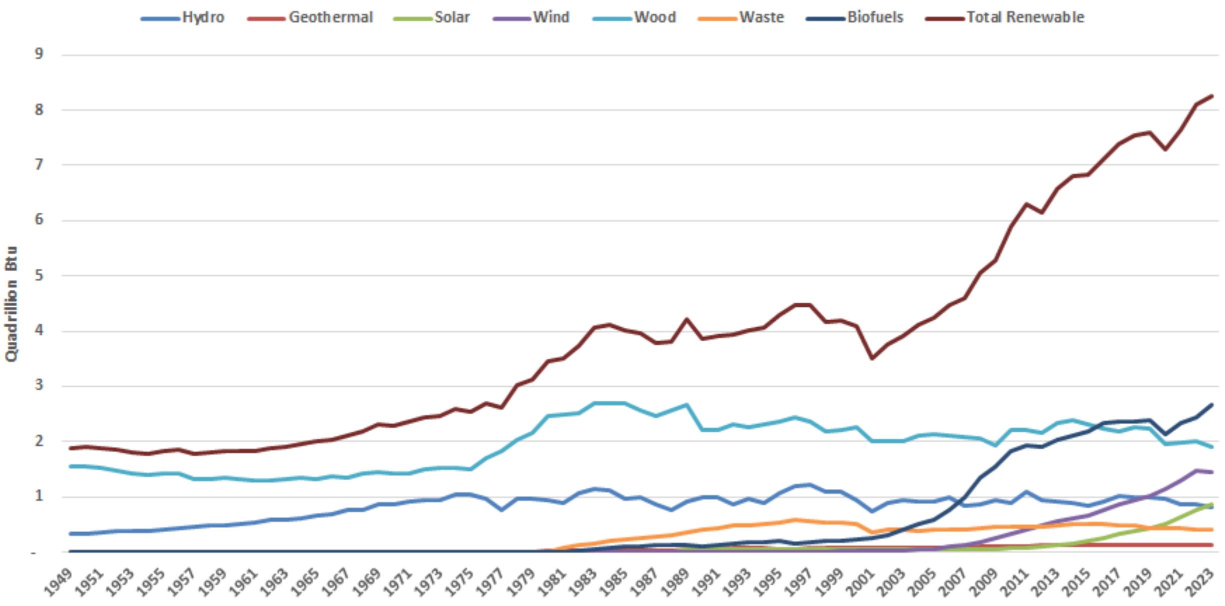


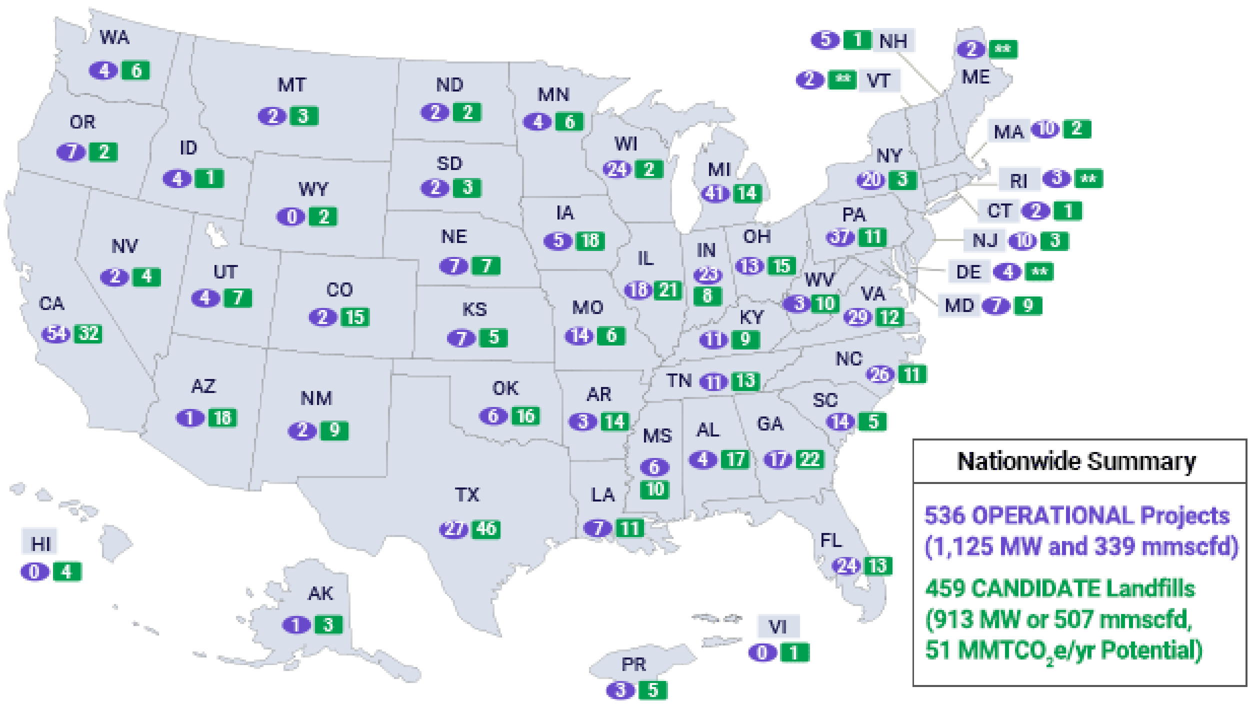
Figure 4-3: U.S. renewable energy consumption 1949-2023 (Data source: EIA [11])

Although not as large a source of energy as wood and wood-derived fuels, municipal solid waste 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 municipal solid waste 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 municipal solid waste 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
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 municipal solid waste to energy plants in the U.S. (Data source: Energy Recovery Council [12])

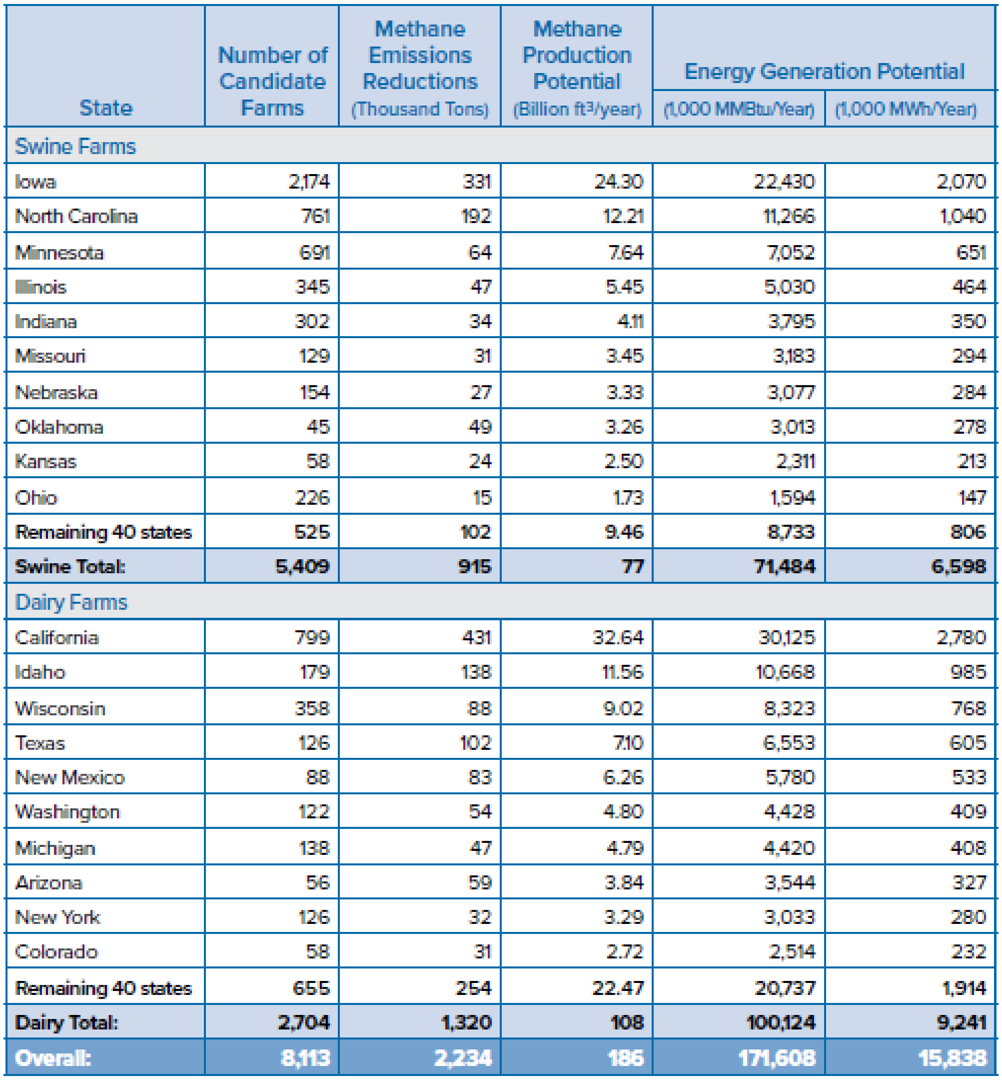
Another organic waste stream in use as a source of energy is landfill gas. According to the EPA there were 536 landfills in the U.S. with operational energy conversion projects with a combined capacity of 1,125 MW electricity generation and 339 million standard cubic feet per day (mmscfd) of gas for thermal energy production. In addition, there were 459 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 July 2024. Twenty-one of the operational landfills and nine of the candidate landfills are in Indiana [13].



Legend
mmscfd – million standard cubic feet per day;
$MMTCO_2e/yr$ – million metric tons 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 343 anaerobic digester biogas recovery systems in operation on livestock farms in the U.S. as of July 2024. The majority of these digesters (247) were on dairy farms, but there were also 39 on swine farms, seven on poultry farms, four on beef cattle farms, five on combined dairy/swine farms, three on combined cattle/swine farms, 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. 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 in these types of farms is handled in a wet slurry state that is hospitable to the waste-digesting microorganisms [15].



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
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 large-scale 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 mid-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 2022. The types of industries using wood residue and byproducts include the paper and pulp industry, which has traditionally used the paper-making byproducts for cogeneration of electricity and process heat. In 2022 waste biomass' contribution to Indiana's renewable energy mix ranked third at 19 percent behind biofuels' 55 percent and wind energy's 20 percent.

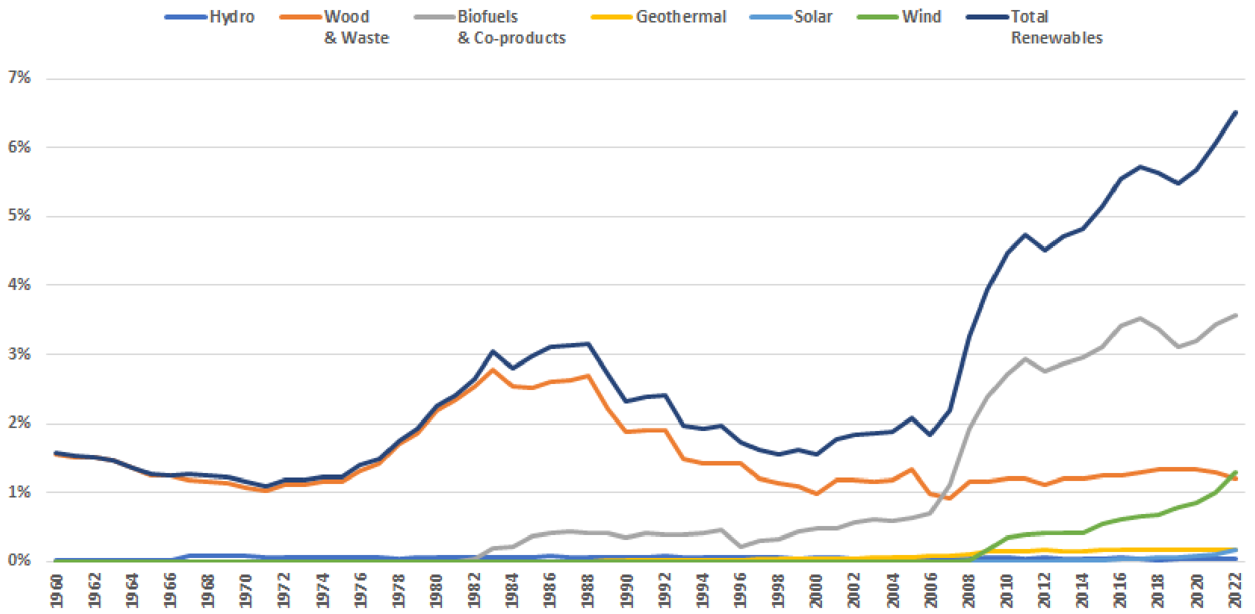


Figure 4-5: Renewables share of Indiana total energy consumption (1960-2022) (Data source: EIA [18])

Municipal solid waste is another source of energy from waste biomass in Indiana. For example, the Covanta Energy Corporation's Indianapolis facility uses municipal solid waste to generate steam for district heating in downtown Indianapolis. The plant processes 703,000 tons of solid waste annually to produce 3.2 billion pounds of steam, which supplies half of the heat energy for the downtown Indianapolis heating loop [19, 20].

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 17 operational landfill gas electricity generating projects in Indiana with a combined 63.5 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 48 MW listed in the EPA database, is the most active user of landfill gas for electricity generation in Indiana. According to the WVPA website, however, WVPA owns and operates 14 landfill projects with a total of 49.6 MW and contracts for power from one 5.6 MW landfill project. The projects listed on the WVPA website are shown in Table 4-6 [21].

Landfill Name	Project Developer	County	Rated Capacity (MW)	End User
National Serv-All LF		Allen	6.4	General Motors
County Line LF	Aria Energy; Republic Services	Fulton	5.898	NIPSCO; WVPA
Blackfoot Landfill	Energy Systems Group	Pike	3.2	CenterPoint
Liberty Landfill	WVPA	White	6.4	WVPA
Earthmovers LF	WVPA	Elkhart	4.8	WVPA
Deercroft RDF	WVPA	LaPorte	4	WVPA
Deercroft RDF	WVPA	LaPorte	3.2	WVPA
Deercroft RDF	WVPA	LaPorte	3.2	WVPA
Jay County LF	WVPA	Jay	3.2	WVPA
Liberty Landfill	WVPA	White	3.2	WVPA
Liberty Landfill	WVPA	White	3.2	WVPA
Oak Ridge RDF	WVPA	Cass	3.2	WVPA
Prairie View RDF	WVPA	St. Joseph	3.2	WVPA
Prairie View RDF	WVPA	St. Joseph	3.2	WVPA
Twin Bridges RDF	WVPA	Hendricks	3.2	WVPA
Twin Bridges RDF	WVPA	Hendricks	3.2	WVPA
Twin Bridges RDF	WVPA	Hendricks	3.2	WVPA
Twin Bridges RDF	WVPA; WM Renewable Energy	Hendricks	3.2	WVPA
County Line LF	Aria Energy	Fulton	1.6	WVPA

Table 4-5: Electricity generating plants at Indiana landfills (Data source: EPA [22])

Landfill Name	Capacity (MW)	Landfill Name	Capacity (MW)
Liberty III	6.4	Prairie View II	3.2
Earthmovers	4.8	Deercroft II	3.2
Twin Bridges I	3.2	Liberty I	3.2
Twin Bridges II	3.2	Liberty II	3.2
Twin Bridges III	3.2	Jay County	3.2
Twin Bridges IV	3.2	Oak Ridge	3.2
Prairie View I	3.2	Clinton (Illinois)	3.2
County Line**	5.6		

*County Line project is on a power purchase agreement

Table 4-6: Wabash Valley Power Association landfill electricity projects (Data source: WVPA [21])

Giraldo, in his 2013 master's thesis [23], 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 at Indiana landfills (Data source: Giraldo [23])

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 eleven such digesters in Indiana. Five of those digesters use the biogas to generate electricity, generating a combined average of 101,072 MWh per year. In four 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, and in one of the projects in Reynolds, Indiana, the gas is purified to high enough purity to where it can be fed into the natural gas pipeline system (. In addition to the digesters listed in the EPA AgSTAR database, SUFG is aware of digesters at the Culver Duck Farm in Middlebury, Indiana, that use the by-products from the duck processing plant to generate an average of 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	White	Cattle 4,500; Swine 800	70,365	Cogeneration
Waste No Energy	White	Cattle 300; Swine 4,000	8,370	408,000 Cogeneration
Curtiss Creek Dairy Digester 1	Jasper	Dairy 12,000	7,818	1,200,000 Cogeneration; CNG
Homestead Dairy	Marshall	Dairy 2,100	7,446	Electricity
Hidden View	Jasper	Dairy 4,000	7,074	Cogeneration
Bos Dairy	Jasper	Dairy 3,600		CNG
Curtiss Creek Dairy Digester 2	Jasper	Dairy 4,300		430,000 CNG
Green Cow Power	Elkhart	Dairy 1,500		907,200 Cogeneration
Herrema Dairy	Jasper	Dairy 5,250		450000 CNG
Reynolds RNG	White	Dairy 9,240		Pipeline Gas
Windy Ridge Dairy	Jasper	Dairy 7,000		840,000 CNG
Culver Duck Farm (processing plant)	Elkhart	Ducks 105,000 gallons processing byproducts per week	9,960	Cogeneration

*Data from 2G Energy Corporation [24]

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

In 2013, it was 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 Tables 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 at Indiana concentrated animal feeding operations (Data source: Giraldo [23])

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. The electricity produced at the West Lafayette plant supplies approximately 15 percent of the total electricity needs at the plant [25]. It was estimated in 2013 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 at Indiana wastewater treatment plants (Data source: Giraldo [23])

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 in Indiana 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 of $60 per dry ton.

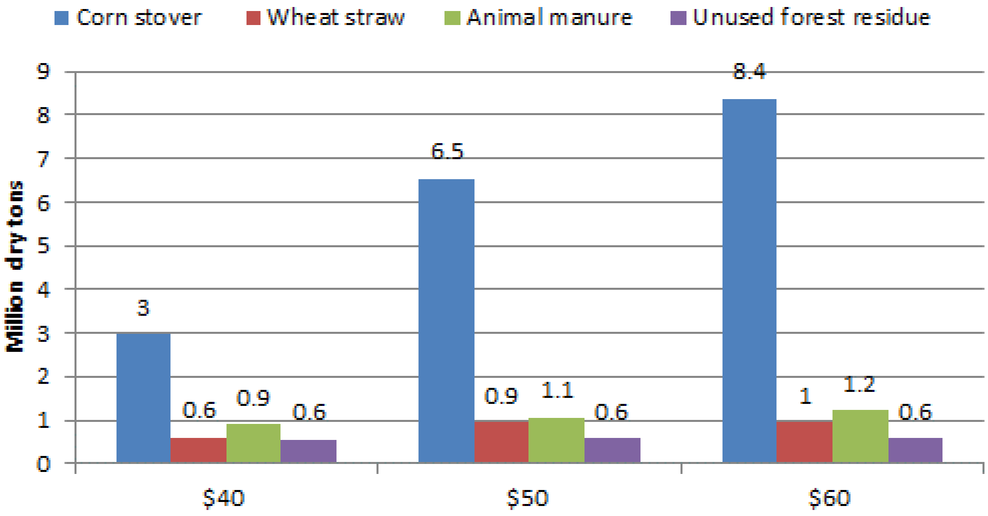


Figure 4-6: Estimated biomass production potential in Indiana (Data source: DOE [17])

4.5 Incentives for organic waste biomass

Federal Incentives

- Renewable Electricity Production Tax Credit (PTC) provides 1.3 cents/kWh (1993 dollars) for open-loop biomass, landfill gas, and municipal solid waste energy technologies. Organic waste biomass falls under the open-loop category. The PTC has been recently extended by the Inflation Reduction Act of 2022 (RA) to include projects beginning construction before the end of 2024. For projects to access the full credit, they are required to meet the prevailing age and apprenticeship described in Section 1.4. Projects can also earn extra credit if they meet the domestic content condition or if they are located in an energy community or an environmental justice community, as described in Section 1.4 [26 -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. Like the PTC above, the ITC has been extended by the IRA until the end of 2024 and projects are required to meet the prevailing wage and apprenticeship conditions. Also, projects can earn extra credit by having the specified amount of domestic content in their power plant or if they are located in an "energy community" as defined by the IRA or in an environmental justice community [26 – 28].

- Clean Electricity Production Tax Credit (CEPTC) is similar to the PTC above, except in addition to renewable generating technologies like organic waste biomass, it is available to all zero-carbon emitting technologies. The CEPTC goes into effect on January 1, 2025, and ends at the end of 2032, or when the carbon emissions from the electricity industry fall by 25 percent below the 2022 level [27, 28].

- Clean Electricity Investment Tax Credit (CEITC) is similar to the ITC, except in addition to renewable generating technologies like organic waste biomass, it is available to all zero-carbon emitting technologies. The CEITC goes into effect on January 1, 2025, and ends at the end of 2032, or when the carbon emissions from the electricity industry fall by 25 percent below the 2022 level [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 [26].

- 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 [26].

- USDA Rural Energy for America Program (REAP) promotes energy efficiency and renewable energy for agricultural producers and rural small businesses through the use of grants and loan guarantees for energy efficiency improvements and renewable energy systems. The program covers up to 25 percent of costs [26, 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].

- 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 [26].

- Green Power Purchasing Goal requires that 7.5 percent of energy used by federal agencies must be obtained from renewable resources [26].

Indiana Incentives

- Net Metering Rule allows utility customers with renewable resource facilities with a maximum capacity of 1 MW to receive a credit for net excess generation in the next billing cycle. Indiana Senate Enrolled Act 309 of 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 from 2018 until either 2022 or when the utility's total net metering load reaches 1.5 percent of their peak demand will receive full retail credit for their generation until July 1, 2032 [26, 31].

- 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 [26].

- Sales and Use Tax Exemption for Electrical Generating Equipment exempts transactions involving manufacturing machinery, tools, and equipment used for the production of tangible personal property, which includes electricity, from state gross retail tax. However, only wind energy has clearly specified rules from the Department of Revenue [26].

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

- NIPSCO offers feed-in tariff incentive rates for electricity generated from renewable resources for up to 15 years. The payment for biomass projects is negotiated with the maximum possible payment set at \$0.0918/kWh. The size of biomass projects eligible for the feed-in tariff is between 100 and 1,000 kW [32].

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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. Solar thermal technologies use the energy from the sun to heat a fluid which can then be used to drive an electric generator. The hot fluid can also be used for non-electric uses such as to make hot water or heat a building. The two solar energy conversion methods and their associated technologies are presented in this report, starting with solar thermal conversion in this section, followed by photovoltaic cells in the next section (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 heating 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.

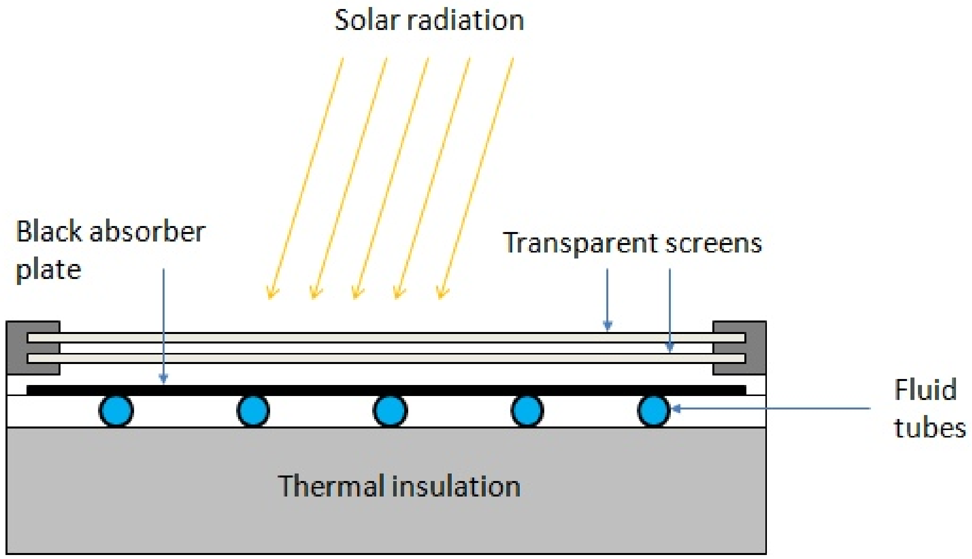

Figure 5-1: The layout of a flat-plate collector (Source: Penn State University [1])

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 is the most developed and widely used CSP technology. It 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 energy storage equipment to store the hot working fluid, thereby providing the ability for the plant to be dispatched to match system demand.

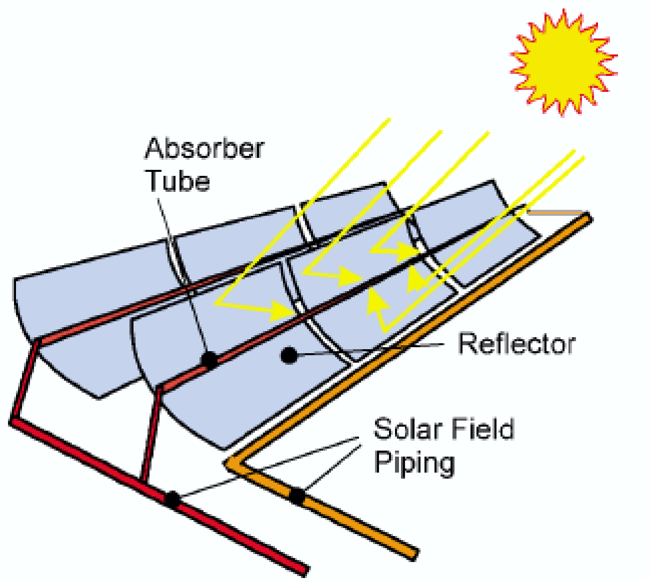

Figure 5-2: A parabolic trough CSP system (Source: IEA [2])

The linear Fresnel CSP system functions a lot like the parabolic trough system. 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. The receiver tube contains a fluid that is used to carry the reflected sun's heat to the energy conversion equipment. 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].

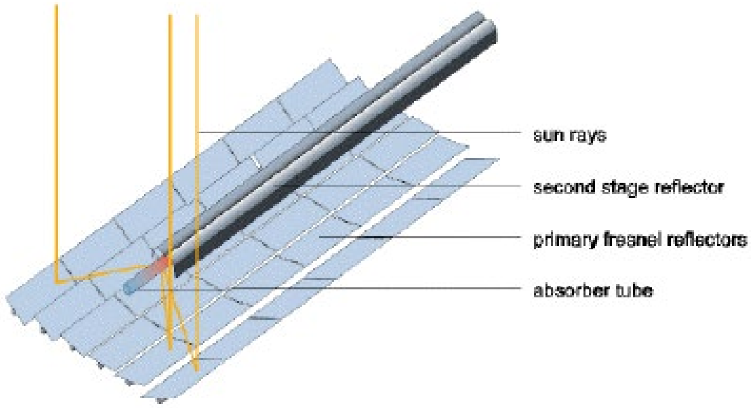

Figure 5-3: A linear Fresnel CSP system (Source: IEA [2])

The power tower CSP system utilizes flat sun-tracking mirrors, which concentrate the solar energy on a tower-mounted heat exchanger, as shown in Figure 5-4. This system avoids the loss of heat 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. 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 [4].

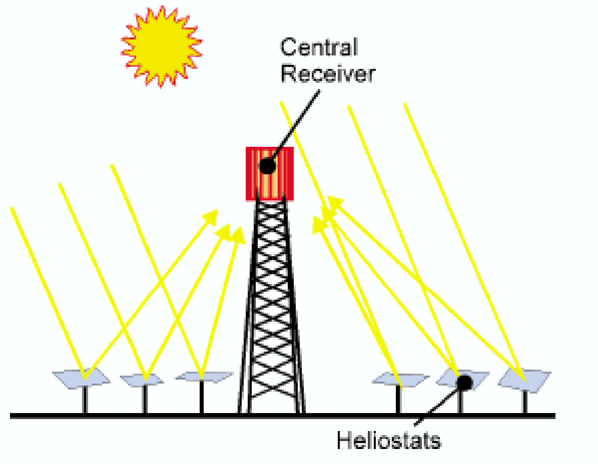

Figure 5-4: A power tower CSP system (Source: IEA [2])

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 installed in the U.S. are no longer operational. They are the 1.5 MW Maricopa project in Arizona and the 1.5 MW project at the Tooele Army Depot in Utah [4].

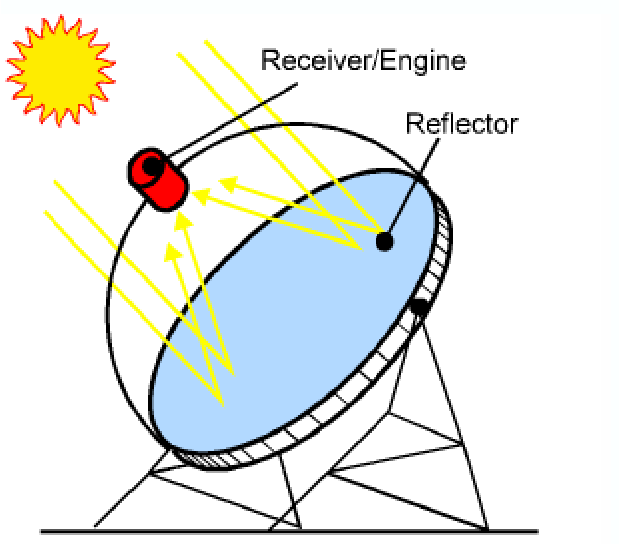

Figure 5-5: A dish/engine CSP system (Source: IEA [2])

5.2 Economics of solar technologies

Table 5-1 shows the overnight capital cost[9] estimates from the National Renewable Energy Laboratory (NREL) for CSP power plants in operation in the U.S. The per-kilowatt cost varies widely, ranging from $4,385/kW for the Nevada Solar One power plant in Boulder City, Nevada, to $9,384/kW for the Crescent Dunes Solar power plant in Tonopah, Nevada.

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[9] 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*" [5]. 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	Location	Capital Cost (2020$/kW)	Capacity (MW)	Technology	Thermal Storage (Hours)	Status	Online Date
Crescent Dunes	Tonopah, NV	9,384	110	Power Tower	10	Operational	2015
Solar Electric Generating Station (SEGS) I	Daggett, CA	9,372	13.8	Parabolic Trough	3	De-commissioned	1984
SEGS II	Daggett, CA	9,082	30	Parabolic Trough	None	De-commissioned	1985
Solana	Phoenix, AZ	8,644	250	Parabolic Trough	6	Operational	2013
Martin Next Generation	Indiantown, FL	7,248	75	Hybrid; Trough	None	Operational	2010
SEGS III	Kramer Junction, CA	6,862	30	Parabolic Trough	None	De-commissioned	1985
Ivanpah Solar	Primm, NV	6,207	377	Power Tower	None	Operational	2014
SEGS IV	Kramer Junction, CA	6,100	30	Parabolic Trough	None	De-commissioned	1989
SEGS V	Kramer Junction, CA	6,100	30	Parabolic Trough	None	De-commissioned	1989
SEGS VI	Kramer Junction, CA	6,100	30	Parabolic Trough	None	De-commissioned	1989
SEGS VII	Kramer Junction, CA	6,100	30	Parabolic Trough	None	De-commissioned	1989
Mojave Solar	Harper Dry Lake, CA	6,078	280	Parabolic Trough	None	Operational	2014
Genesis	Blythe, CA	5,171	250	Parabolic Trough	None	Operational	2014
SEGS VIII	Harper Dry Lake, CA	5,158	80	Parabolic Trough	None	De-commissioned	1989
SEGS IX	Harper Dry Lake, CA	4,974	80	Parabolic Trough	None	Operational	1990
Nevada Solar One	Boulder City, NV	4,385	72	Parabolic Trough	0.5	Operational	2007

Table 5-1: Estimated capital cost of CSP plants in the U.S. (Data sources NREL [4])

Figure 5-6 shows the overnight capital cost estimates of utility-scale electricity generating technologies given in the March 2023 EIA update of generating plant costs for the technologies modeled in the 2023 Annual Energy Outlook. The solar thermal technology's estimated capital cost of $8,732/kW is the most expensive of the generating technologies (renewable and non-renewable) modeled by the EIA in the 2023 Annual Energy Outlook.

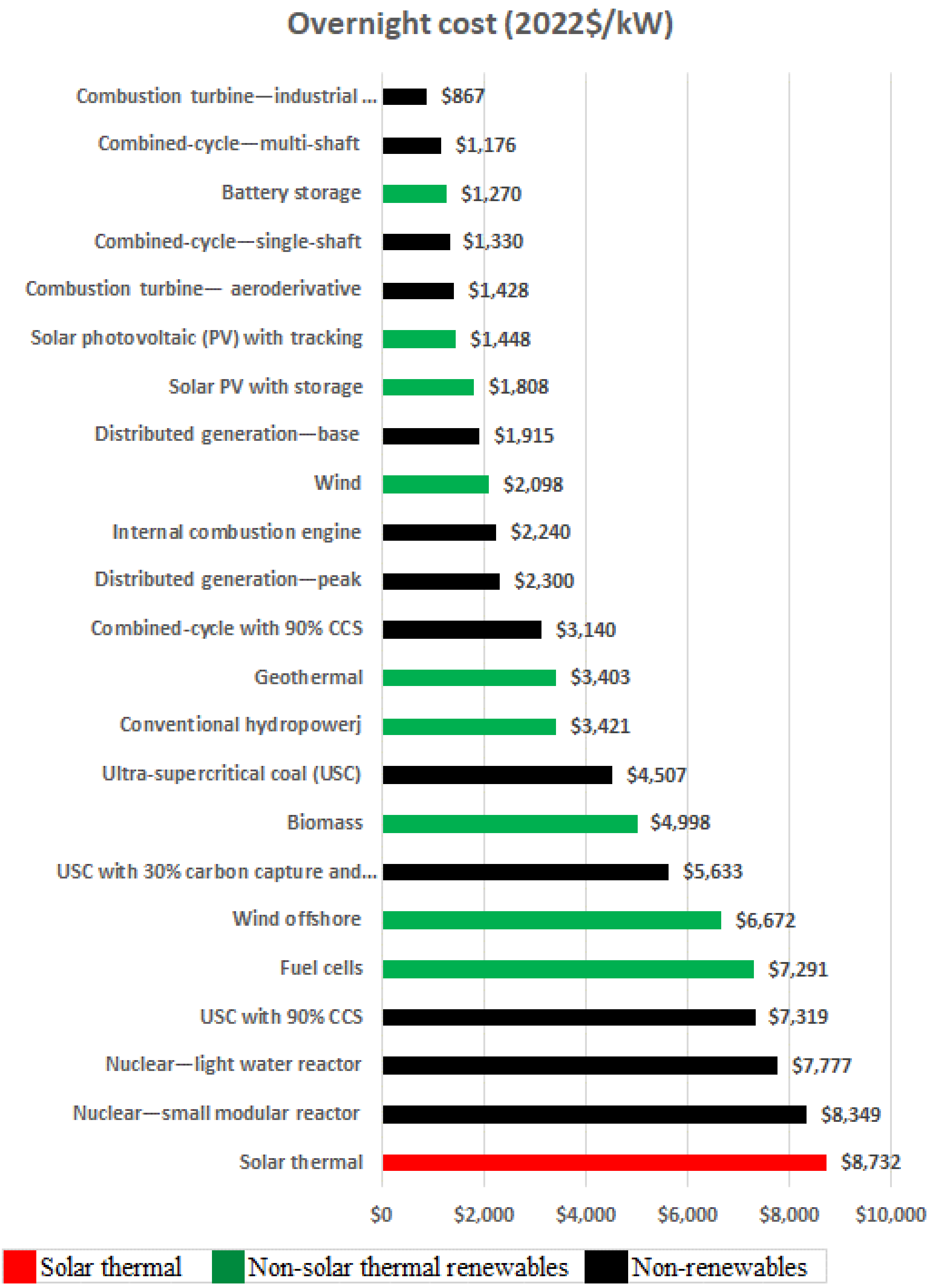


Figure 5-6: Estimated capital cost of generating technologies (Data source: EIA [5])

Figure 5-7 shows the estimate of the fixed and variable operating and maintenance (O&M) costs of the generating technologies modeled in the 2022 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 $96/kW. The fixed O&M cost is higher than that of PV ($17/kW) and land-based wind ($30/kW) but lower than offshore wind, biomass and geothermal.

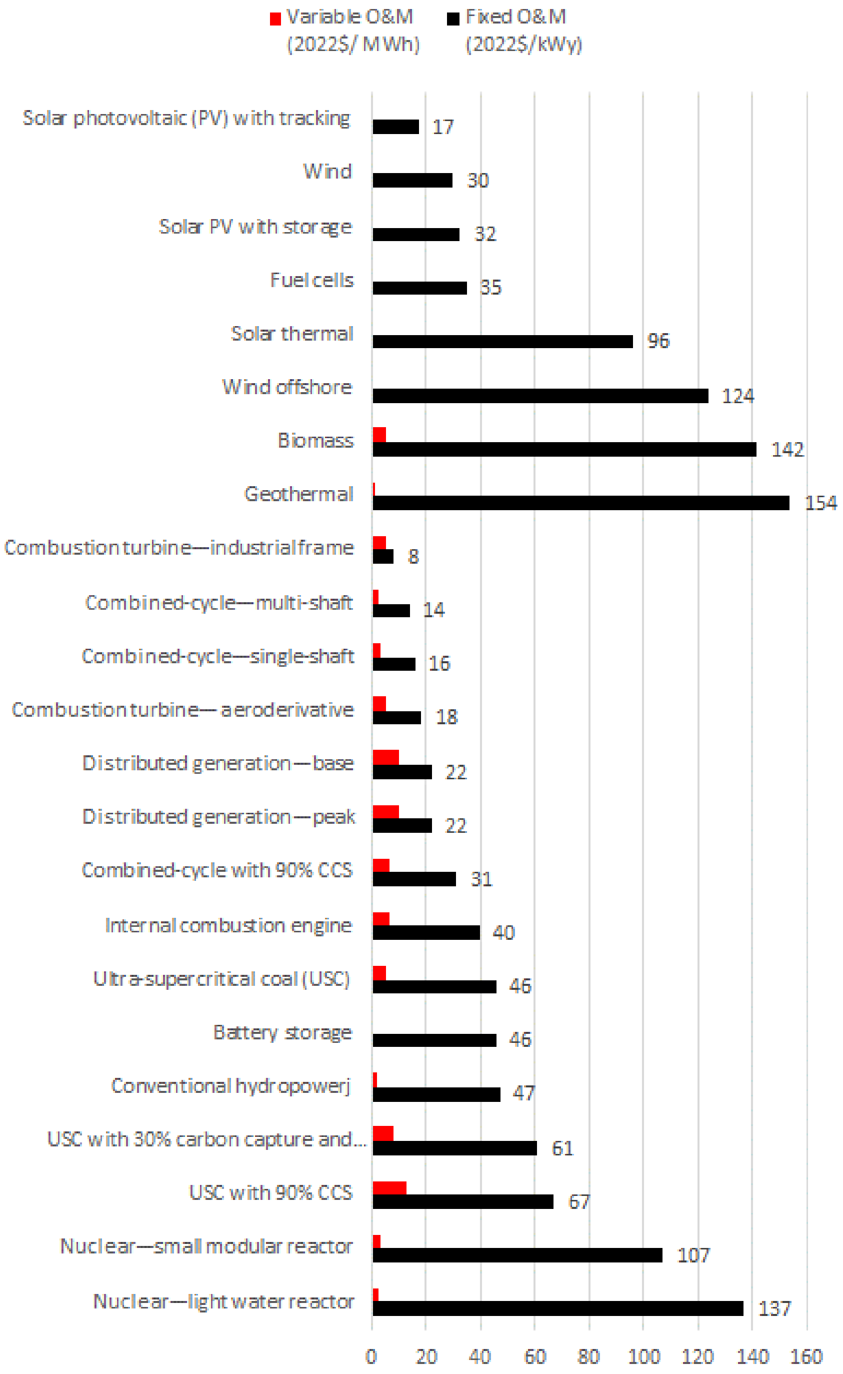


Figure 5-7: Operating and maintenance cost of generating technologies (Data source: EIA [5])

5.3 State of solar energy nationally

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

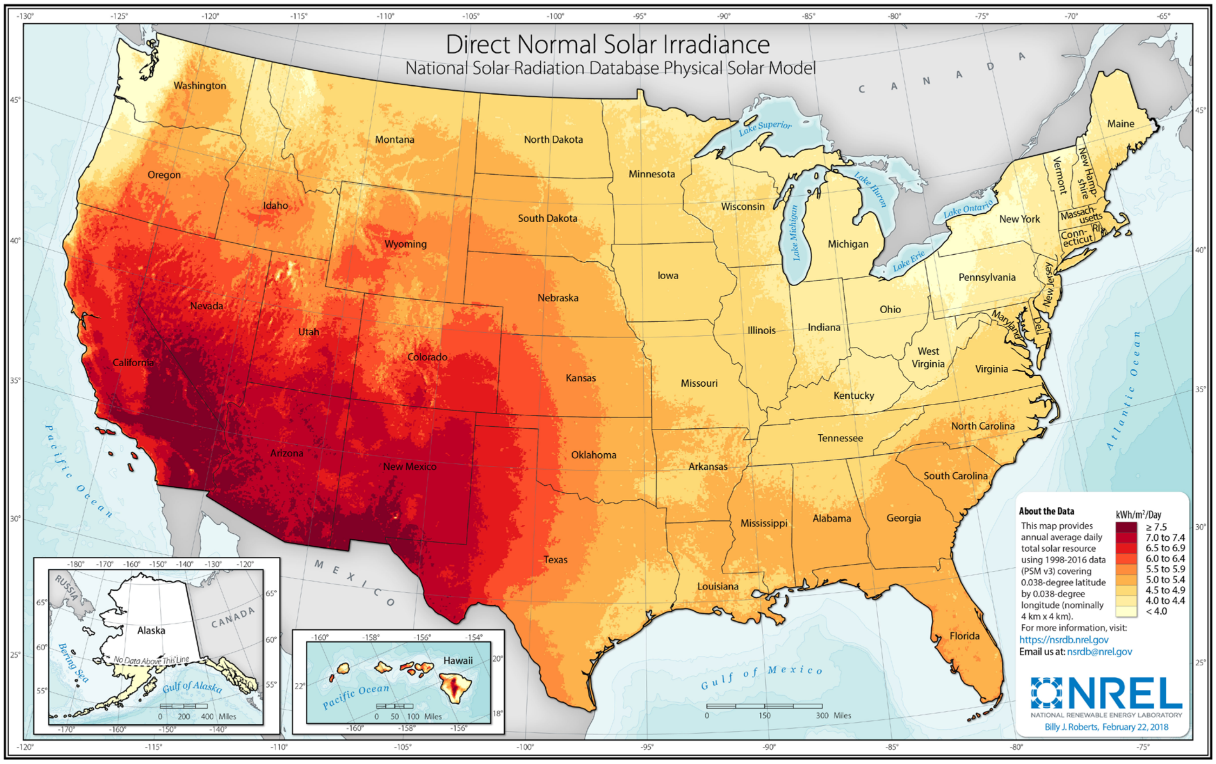


Figure 5-8: Solar power resource in the U.S. (Source: NREL [6])

Between 1980 and 2016, there were two surges in the installation of CSP electricity generating plants. The first surge in the 1980s saw the installation of 354 MW of CSP capacity, most of which was part of the multiphase, multilocation, Solar Energy Generating System (SEGS) CSP in California. The second surge of CSP capacity happened between 2007 and 2016 when a further 1404 MW of CSP capacity was installed. Figure 5-9 shows the annual and cumulative capacity additions in the U.S. Since 2016, SUFG is not aware of any new CSP systems coming online or under construction in the U.S. Instead, a total of 288 MW of CSP capacity has been decommissioned, including all but 80 MW of the 354 MW SEGS system in California.

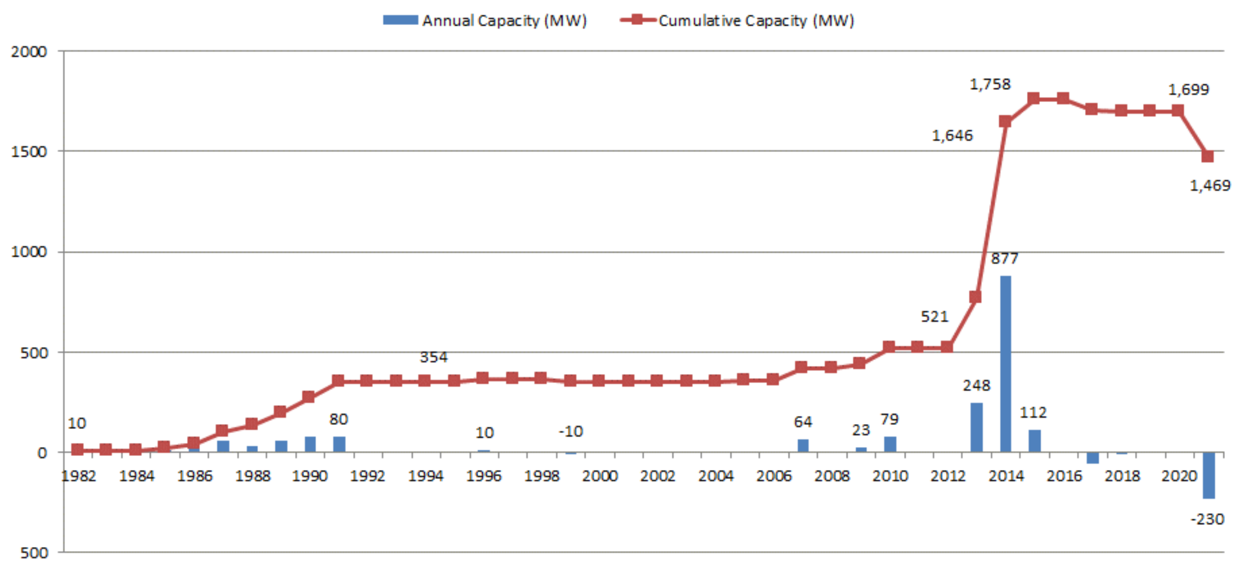


Figure 5-9: Solar thermal power capacity installed in the U.S. (Data sources: NREL [4, 7], SEIA [8], IREC [9])

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	**Location**	**Capacity (MW)**	**Technology**	**Year Operational**
Solar Electric Generating Station IX	Harper Lake, CA	80	Parabolic Trough	1990
Nevada Solar One	Boulder City, NV	72	Parabolic Trough	2007
Martin Next Generation	Indiantown, FL	75	Hybrid; Trough	2010
Solana Generating Station	Phoenix, AZ	250	Parabolic Trough	2013
Ivanpah Solar	Primm, NV	377	Power Tower	2014
Mojave Solar Project	Harper Lake, CA	280	Parabolic Trough	2014
Genesis Solar Energy	Blythe, CA	250	Parabolic Trough	2014
Crescent Dunes Solar	Tonopah, NV	110	Power Tower	2015

Table 5-2: Operating concentrating solar power plants in the U.S (Data source: NREL [4, 7])

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
SEGS III	CA	30	Parabolic trough	1987
SEGS IV	CA	30	Parabolic trough	1987
SEGS V	CA	30	Parabolic trough	1988
SEGS VI	CA	30	Parabolic trough	1989
SEGS VII	CA	30	Parabolic trough	1989
SEGS VIII	CA	80	Parabolic trough	1990
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
Stillwater Geosolar Hybrid	NV	2	Parabolic trough	2015

Table 5-3: Concentrating solar power plants in the U.S. that are no longer operating (Data source: NREL [4, 7])

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. Table 5-4 is a list of concentrated solar thermal projects listed as under construction in the National Renewable Energy Laboratory's Solar Paces website.

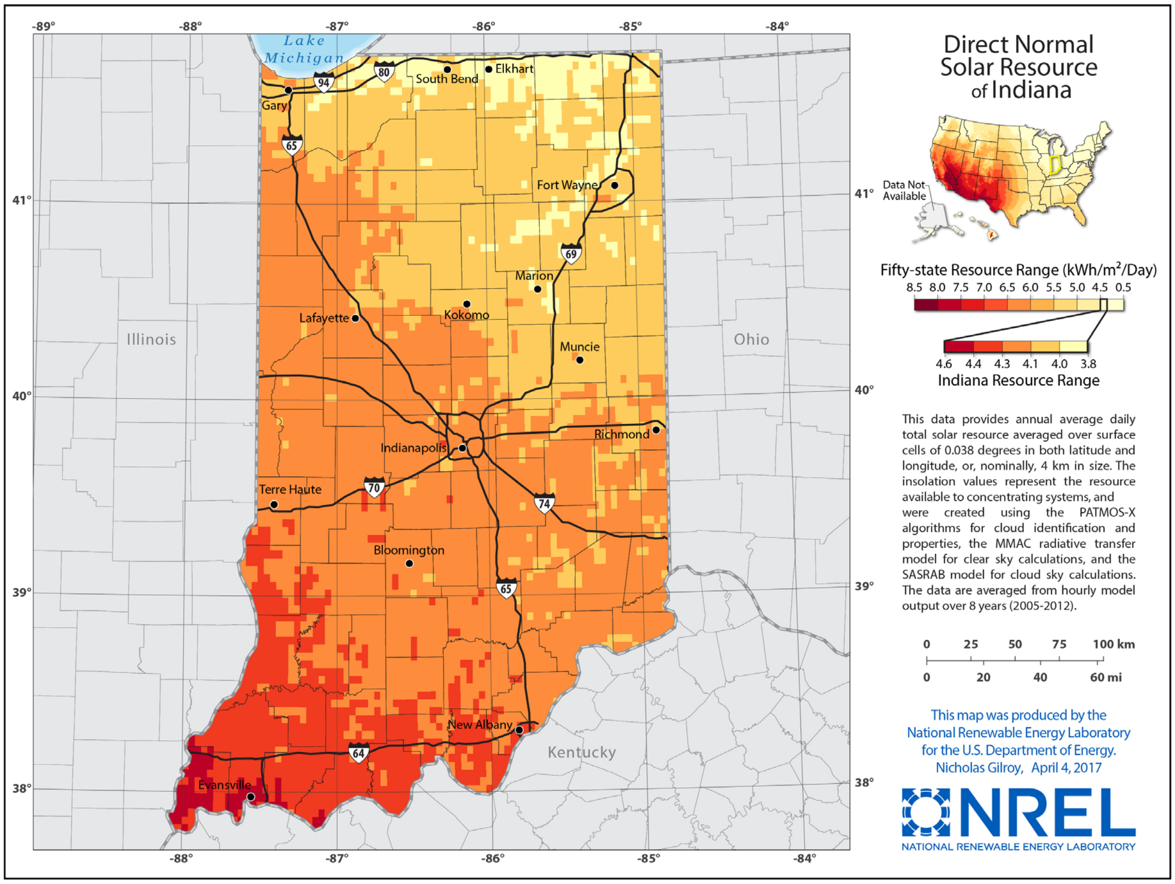
Project Name	Country	CSP Technology	CSP Capacity (MW)	Other Technology in Hybrid	Hybrid Technology Capacity (MW)
Noor Energy 1 / DEWA IV trough segment	United Arab Emirates	Parabolic Trough	600	PV	250
Huidong New Energy Akesai	China	Power Tower	110	PV	640
Noor Energy 1 / DEWA IV tower segment	United Arab Emirates	Power Tower	100	PV	250
Jinta Zhongguang Solar	China	Power Tower	100	PV	600
Redstone	South Africa	Power Tower	100	PV	
CEIC Dunhuang	China	Fresnel	100	PV	600
ISCC Duba 1	Saudi Arabia	Parabolic Trough	43	Gas combined Cycle	605
Partanna MS-LFR	Italy	Linear Fresnel	4.26	PV, Natural gas boiler	5.6
Stromboli Solar	Italy	Linear Fresnel	4	None	None

Table 5-4: Concentrating solar power plants under construction outside the U.S. (Data source: NREL [4])

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 very high capital cost for CSP power plants compared to other generating technologies, makes Indiana a less than ideal location for multi-megawatt CSP plants compared to such states as California, Arizona, Nevada, and Florida. The 1,494 MW of solar thermal power plants currently operating in the U.S. are located in three states as follows: California – 610 MW, Nevada – 559 MW, Arizona – 250 MW and Florida – 75 MW. However, there is some potential for water-heating applications of solar thermal technologies in Indiana.

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



This data provides annual average daily total solar resource averaged over surface cells of 0.038 degrees in both latitude and longitude, or, nominally, 4 km in size. The insolation values represent the resource available to concentrating systems, and were created using the PATMOS-X algorithms for cloud identification and properties, the MMAC radiative transfer model for clear sky calculations, and the SASRAB model for cloud sky calculations. The data are averaged from hourly model output over 8 years (2005-2012).

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy. Nicholas Gilroy, April 4, 2017

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

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 ITC has been extended by the Inflation Reduction Act of 2022 to include projects that begin construction before the end of 2024. The full 30 percent credit is conditioned on the workers on the project being paid the prevailing wages at the project's locality and a specified proportion of the workforce being enrolled in the apprenticeship program as defined in the National Apprenticeship Act. A project that does not meet the prevailing wage and apprenticeship conditions qualifies for only 6 percent credit. A project can earn an extra 10 percent credit by using power plant equipment with a specified proportion of domestic content, by locating in an "energy community," or by locating in an "environmental justice community." The definition of an "energy community" and "environmental justice community" are given in Section 1.4 of this report. A project located on a low-income economic development project or residential building qualifies for an extra 20 percent tax credit [11, 12].

- Renewable Electricity Production Tax Credit (PTC). The Inflation Reduction Act 2022 has added solar thermal electric to the list of technologies that qualify for the PTC. Projects can get as much as 1.5 cents/kWh (1993 dollars) if they meet the prevailing wage and apprenticeship conditions specified above. Projects that don't meet the prevailing wage and apprenticeship conditions only qualify for 0.3 cents/kWh (1993 dollars) credit. Projects can earn 10 percent extra credit if they meet the domestic content condition and are located in an energy community or a low-income community. The ten percent for the PTC is calculated on the base 1.5 cents/kWh (1993) credit. Projects can earn 20 percent credit if they are located in a low-income residential development [11, 12].

- Clean Electricity Investment Tax Credit (CEITC) credits 30 percent of construction cost to all electricity-generating technologies that have zero greenhouse gas emissions. The credit comes into effect in 2025 and expires either at the end of 2032 or when greenhouse emissions from the electricity industry are reduced by 25 percent below the 2022 level. To qualify for the full credit, projects must meet the prevailing wage and apprenticeship conditions, just like for the PTC above. Projects can also draw an extra 10 or 20 percent credit if they meet the conditions specified for the PTC above [11, 12].

- The Clean Electricity Production Tax Credit (CEPTC) enacted for the first time by the Inflation Reduction Act 2022 is similar to the PTC above, except it includes all zero carbon-emitting technologies and does not go into effect until 2025. Projects qualify for the CEPTC if they commence construction between January 1, 2025, and the end of 2032. To qualify for the full credit, projects must meet the prevailing wage and apprenticeship conditions, just like for the PTC above. Projects can also draw an extra 10 or 20 percent credit if they meet the conditions specified for the PTC above [11, 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 for projects placed in service in 2020 through 2022 and 22 percent for projects placed in service in 2023. The credit does not apply to systems used to heat swimming pools and hot tubs [13].

- U.S. DOE Loan Guarantee Program (Section 1703, Title IV of Energy Policy Act of 2005) provides loan guarantees for large-scale innovative, high technology risk renewable energy projects that reduce the emission of pollutants [13].

- 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, and December 31, 2023, provided for by the Tax Cuts and Jobs Act of 2017 [13].

- USDA Rural Energy for America Program (REAP) promotes energy efficiency and renewable energy for agricultural producers and rural small businesses through the use of grants and loan guarantees for energy efficiency improvements and renewable energy systems. The program covers up to 25 percent of costs [13, 14].

- 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 resource generation [15].

- Green Power Purchasing Goal requires that 7.5 percent of energy used by federal agencies must be obtained from renewable resources [13].

- Energy Efficiency Mortgage can be used by homeowners to finance a variety of energy efficiency measures, including renewable energy technologies, in new or existing homes. The federal government subsidizes these mortgages by insuring them through the Federal Housing Authority or the Department of Veterans Affairs [13].

Indiana Incentives

- Net Metering Rule qualifies renewable resources with a maximum capacity of 1 MW for net metering in Indiana. The net excess generation is credited to the customer in the next billing cycle. The aggregate capacity limit is set at 1 percent of the utility's most recent summer peak. Indiana Senate 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 continue to receive the full retail credit until July 1, 2047, and those installed from 2018 until either 2022 or when the utility's total net metering load reaches 1.5 percent of their peak demand will receive full retail credit for their generation until June 30, 2032 [13, 16].

- Renewable Energy Property Tax Exemption provides property tax exemptions for solar thermal, PV, wind, hydroelectric and geothermal systems [13].

- Community Conservation Challenge Grant provides $20,000-$80,000 in grants for community energy conservation projects that reduce energy consumption or displace the use of traditional energy sources [13].

- 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 [13].

- 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 that are enforceable by law [13].

- 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 [13].

- NIPSCO offers feed-in tariff incentive rates for electricity generated from renewable resources for up to 15 years. The payment for solar systems from 5kW to under 10kW is $0.1564/kW and $0.138/kW for solar systems larger than 10kW up to 200kW [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. When these two surfaces are connected through an external load, electrical current flows [1].

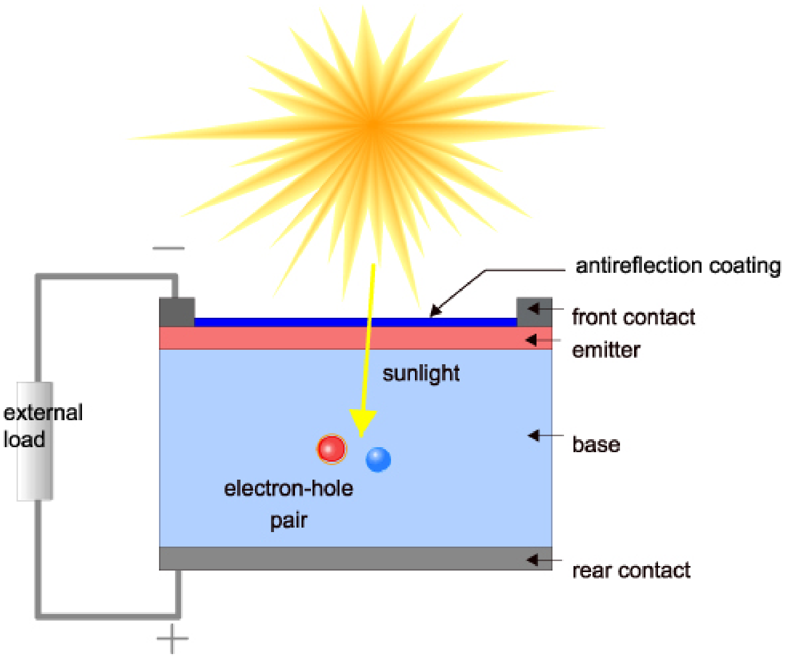

Figure 6-1: Photovoltaic cell operation (Source: EIA [2])

The photovoltaic cell is the basic building block of a PV system. Individual cells range in surface area from 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 a panel. Many of these panels are connected to form the large-scale multi-megawatt arrays in a modern solar power plant. A complete PV system will include other components such as inverters[10] and mounting systems [1].

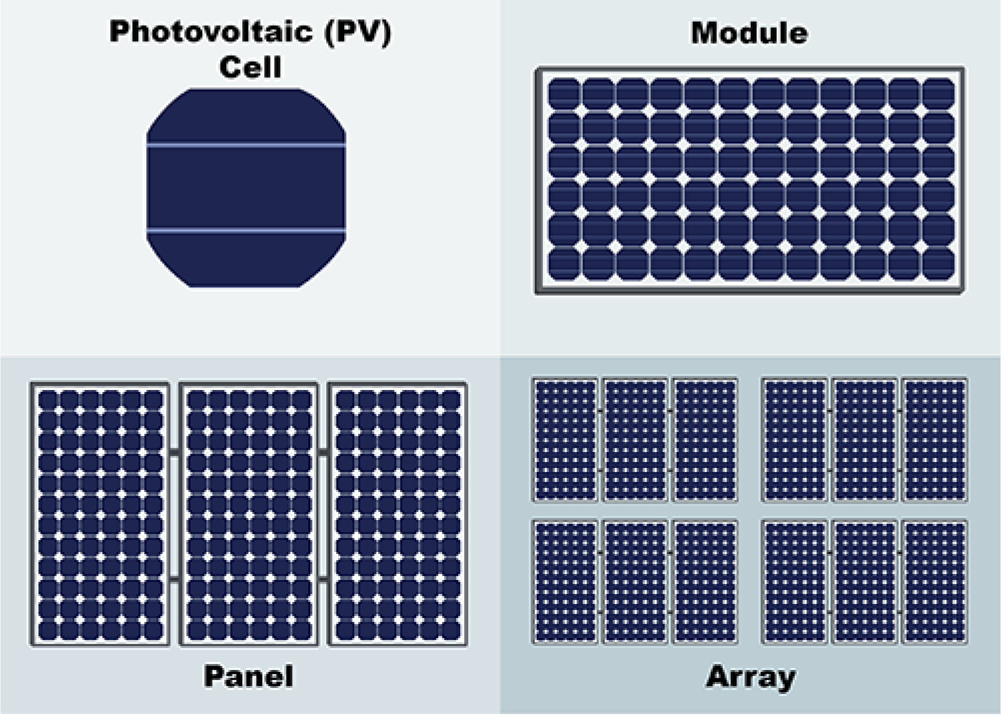

Figure 6-2: Illustration of a cell, module, panel and array of a PV power plant (Source: Florida Solar Energy Center [3])

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 nearly 146 gigawatts (GW) of installed PV capacity in the U.S. at the end of March 2024 [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

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[10] 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.

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 can be easily fitted onto building structures such as roofing shingles, facades and as glazing on sky lights.

The third category of photovoltaic cell technology in commercial use is the concentrating photovoltaic cell (CPV) technology. CPV systems use optical lenses to focus the sun's rays onto small, high efficiency PV cells, thus reducing the amount of photovoltaic material needed. Unlike the other photovoltaic technologies, CPV systems require direct sunlight and therefore their viability is restricted to sunny locations. CPV technology has not had as much commercial success as crystalline silicon PV due to its much higher capital cost, as much as 2.5 to 4 times as much as crystalline silicon PV technology [5]. Figure 6-3 shows the layout of a CPV cell.

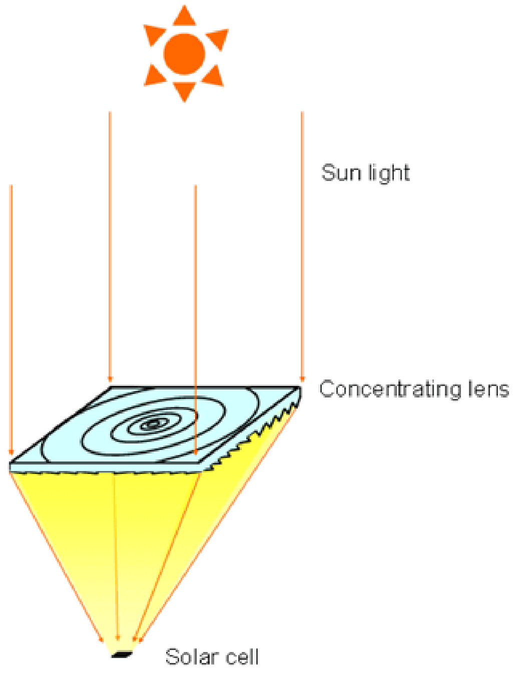

Figure 6-3: Illustration of concentrating photovoltaic cell (Source: Kuraray [6])

According to the U.S. DOE Solar Energy Technology Office, approximately ninety-five 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 lifetimes. 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 inflation-adjusted 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). As can be seen in Figure 6-4 installed prices for all three groups of distributed PV systems have fallen substantially from 2000 to 2023. The median prices for residential systems have fallen from \$14.3/W in 2000 to \$4.2/W in 2022, from \$13.3/W in 2002 to \$3.2/W in 2023 for small non-residential systems, and from \$11.1/W in 2004 for large non-residential systems to \$2.3/W in 2023. The price drop in the last few years, unlike the 2008 – 2013 time period when the price drop was driven by the rapid decline in PV module prices, was driven primarily by a drop in the costs of non-PV components and other "soft" costs, such as installer fees. The installed price in Figure 6-4 is the upfront cost and does not include any financial incentives.

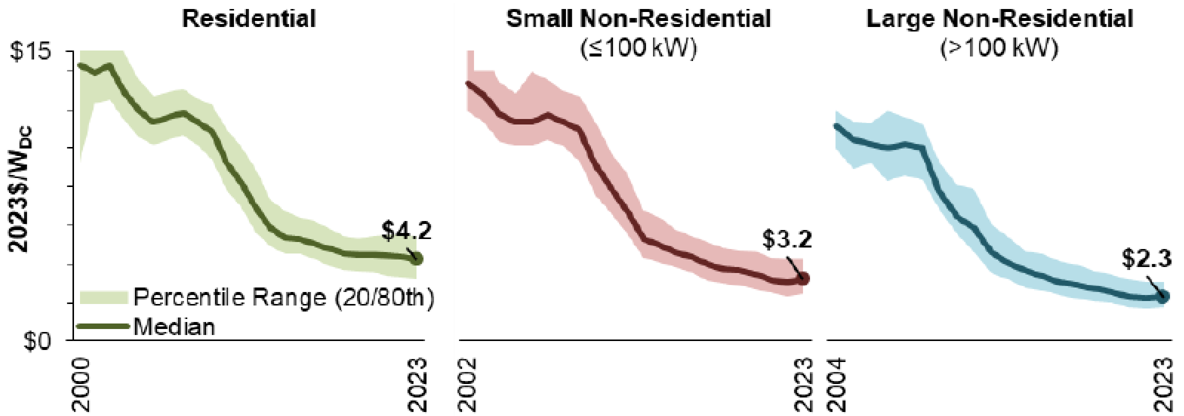

Figure 6-4: Installed price trends among grid-connected, distributed PV systems (Source: LBNL [9])

Figure 6-5 shows the installed cost in \$/W for the utility-scale PV projects in the Berkeley lab's database based on the year of the project's commissioning. Utility-scale in the Berkeley lab's report includes ground-mounted PV projects larger than 5 MW in capacity. As can be seen in the figure, the median price for utility-scale PV projects in the database has dropped from \$6.03/W for the projects commissioned in 2010 to \$1.32/W for the projects commissioned in 2022.

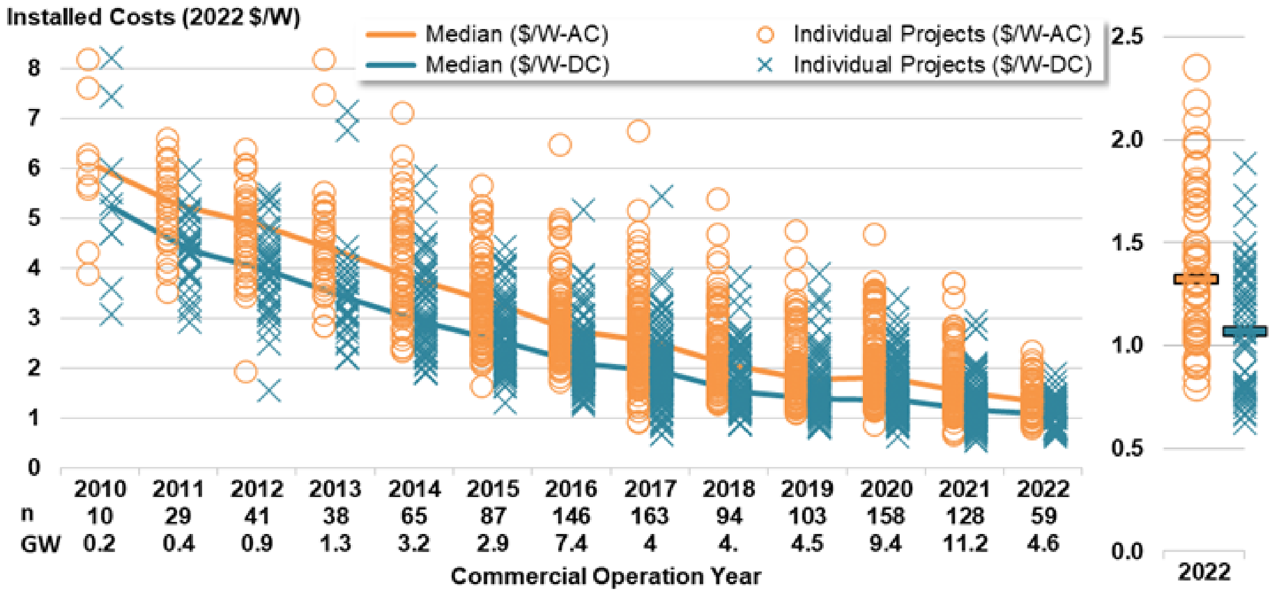

Figure 6-5: Installed cost of utility-scale PV systems over time (Source: LBNL [10])

Figure 6-6 shows the average construction costs of generators installed in the U.S. from 2013 to 2022, according to EIA historical generator cost data released in September 2024. As can be seen in the Figure the construction cost of PV systems has dropped by 57 percent from 3,705/kW in 2013 to $1,588/kW in 2022. The data included in the EIA report is for PV systems one MW or more installed on the utility side of the meter.

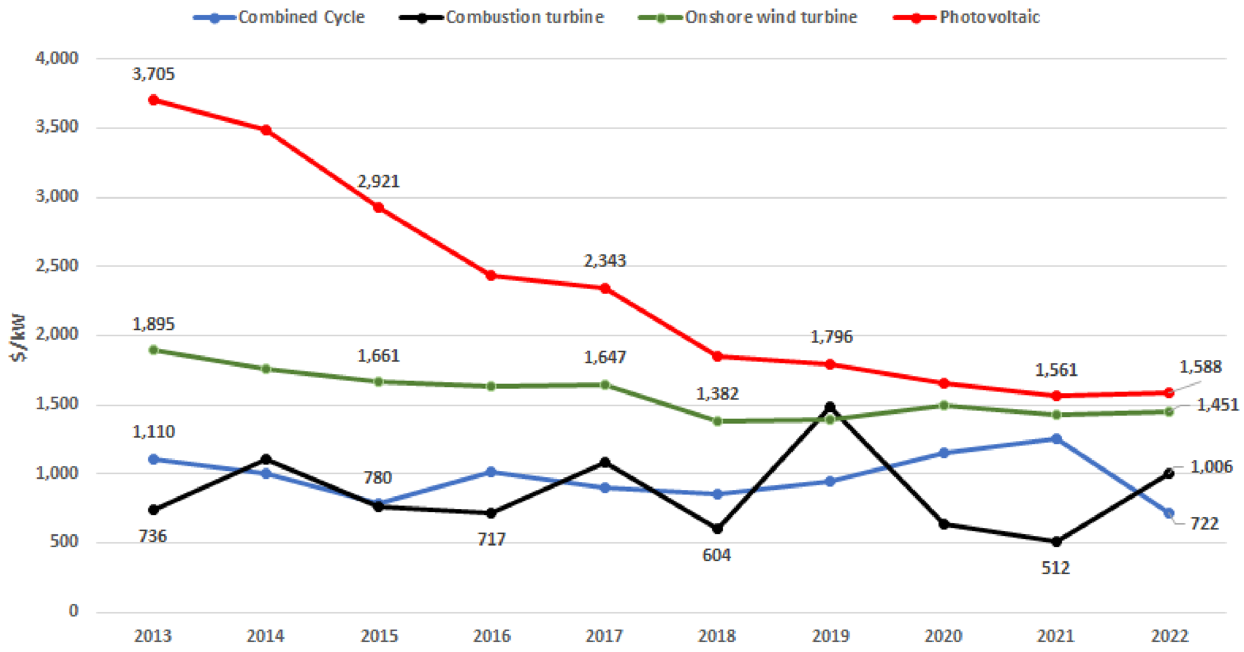

Figure 6-6: Average construction cost of generation installed in the U.S. (2013-2022)
(Data source: EIA [11])

Figure 6-7 shows EIA's estimate of the capital cost of utility-scale photovoltaic electricity generating plants alongside other utility-scale electricity generating technologies issued in March 2023[11] to populate the National Energy Modeling System for the 2023 EIA Annual Energy Outlook. The estimated cost of a standalone utility-scale PV plant, that is, one not coupled with battery storage, was $1,448/kW, and $1,808/kW for a PV plant coupled with battery storage. The estimated capital cost of solar PV, according to the EIA, was for the first time estimated to be lower than that of an onshore wind power plant, which EIA estimates at $2,098/kW.

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[11] EIA will not be releasing an Annual Energy Outlook in 2024, due to work in progress to update the National Energy Modeling System. The next EIA annual energy outlook will be released in 2025 [30]

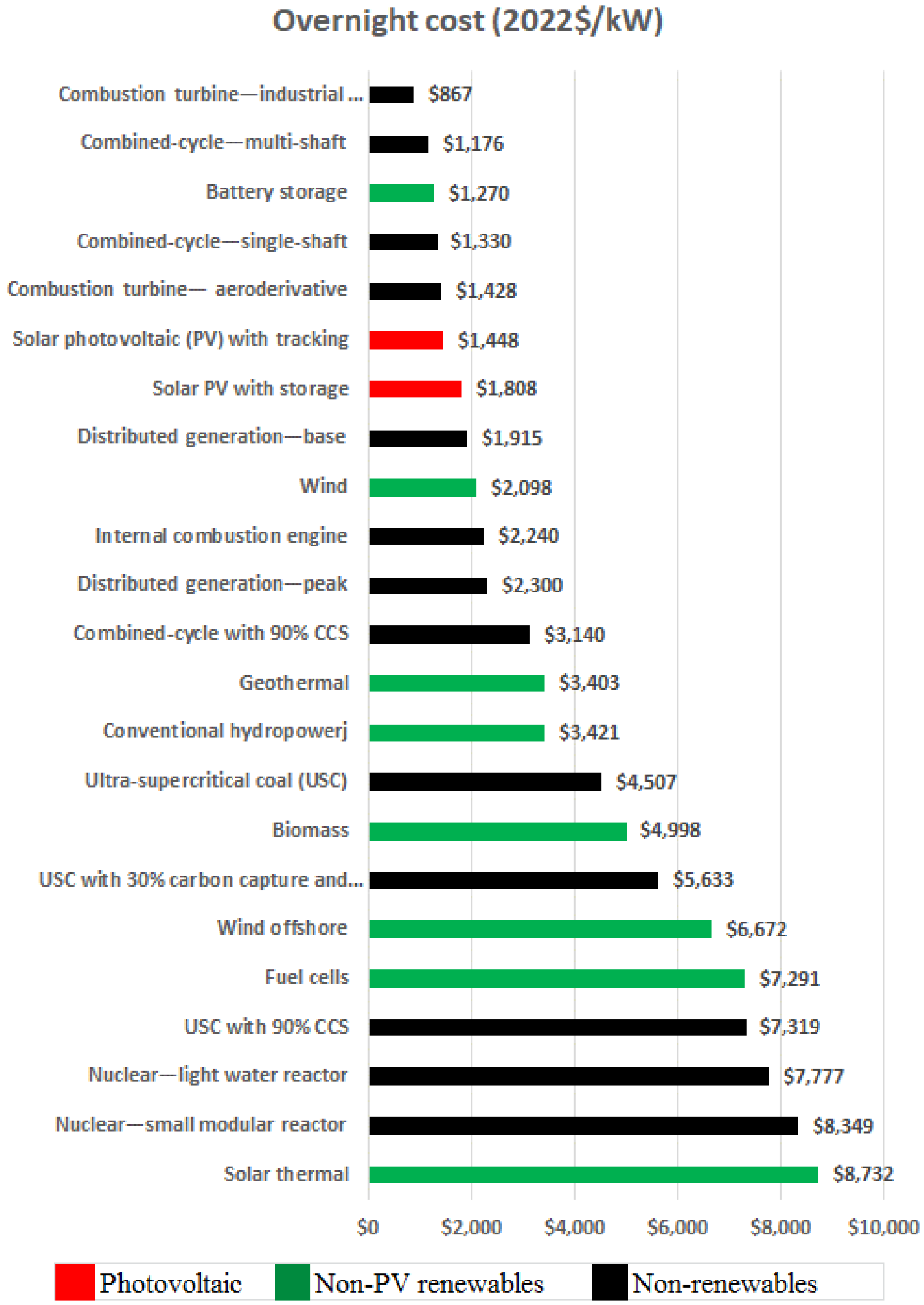

Figure 6-7: Estimated generating technologies capital costs (Data source: EIA [12])

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 $17/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 $32/kW-yr.

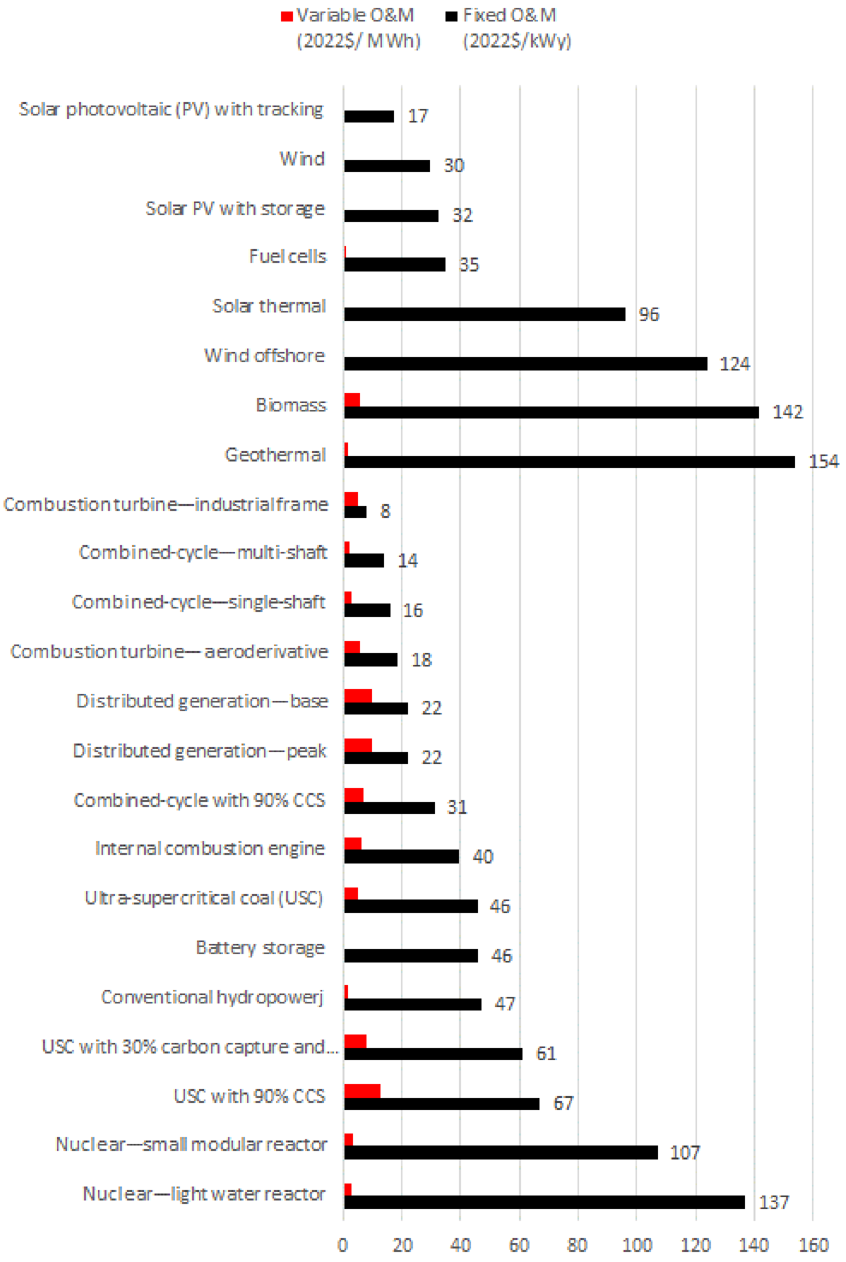

Figure 6-8: Estimated generating technologies fixed and variable O&M costs (Data source: EIA [12])

6.3 State of PV systems nationally

Solar photovoltaic generating capacity installed in the U.S. has been increasing steadily in the last twenty years, growing from a mere 393 MW in 2010 to over 146 GW at the end of March 2024. Figure 6-9 shows the annual and the cumulative installed capacity of PV systems in the U.S.

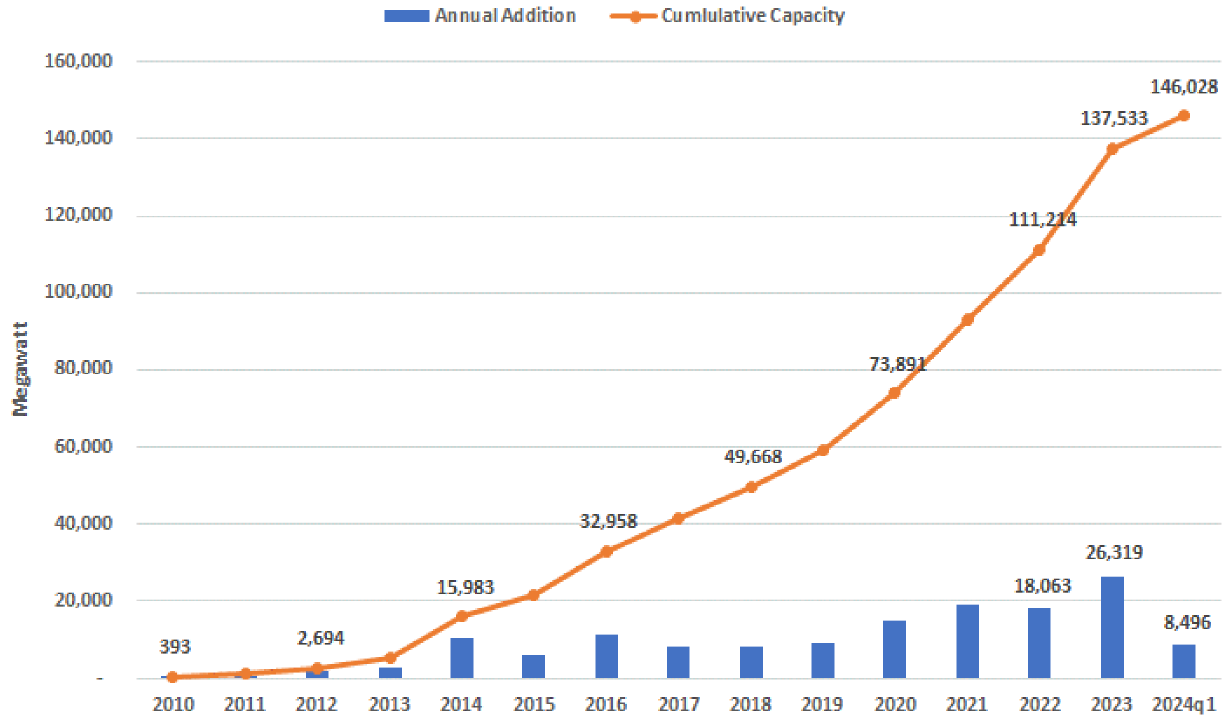

Figure 6-9: Installed U.S. PV capacity (Data source: EIA [4, 13])

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 systems. The decline in the cost of PV systems is described in Section 6.2 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 access to the credit.

Most recently the ITC was extended in August 2022 by the Inflation Reduction (IRA) to 2032 in two stages. The ITC in its current form was extended to include projects beginning construction before the end of 2024, and then at the beginning of 2025, a new Clean Electricity Investment Tax Credit (CEITC) kicks in and continues until the end of 2032. The IRA also expanded the production tax credit (PTC) which was also extended to the end of 2024 to include PV projects. In addition, PV projects qualify for the new Clean Electricity Production Tax Credit (CEPTC) which, like the CEITC, comes into effect at the beginning of 2025 and continues to the end of 2032. A more detailed presentation of the CEITC, the CEPTC and other incentives included in the Inflation Reduction Act is given in Section 1.4 of this report.

At the state level, 29 states and the District of Columbia have a renewable portfolio standard. Figure 6-10 shows the states with renewable portfolio standards and goals. PV systems are the most common renewable energy technology in use for residential customer-side distributed generation.

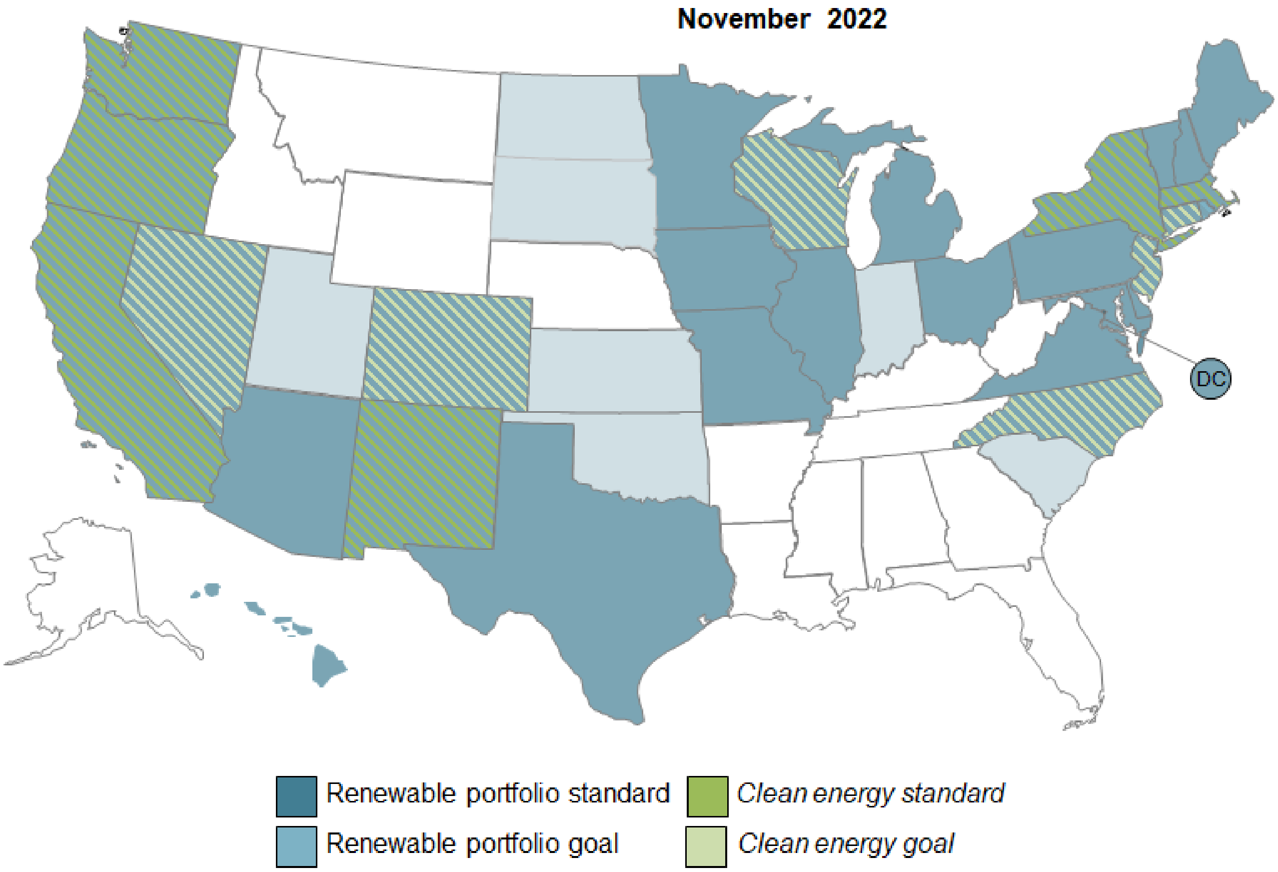

Figure 6-10: Renewable portfolio standards and goals (Source: DSIRE [14])

Since January 2018, the U.S. has imposed import tariffs on solar panels imported from China. The four-year Section 201[12] tariffs started at 30 percent in 2018 and were scheduled to drop by 5 percent per year until they expired in February 2022. In January 2022 the tariffs were extended for

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[12] 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.

another two years, but their impact was mitigated by the doubling of the annual import threshold below which the imports did not apply to 5.5 GW [15, 16, 17].

In April 2022 the U.S. Department of Commerce, acting on a petition from the U.S. manufacturer Auxin Solar, launched an investigation on whether Chinese manufacturers were circumventing the Section 201 tariffs by routing solar cells through the Southeast Asian nations of Cambodia, Malaysia, Thailand, and Vietnam. The uncertainty caused by this investigation cast a cloud over the industry in the first half of 2022, causing the delay of some projects. In June 2022 the president issued a waiver on any tariffs resulting from this investigation until June 2024. So, although a preliminary investigation in December 2022 and a final determination in August 2023 concluded that Chinese firms were using these third-party nations to evade the Section 201 tariffs, the resulting required tariffs against panels from Cambodia, Malaysia, Thailand, and Vietnam did not come into effect. In May 2024, the federal government announced an increase in tariffs on solar panels imports from China from 25 to 50 percent and started an investigation like the one in 2022 on whether Chinese manufacturers were using Southeast Asian nations to circumvent the tariffs [18, 19].

6.4 PV systems in Indiana

Like 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 can be seen in Figure 6-11. The installation of multi-megawatt PV solar projects started in 2013 in Marion County and in Northern Indiana with the implementation of feed-in tariffs offered by AES Indiana and NIPSCO with such notable projects as the 10 MW solar farm at the Indianapolis International Airport. A total of 96 MW of PV capacity was installed in the AES service territory between 2013 and 2018 through this tariff. At the end of 2023 23 MW of PV capacity had been interconnected to the NIPSCSO system under their feed-in tariff. The other driver for the multimegawatt-sized PV projects in this phase of PV installation growth in Indiana was the expansion of the Indiana net metering rule in 2011 to include systems up to 1 MW in capacity. Approximately 188 MW of PV capacity has been installed across the state under the net metering tariff. The availability of net metering for new customers was discontinued by a 2017 statute at the end of June 2022.

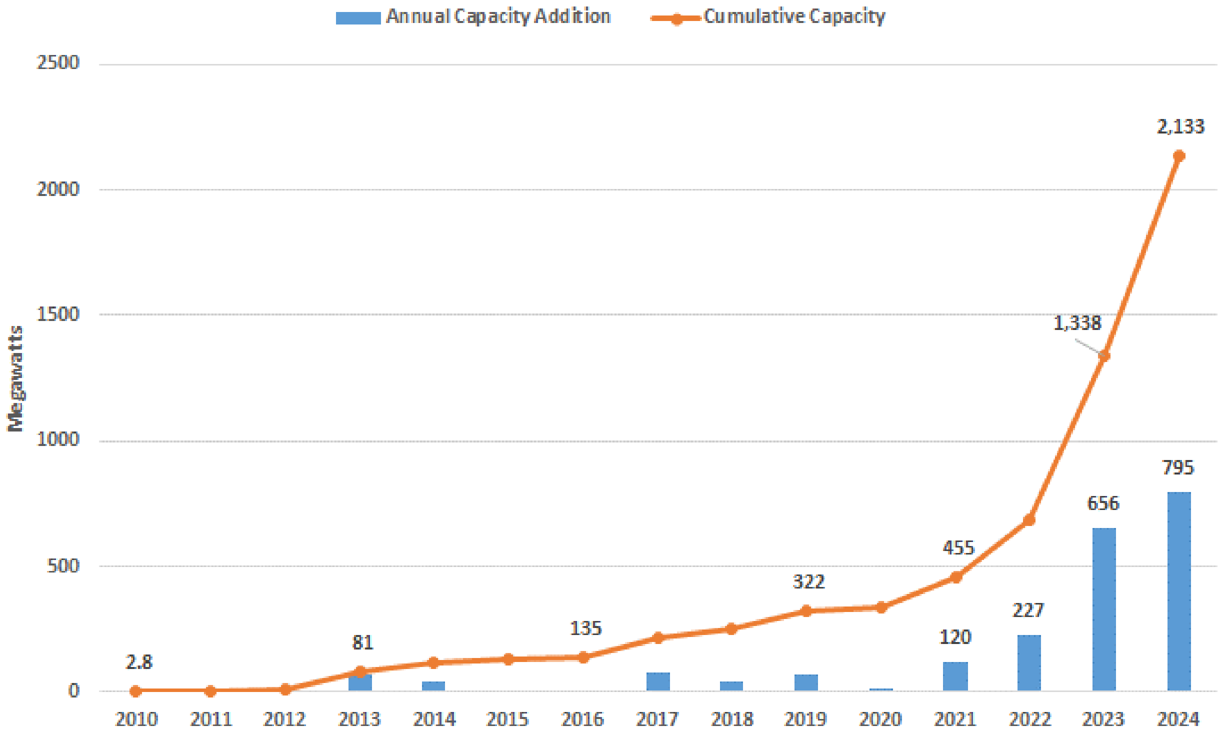

Figure 6-11: Growth in Installed PV capacity in Indiana (Data source: IURC [20, 21], NREL [22])

The start of the second phase of growth in solar PV generating capacity was marked by the construction of the 200 MW Riverstart Solar Park in Randolph County, commissioned at the beginning of 2022. In this new phase, the solar farms are much larger and are no longer interconnected on the customer side of the meter through net metering or feed-in tariffs, but rather utilities are now including PV as part of their generation portfolio, either through direct ownership or through long-term power purchase agreements with merchant developers.

As of the writing of this report, six utility-scale PV projects, in addition to the Riverstart solar farm, with a combined capacity of 1,413 MW, have been commissioned in Indiana, bringing the total installed capacity to 2,133 MW. An additional eleven projects with a combined capacity of 2,471 MW were under construction at the writing of this report, with an expectation to be commissioned in 2024 and 2025. Table 6-1 is a list of the seven utility-scale PV projects currently operating in Indiana while Table 6-2 is a list of the eleven projects that were under construction at the writing of this report.

Project	Utility Interconnected	County	Capacity (MW$_{AC}$)	In-service Year
Riverstart Solar Park	Hoosier	Randolph	200	2022
Bellflower Solar Project	Verizon#	Rush & Henry	153	2023
Dunns Bridge Solar Center Phase I	NIPSCO	Jasper	265	2023
Indiana Crossroads Solar	NIPSCO	White	200	2023
Cavalry Energy Center	NIPSCO	White	200	2024
Mammoth Solar Phase I (North)	AEP	Starke & Pulaski	400	2024
Hardy Hills Solar	AES Indiana	Clinton	195	2024

[#] Bellflower Solar selling its output in a PPA to Verizon Communications

Table 6-1: Operating large-scale solar farms in Indiana (Data source: IURC [21])

Project	County	Developer	Utility Buyer	Capacity (MW$_{AC}$)	Planned In-service Year
Dunns Bridge Solar/Storage Phase II	Jasper	NextEra	NIPSCO	435	2024
Honeysuckle Solar	St. Joseph	Lightsource	Unknown	150	2024
Mammoth Solar Phase I (North)	Starke & Pulaski	Doral	Unknown	400	2024
Riverstart Solar Park III	Randolph	EDPR	Unknown	100	2024
Twin Lakes Solar	White	ENGIE	Unknown	150	2024
Appleseed Solar	Cass	NextEra	NIPSCO	200	2025
Fairbanks Solar Energy Center	Sullivan	Invenergy	NIPSCO	250	2025
Petersburg Energy Center	Pike	NextEra	AES Indiana	250	2025
Posey County Solar	Posey	Capital Dynamics	CenterPoint	191	2025
Ratts 1 Solar	Pike	Arevon Energy	IMPA	150	2025
Speedway Solar	Shelby	Ranger Power	Duke	199	2025

Total under construction **2,471**

Table 6-2: Utility-scale PV projects under construction in Indiana (Data source: IURC [21])

In addition to the ten projects under construction, there were a further 35 projects with a combined capacity of 5,993 MW, which had received approval from the IURC, whose construction had not started. Table 6-3 is a list of these 35 projects.

Project	**County**	**Capacity (MW_{AC})**	**Planned In-service date**
Blackford Solar	150	Blackford	2025
Elkhart Solar	100	Elkhart	2025
Gibson Solar Ph1	200	Gibson	2025
Lone Oak Solar Energy	120	Madison	2025
Riverstart Solar Park IV	150	Randolph	2025
Sun Chief Solar	100	Jay	2025
Thalassa Solar***	116.4	Dekalb	2025
Vermillion Rise Solar	185	Vermillion	2025
Cherry Hill Solar Energy	100	LaGrange	2026
Emerald Green Solar	200	Howard	2026
Honey Creek Solar Phase I	200	White	2026
Honey Creek Solar Phase II	180	White	2026
IN Solar 1/Wheatland Solar	150	Knox	2026
Locomotive Solar	200	Howard	2026
Mammoth Solar Phase II (South)	300	Pulaski	2026
Mammoth Solar Phase III (Central)	600	Pulaski	2026
Ratts 2 Solar	150	Knox	2026
Rose Gold Solar	150	Jay	2026
Skycrest Solar	155	Jay	2026
Trade Post Solar	200	Sullivan	2026
Crosstrack Solar	130	Pike	2027
Crossvine Solar	100	Dubois	2027
Foundry Works	200	Lake	2027
Gibson Solar Ph 2	80	Gibson	2027
Honey Creek Solar Phase III	200	White	2027
Lake Trout Solar	245	Blackford	2027
Mayapple Solar	224	Pulaski	2027
Merrillville Solar	57.5	Lake	2027
Moss Creek	200	Pulaski	2027
Reclamation Solar Energy	150	Gibson	2027
Elliott Solar~	200	Gibson	2028
Crossroads Solar	200	Fountain	NA
Greensboro Solar Center	100	Henry	NA
Rustic Hills Solar	100	Warrick	NA
Rustic Hills Solar II/Warrick Co Solar Project	100	Warrick	NA

Total approved but not started construction **5,993**

Table 6-3: Approved utility-scale PV projects in Indiana not yet under construction (Data source: IURC [21])

Unlike the growth in PV capacity in the 2013 – 2020 period that was driven by net-metering and feed-in tariffs, the more recent growth of utility-scale PV solar capacity is driven by more fundamental industry-wide issues of the need for replacement capacity for aging generating fleet working in combination with the pressure to lower the carbon emissions of the electricity industry in line with the national and global climate goals.

In addition, the Federal government has provided a generous incentive package through the Inflation Reduction Act of 2022 (IRA). In the IRA the investment tax credit (ITC) available to PV power plants was extended to 2032 in two stages. In the first stage, the ITC was extended to include projects beginning construction before the end of 2024. From 2025 a new 30 percent Clean Electricity Investment Tax Credit (CEITC) kicks in and continues to include projects beginning construction in 2032 or until greenhouse gas emissions from the electricity sector fall to 75 percent below the 2022 level. The CEITC is identical to the ITC except it is expanded to include other non-carbon emitting technologies such as nuclear.

In addition, the Inflation Reduction Act made provision for PV projects to qualify for the 1.5 cents/kWh (1993 dollars) production tax credit, which was extended, like the ITC, to the end of 2024, and also for the new Clean Electricity Production Tax Credit (CEPTC) that runs from the beginning of 2025 to the end of 2032 or until greenhouse gas emissions from the electricity sector fall to 75 percent below the 2022 level. A more detailed presentation of the CEITC, CEPTC and other incentives in the Inflation Reduction Act are given in Section 1.4 of this report.

6.5 Incentives for PV systems

Federal Incentives

- Business Renewable Energy Investment Tax Credit (ITC) is a corporate tax credit that credits up to 30 percent of expenditures on solar PV installations. The ITC was extended by the Inflation Reduction Act of 2022 to include projects that begin construction before the end of 2024. The full 30 percent credit is conditioned on the workers on the project being paid the prevailing wages at the project's locality and a specified proportion of the workforce being enrolled in the apprenticeship program as defined in the National Apprenticeship Act. A project that does not meet the prevailing wage and apprenticeship conditions qualifies for only 6 percent credit. A project can earn an extra 10 percent credit by using power plant equipment with a specified proportion of domestic content, by locating in an "energy community" or by locating in an "environmental justice community." The definition of an "energy community" and "environmental justice community" are given in Section 1.4 of this report. A project located on a low-income economic development project or residential building qualifies for an extra 20 percent tax credit [23, 24].

- Residential Renewable Energy Tax Credit is a personal tax credit that credits up to 30 percent of expenditures on solar PV installations on residential properties. The tax credit has been extended by the IRA to include projects that start construction before the end of 2024 [23, 24].

- The Clean Electricity Investment Tax Credit (CEITC) enacted for the first time by the Inflation Reduction Act of 2022 is similar to the ITC above, except it includes all zero carbon-emitting technologies and does not come into effect until 2025. Projects qualify for the CEITC if they commence construction between January 1, 2025 and the end of 2032. To qualify for the full 30 percent credit, a project must meet the prevailing wage and apprenticeship conditions, just as in the ITC above. Projects also can qualify for an additional 10 percent credit if they meet the conditions specified for the ITC above [23, 24].

- Renewable Electricity Production Tax Credit (PTC). The Inflation Reduction Act 2022 has added photovoltaics to the list of technologies that qualify for the PTC. Projects can get as much as 1.5 cents/kWh (1993 dollars) if they meet the prevailing wage and apprenticeship conditions specified above. Projects that don't meet the prevailing wage and apprenticeship conditions only qualify for 0.3 cents/kWh (1993 dollars) credit. Projects can earn 10 percent extra credit if they meet the domestic content condition and another 10 percent if they are located in an energy community or a low-income community. The ten percent for the PTC is calculated on the base 1.5 cents/kWh (1993) credit. Projects can earn 20 percent credit if they are located in a low-income residential development [23, 24].

- The Clean Electricity Production Tax Credit (CEPTC) enacted for the first time by the Inflation Reduction Act of 2022 is similar to the PTC above, except it includes all zero carbon-emitting technologies and does not go into effect until 2025. Projects qualify for the CEPTC if they commence construction between January 1, 2025 and the end of 2032. To qualify for the full credit, projects must meet the prevailing wage and apprenticeship conditions, just like for the PTC above. Projects can also draw an extra 10 or 20 percent credit if they meet the conditions specified for the PTC above [23, 24].

- 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 [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 and 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 [15, 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 [14].

- Energy Efficiency Mortgage can be used by homeowners to finance a variety of energy efficiency measures, including renewable energy technologies, in new or existing homes. The federal government subsidizes these mortgages by insuring them through the Federal Housing Authority or the Department of Veterans Affairs [14].

Indiana Incentives

- Senate Enrolled Act 390 (SEA 390), the Indiana commercial solar and wind energy ready communities Act provides for a mechanism to incentivize counties and municipalities to make solar and wind friendly regulations. It provides for the Indiana Office of Energy Development to certify counties and municipalities as *commercial solar energy ready communities and wind energy ready communities* if their commercial solar and wind regulations are not more restrictive than the state-wide default standard set by Indiana law. Although funds had not been appropriated for the purpose, SAE 390 also provides for $1/MWh production tax credit for ten years paid to the counties that meet the *solar energy ready communities and wind energy ready communities* certification for a commercial solar or wind project installed in the county/municipality [27]

- 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 continue to receive the full retail credit until July 1, 2047 and those installed from 2018 until either 2022 or when the utility's total net metering load reaches 1.5 percent of their peak demand will receive full retail credit for their generation until July

1, 2032 [15, 28].

- Renewable Energy Property Tax Exemption provides property tax exemptions for solar thermal, PV, wind, hydroelectric and geothermal systems [14].

- Community Conservation Challenge Grant provides $25,000-$100,000 in grants for community energy conservation projects that reduce energy consumption or displace the use of traditional energy sources [14].

- 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 [14].

- 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 [14].

- 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 $0.1564/kW and $0.138/kW for solar systems larger than 10kW up to 200kW [29].

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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 French Engineer Bernard Forest de Bélidor. 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 start of the 20th century hydropower provided over 30 percent of the electricity generated in the U.S. With the rise of other fuels, such as coal, nuclear, natural gas, wind and solar, the role of hydroelectricity has dropped steadily to the point that it supplied only 6 percent of the total electricity generated in 2023. Starting in 2019 hydroelectricity has been overtaken by wind as the main source of renewable electricity in the U.S. In 2023, electricity generated from wind constituted 48 percent of the renewable electricity generated in the U.S., while hydroelectricity contributed 26 percent. Solar generation is also steadily increasing, contributing 19 percent of the renewable electricity generated in 2023 [3, 4].

There are several different types of hydropower facilities in operation. They include impoundment hydropower, diversion, run-of-the-river, micro hydro, and pumped storage.

Impoundment hydropower is the most common hydropower facility. It involves storing water in a dam and then releasing this water as needed through the turbines to generate electricity. These dams also serve the purpose of flood control. Figure 7-1 shows the schematic of an impoundment hydropower plant [5].

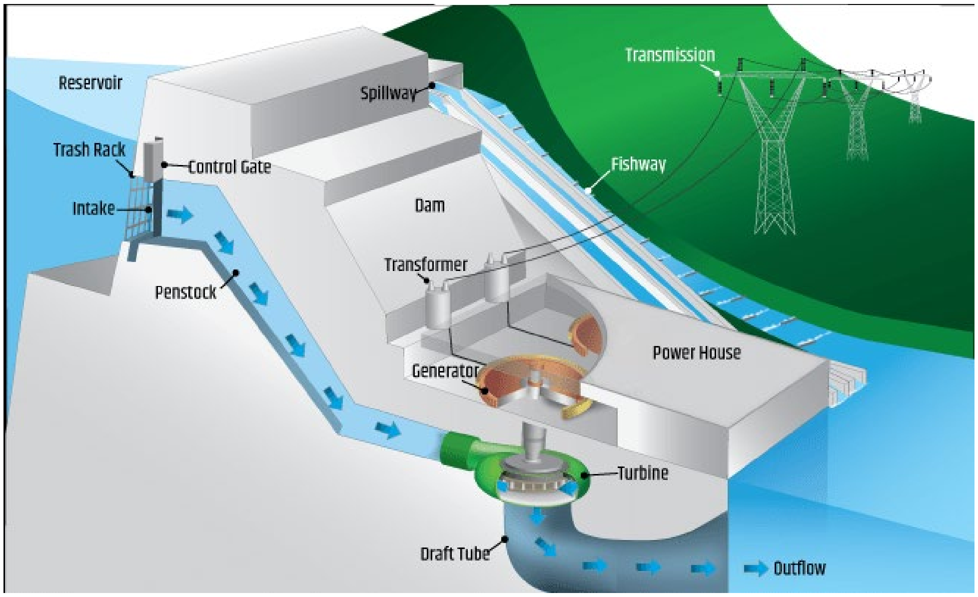

Figure 7-1: Schematic of an impoundment hydropower facility (Source: DOE [6])

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

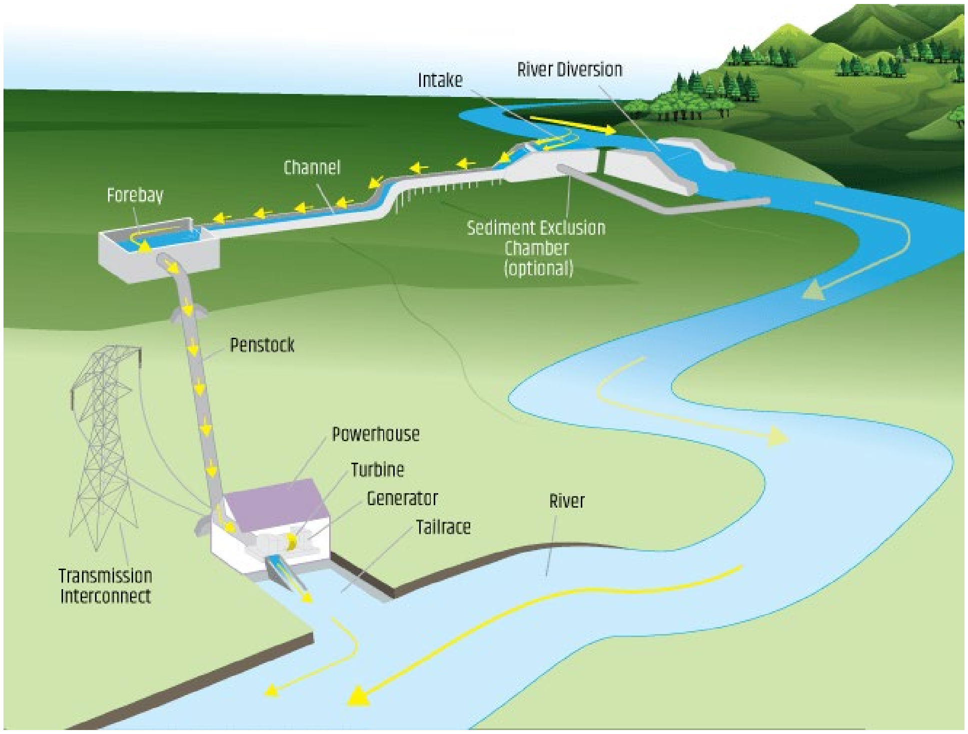

Figure 7-2: Schematic of a diversion hydropower facility (Source: DOE [6])

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 Oakdale run-of-river hydropower plant on Lake Freeman.

Figure 7-3: Oakdale run-of-river hydropower plant in Carroll County (Source: NIPSCO [7])

Micro hydropower 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 home or business. Figure 7-4 shows a photograph of a micro hydro power plant manufactured by Suneco Green Energy.

Figure 7-4: Micro hydropower facility (Source: Suneco Green Energy [8])

Pumped storage hydropower plants are currently the most common large-scale energy storage technology. When electricity demand is low and electricity prices are low, electricity from the grid 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 prices are higher. Figure 7-5 is a schematic of a pumped storage hydropower plant. A more detailed discussion of pumped storage hydropower plants is given in Section 8 of this report.

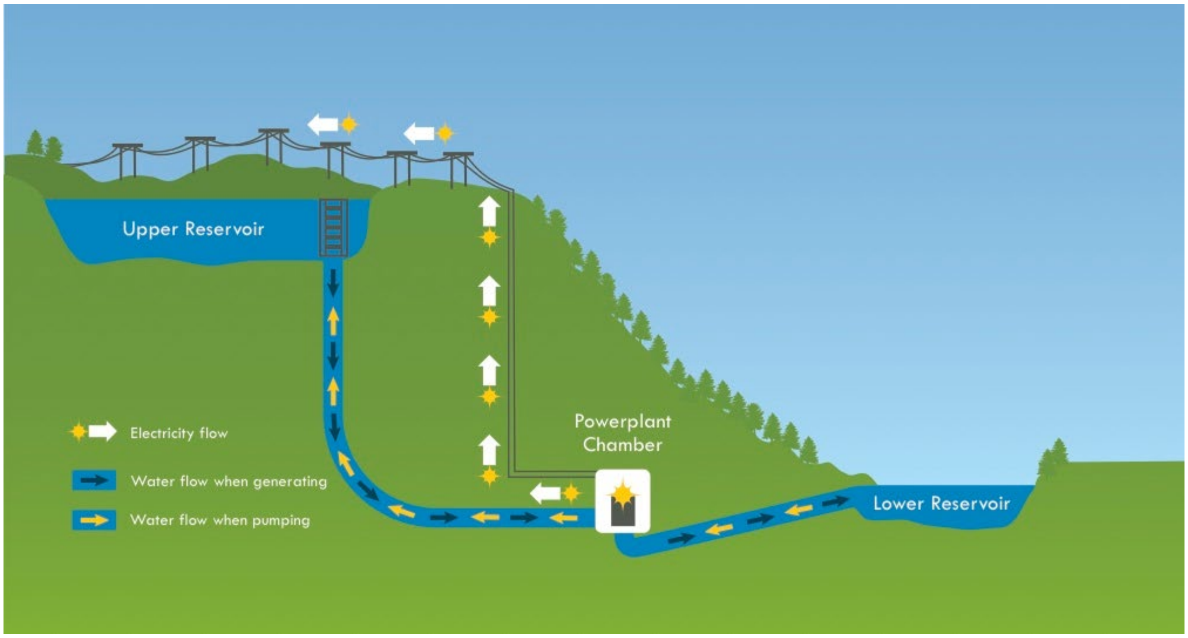

Figure 7-5: Schematic of a pumped hydro facility (Source: DC Thompson and Company [9])

In addition to types of hydropower facilities, 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 hydropower projects –impulse and reaction turbine types. The impulse turbine type uses the velocity of the water while the reaction turbine uses both the velocity of the water and the pressure drop as the water passes through the turbine. The impulse turbine is more suited to a high head,[13] low flow application while the reaction turbine is more suited to a lower head, faster flow situation [10].

7.2 Economics of hydropower

Hydropower projects are very capital intensive, and the cost is very site specific. Figure 7-6 shows the capital cost ranges for U.S. hydropower projects from 1980 to 2020 expressed in 2019 dollars

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

obtained from the 2021 DOE U.S. *Hydropower Market Report*. The projects are arranged in three groups: *canals/conduits, non-powered dams (NPD) and new stream-reach development (NSD)*. *Canal/conduit* hydropower projects are those constructed on water conveyance conduits put in place primarily for irrigation or water supply. *Non-powered dams* are hydropower projects added to dams already in place for other purposes, such as water storage, irrigation, or navigation, while new *stream-reach development* projects are small capacity hydropower projects that can be built on streams with minimal environmental impact [11].

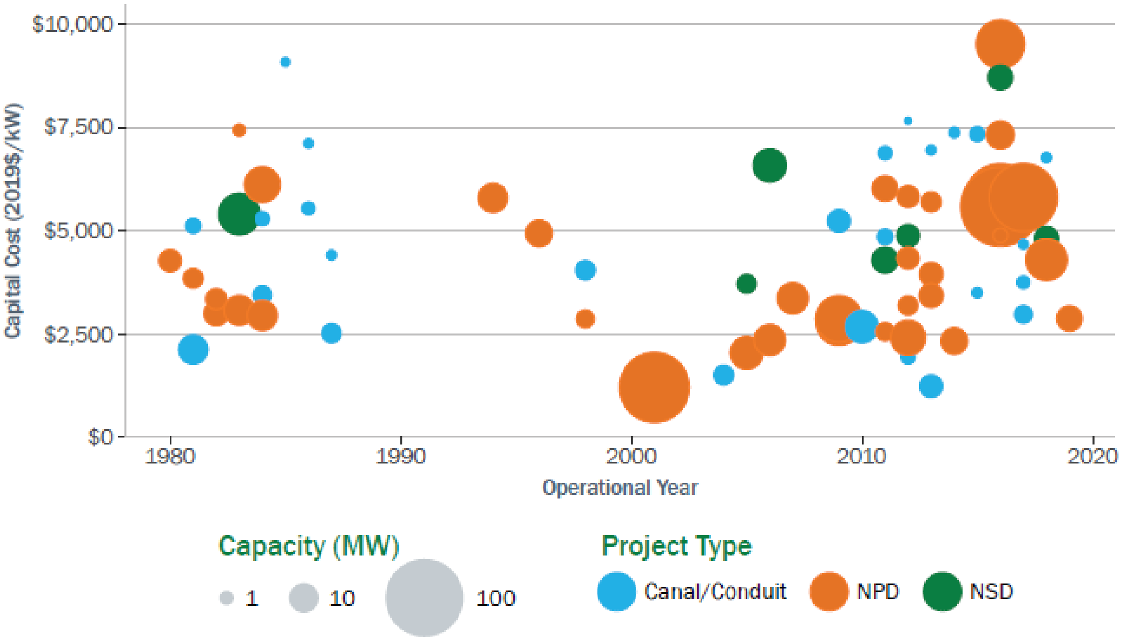

Figure 7-6: Capital cost of new U.S. hydropower plants constructed (1980-2020) (Source: DOE [11])

Table 7-1 shows capital cost 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 $7,889/kW cost in 2011 dollars estimate for the American Municipal Power's Willow Island hydroelectric plant on the Ohio River.

Project		Time[*]	Initial Capital Costs ($/kW) [**]
EIA estimates		2018	3,421
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
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	Not Available	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 2022 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.

Table 7-1: Initial capital costs of hydropower projects (Data sources: EIA, Maui Electric Company [12-14])

Once constructed, hydroelectric power plants have a major cost advantage since, in addition to the free fuel, they have moderately low O&M costs. According to the February 2023 EIA electricity generating technologies cost estimates, 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 Figure 7-7, hydroelectricity's variable O&M costs are estimated at $1.57/MWh, and the fixed O&M cost is $47/kW-yr for a conventional hydroelectric plant. Impoundment hydropower plants, that is, those with dams that hold substantial amounts of water in a reservoir, have an added advantage over some of the other renewable resources (for example, wind and solar) in that they are dispatchable. That is, the system operator can control the hydropower plant's output to match the system load. In addition, pumped hydro is the most economical energy storage technology among large-scale storage technologies in use in the electricity industry today.

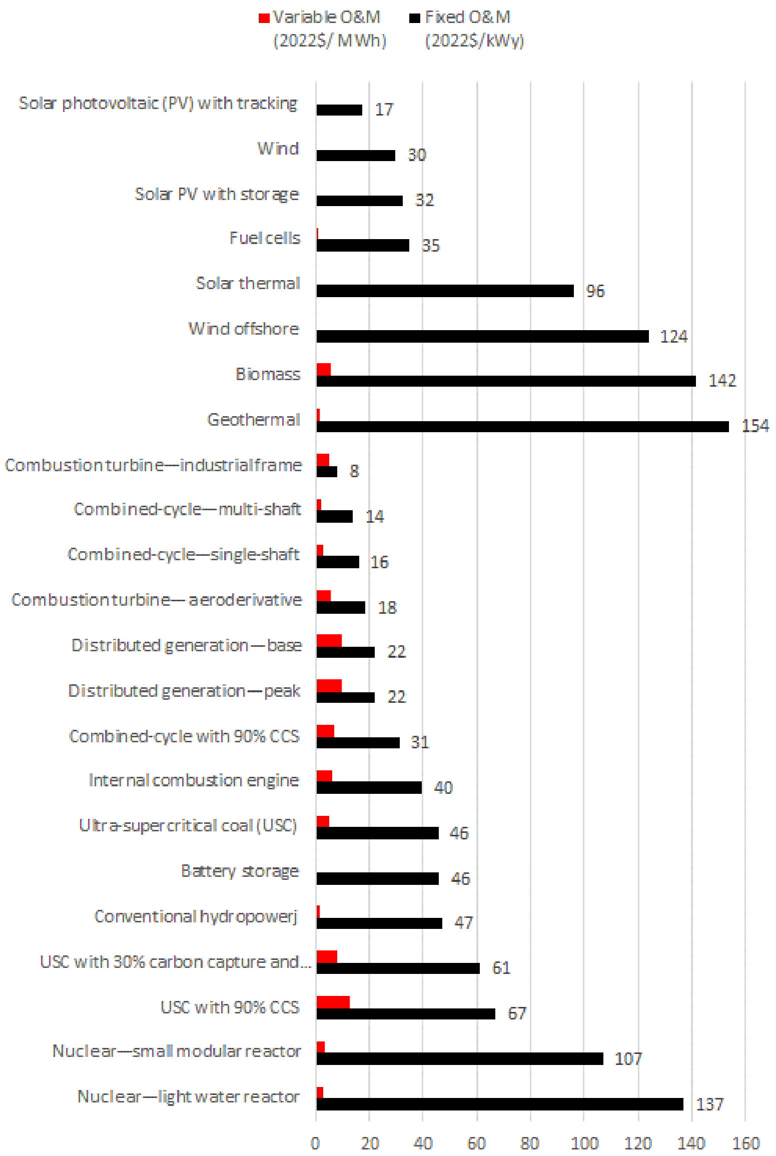

Figure 7-7: Estimated generating technologies fixed and variable O&M costs (Data source: EIA [12])

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 2023. In the early parts of the 20th century, hydroelectricity accounted for virtually all the renewable electricity generated in the U.S. with all other renewable resources combined contributing less than one percent up to 1974. Hydroelectricity's dominance has reduced to where, in 2019, it was overtaken by wind as the main source of renewable electricity; in 2023, wind contributed 48 percent of the renewable electricity while hydroelectricity contributed 26 percent.

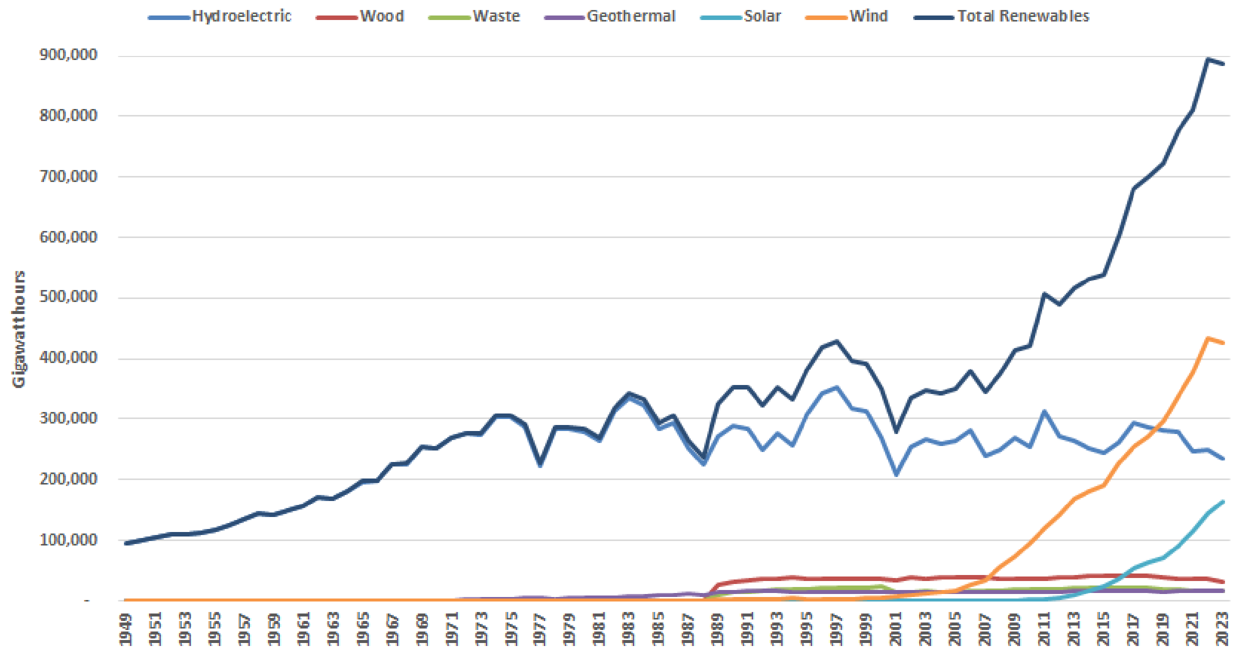

Figure 7-8: Net renewable electricity generation in the U.S. (1949-2023) (Data source: EIA [4])

The total installed hydropower capacity in the U.S. is 102 gigawatts (GW), consisting of 80 gigawatts (GW) of conventional hydro and 22 GW of pumped hydro plants [11, 15]. Table 7-2 is a list of the ten largest hydropower plants in the U.S.

Hydropower Plant Name	River	State	Nameplate Capacity (MW)	Year of completion
Grand Coulee	Columbia	Washington	6,495	1941-1984
Bath County*	Little Back Creek	Virginia	2,862	1985
Chief Joseph	Columbia	Washington	2,456	1955-1979
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	1,675	1972-1978

*Pumped hydropower stations

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

Table 7-3 shows the top ten hydro states ranked by their hydroelectricity output in 2022 and Table 7-4 shows the top ten hydro states ranked by installed hydro capacity at the end of 2022. Over 60 percent of the hydroelectricity generation in 2022 was from the top four states of Washington, Oregon, New York, and California and nearly half the nameplate hydroelectric capacity in the U.S. in 2022 was in the top four states of Washington, California, Oregon and New York.

State	2021 Generation (GWh)	percent of U.S. generation
Washington	78,916	31%
Oregon	31,304	12%
New York	27,432	11%
California	17,644	7%
Alabama	10,188	4%
Montana	9,886	4%
Tennessee	9,198	4%
Idaho	8,360	3%
Arizona	5,298	2%
North Carolina	4,686	2%

Table 7-3: <u>Top ten U.S. hydropower generating states in 2022 (GWh)</u> (Data source: EIA [16])

State	2022 Nameplate Capacity (MW)	Percent of U.S. Hydro Capacity
Washington	21,606	21%
California	13,804	14%
Oregon	8,435	8%
New York	5,924	6%
Tennessee	4,218	4%
South Carolina	4,199	4%
Virginia	3,932	4%
Georgia	3,597	4%
Alabama	3,318	3%
Arizona	2,912	3%

Table 7-4: <u>Top ten U.S. hydropower capacity states at the end of 2022</u> (Data source: EIA [17])

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 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. 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.

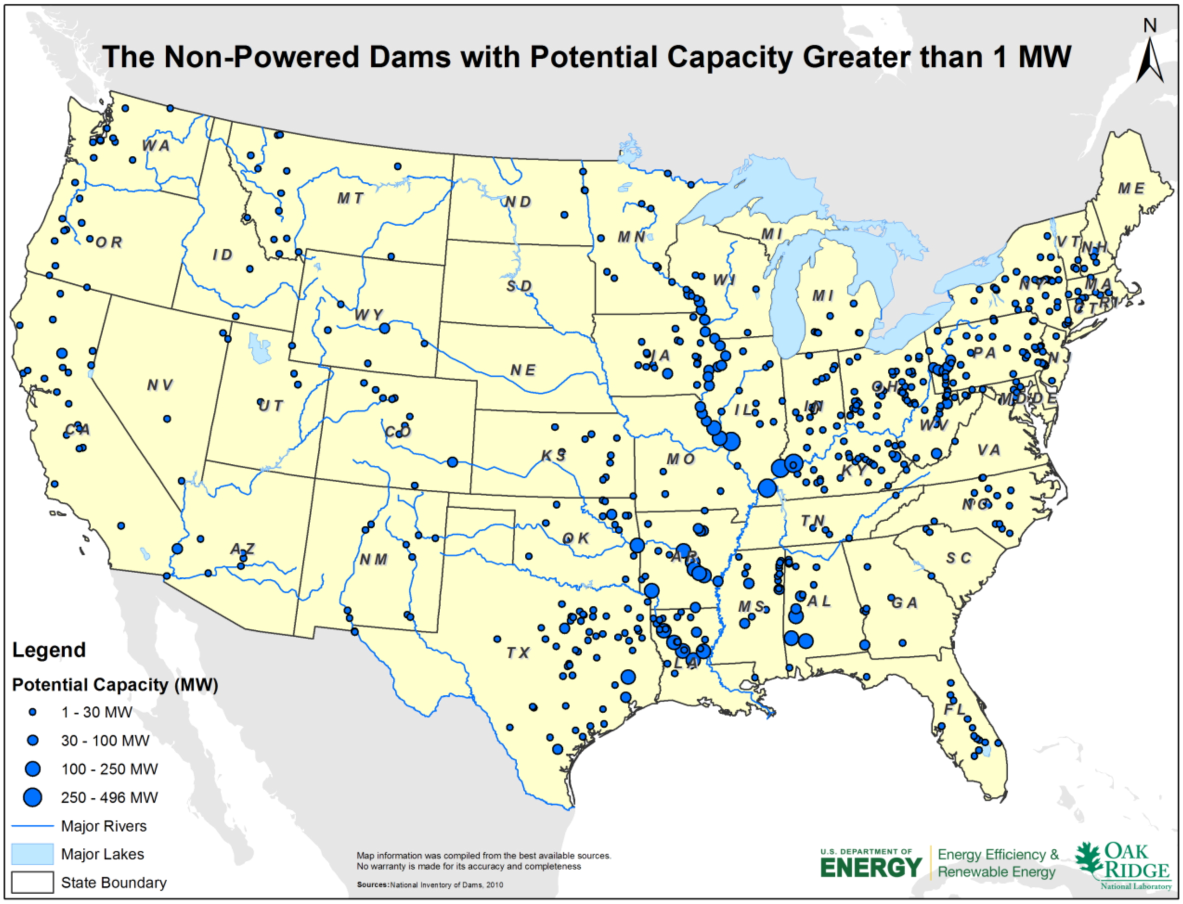

Figure 7-9: Non-powered dams with potential capacity over 1 MW (Source: DOE [18])

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

Table 7-5: Hydropower potential from non-powered dams by state (Data source: DOE [18])

Building onto the 2012 DOE study referred to above, the United States Army Corps of Engineers (USACE) did a more rigorous analysis of the 419 of these non-powered dams that were owned and operated by the United States Army Corps of Engineers. They identified 223 such dams nationally that could be developed into hydropower plants using the following criteria.

- Have the potential to support at least 1 MW of hydropower generation capacity.
- Have no current Federal Energy Regulatory Commission (FERC) license issued.
- That have no obvious hindrance to the development of a hydropower plant.

Table 7-6 provides the distribution of the 223 USACE-operated currently non-powered dams in the lower 48 U.S. states.

U.S. Army Corps of Engineers Region	Number of Technically Feasible Projects	Potential Capacity (MW)	Economically Feasible Capacity (MW)
Great Lakes & Ohio River	71	1,962	898
Mississippi Valley	50	1,568	940
Southwestern	39	288	63
North Atlantic	21	349	51
South Atlantic	19	672	325
Northwestern	12	116	113
South Pacific	11	1,302	429
Total	**223**	**6,256**	**2,819**

Table 7-6: Potential Capacity from non-powered dams owned by the U.S. Army Corps of Engineers (Data source: USACE [19])

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

7.4 Hydropower in Indiana

Until the commissioning of the first wind farm in Indiana in 2008, hydroelectricity was the main source of renewable electricity as shown in Figure 7-10. With 3,668 MW of utility-scale installed wind capacity at the end of 2022 compared to 105 MW of hydropower installed capacity, wind is now the dominant source of renewable electricity. Furthermore, the photovoltaic capacity has also been climbing rapidly to overtake hydropower with 1,938 MW of installed solar at the writing of this report.

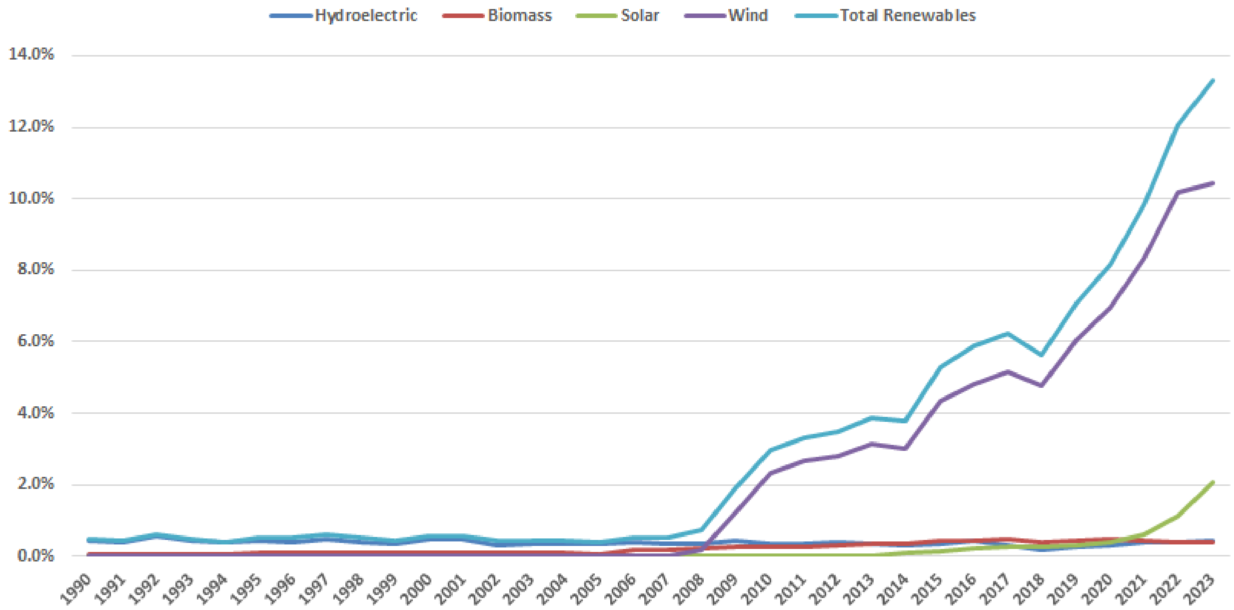

Figure 7-10: Renewables share of Indiana net electricity generation (1990-2023) (Data source: EIA [21])

The 2012 DOE national assessment of hydropower potential from non-powered dams referred to in the preceding section of this report estimated that Indiana had a total potential of 454 MW hydropower capacity from already existing, non-powered dams. Table 7-7 lists the dams in Indiana with a potential greater than 1 MW of hydropower development. The capacity of the two dams on the Ohio River is assigned in equal proportions between Indiana and Kentucky.

Dam Name	County	City	River	Hydro-power Potential (MW)
John T. Myers locks & 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 7-7: Indiana non-powered dams with potential capacity over 1 MW (Data source: DOE [20])

The 2013 U.S. Army Corps of Engineers hydropower study, referred to earlier, estimates that there are eleven non-powered dams owned and operated by the U.S. Army Corps of Engineers in Indiana with potential for economically feasible hydropower development as shown in Table 7-8. Their total estimated capacity is 352 MW and 1,291 GWh of electricity in a year.

Name of Dam	**Estimated Capacity (MW)**	**Estimated Annual Generation (MWh)**	**Average Head (Feet)**	**Average Flow $(\text{feet})^3$/second**
John T. Myers locks & dam	115	731,882	16	158,807
Newburgh locks & dam	97	371,585	14	137,799
Brookeville Lake dam	32	36,507	122	500
Mississinewa lake dam	26	33,508	76	816
Salamonie lake dam	23	24,435	78	559
J. Edward Roush lake dam	18	16,584	40	673
Cagles mill lake dam	11	14,930	56	378
Monroe lake dam	10	17,416	55	535
Cecil M Harden lake dam	7	9,404	70	234
Green river lock & dam 1	6	27,815	8	11,135
Patoka lake dam	5	7,119	57	216
Total	**352**	**1,291,185**		

Table 7-8: Potential Capacity from non-powered dams owned by the U.S. Army Corps of Engineers in Indiana (Data source: USACE [19])

The 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 [20].

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 the 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 [22, 23].

The University of Notre Dame's 2.5 MW hydroelectric project on the Saint Joseph River in South bend was completed and started generating electricity in May 2022. 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 for the Seitz Park in downtown South Bend where the hydroelectric project is located. Construction on the project started in 2019 [24, 25].

7.5 Incentives for hydropower

Federal Incentives

- Clean Electricity Investment Tax Credit (CEITC) enacted in the Inflation Reduction Act 2022 credits 30 percent of construction cost to all electricity-generating technologies which have zero greenhouse gas emissions. The credit comes into effect in 2025 and expires either at the end of 2032 or whenever greenhouse emissions from the electricity industry reduce by 25 percent below the 2022 level [26, 27].

- Clean Electricity Production Tax Credit (CEPTC) provides a 1.5 cents/kWh (1993 dollars) credit for electricity generated from all zero-carbon emitting technologies. The credit goes into effect in 2025 and expires at the end of 2032 or whenever greenhouse emissions from the electricity industry are reduced by 25 percent below the 2022 level [26, 27].

- 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 [28].

- 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 [28, 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 [28].

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 continue to receive the full retail credit until July 1, 2047, and those installed from 2018 until either 2022 or when the utility's total net metering load reaches 1.5 percent of their peak demand will receive full retail credit for their generation until June

30, 2032 [28, 31].

- Renewable Energy Property Tax Exemption provides property tax exemptions for solar, wind, hydroelectric, and geothermal systems [28].

- 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 [28].

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8. Underground Pumped Storage Hydropower

8.1 Introduction

An underground pumped storage hydropower plant is a pumped storage hydropower plant where at least one of the reservoirs, usually the lower one, is located underground. This can be an artificially constructed cavern or an abandoned mine, or any other underground chamber with the ability to hold water without losing it through leaks. In some designs, it has been proposed to put both reservoirs underground to reduce the footprint of the power plant even further.

Although there have been many feasibility studies, a recent increase in interest, and a number of proposals to build underground pumped storage hydropower plants worldwide, SUFG is not aware of any underground pumped storage hydropower in operation or under construction anywhere in the world as of the writing of this report. In contrast, conventional surface-level pumped storage hydropower plants have been in operation for decades in the U.S. and globally. They have been the dominant technology in use for utility-scale energy storage both in the U.S. and globally, constituting as much as 93 percent of utility-scale electrical energy storage capacity (MW) the U.S. at the end of 2019 [1]. The basic structure of a pumped storage hydropower plant consists of two water reservoirs at differing heights, as shown in Figure 8-1. As mentioned earlier, the more common arrangement in existing pumped-storage hydroelectric power plants is for both reservoirs to be surface-level lakes at differing elevations.

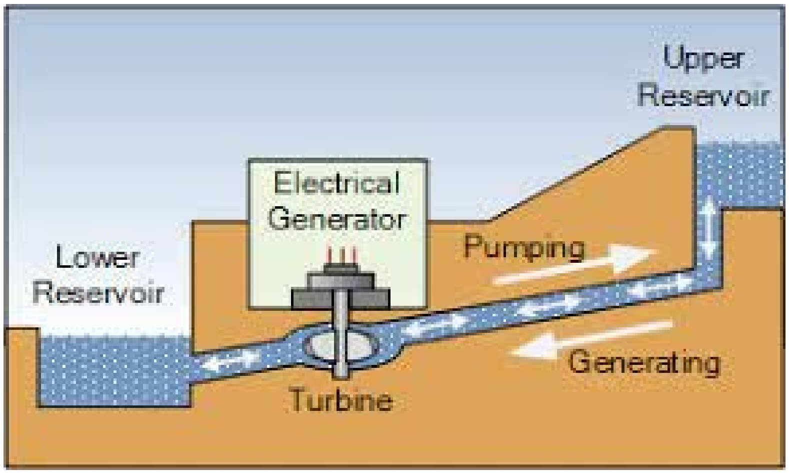

Figure 8-1: Schematic of a pumped storage hydropower plant (Source: Alternative Energy Tutorials [2])

During periods of low electricity demand, electricity from the grid is used to pump water from the lower to the upper reservoir. Then during times of high electricity demand this water is released through a turbine to the lower reservoir to generate electricity. An example of a pumped storage power plant close to Indiana is the 1,872 MW Ludington Pumped Storage Hydropower plant in Ludington, Michigan. In this pumped storage plant, Lake Michigan is used as the lower reservoir, while the upper reservoir is a man-made lake at the elevated plateau above the lake shore [3].

The main driver behind the impetus to build underground pumped-storage hydropower plants is that conventional pumped-storage hydropower plants require the availability of topography with significant elevation differences. Sites with this type of topography have, for the most part, been exhausted, and where they exist, the proposal to flood large tracts of land to create the reservoirs faces fierce public resistance. Underground pumped storage hydropower technology overcomes this siting constraint by placing one or both of the reservoirs underground. Further, since the power rating of a hydropower plant is proportional to the height that the water falls before encountering the turbines for a given reservoir volume, one can reduce the size of the upper surface reservoir by increasing the depth at which the lower reservoir is excavated. This can be done at a reasonable cost because the excavation cost of the reservoir does not increase proportionally with increasing depth [4].

Figure 8-2 is the schematic of a typical underground pumped storage hydropower plant where only one of the reservoirs, the lower one, is underground, in a specially constructed cavern or in an abandoned mine.

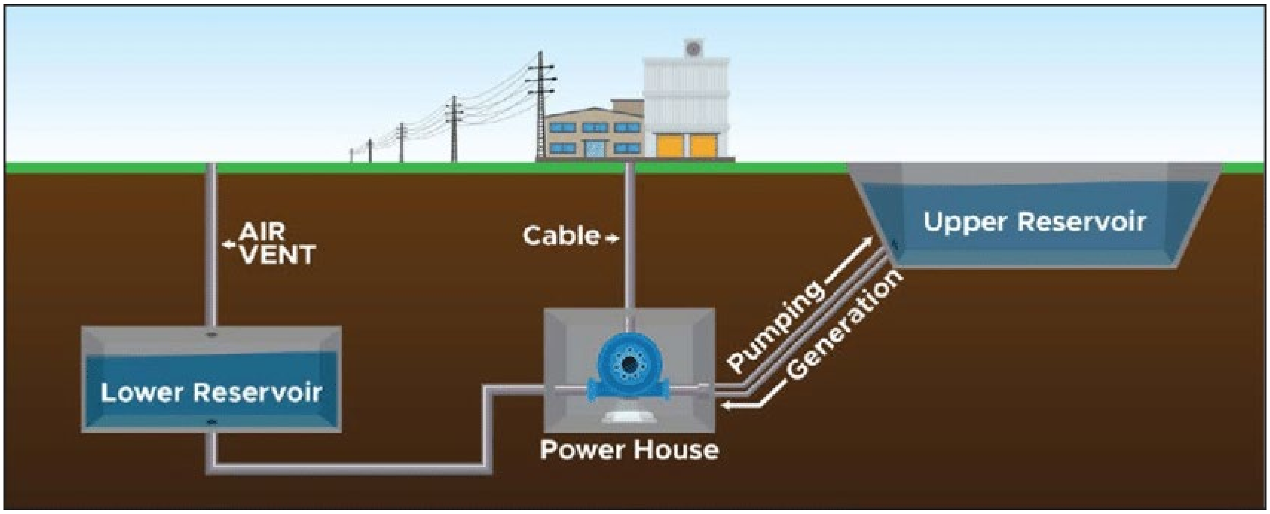

Figure 8-2: Schematic of an underground pumped storage hydropower plant (Source: ResearchGate [5])

In some conventional pumped storage hydropower plants, the power plant equipment (turbines and transformers, pressure pipes, etc.) are placed underground. This arrangement, however, does not constitute an underground pumped storage hydropower plant, as discussed in this report; one of the two reservoirs has to be placed underground for a pumped storage hydropower plant to be considered an underground pumped storage hydropower plant [4].

8.2 Economics of underground pumped storage hydropower

Many studies in the U.S. and elsewhere have been done establishing that underground pumped storage hydropower is both technically viable and, at least from modeling studies, an economical technology for large-scale storage of energy for the electrical grid [4, 6]. Most of the feasibility studies done for underground pumped hydropower in the U.S. in the 1980s were focused on building the power plants with man-made underground reservoirs as close to the demand centers (cities) as possible, with the only limitation being the presence of the required hard impervious rock formations that could hold water without leaking. The use of abandoned mines for the lower reservoir has received more attention in recent years as more coal mines are made available by the move towards less carbon intense energy.

The cost of building underground pumped storage hydropower plants using abandoned mines is very site specific and depends on how well fitted the caverns in the abandoned mines are to hold the water and the power plant equipment. A few of those studies found in literature, and their cost estimates are presented below.

Reinhard Madlener and Jan Martin Specht (2013, 2020). This paper, first published in 2013 and then revised in 2020, presents the results of an economic analysis done on the possibility of building pumped storage hydropower plants using the many abandoned deep coal mines in the Ruhr region of Germany. Although this study is cited in literature as one of the most rigorous techno-economic analysis of underground pumped storage hydropower plants using abandoned coal mines, the authors make a point to emphasize that there are numerous uncertainties in the data and assumptions made in the study and much more needs to be done to get a more accurate estimate of the costs and potential profitability of underground pumped storage hydropower plants in underground mines.

Figure 8-3 shows the capital cost of a 2,500 MWh underground pumped storage hydropower plant in Euros (€) per kW as a function of the realized head[14] of water. The realized head is determined by the depth of the mine at which the lower reservoir is constructed. For example, for a lower reservoir placement that results in a 1,000-meter head, the capital cost for a 5-hour discharge turbine is €1,265/kW and €2,024/kW for an 8-hour discharge turbine. At an exchange rate of 0.8 euros to a U.S. dollar, this capital cost converts to $1,580/kW for a 5-hour discharge power plant

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[14] The head (also known as the hydraulic head) is a measure of the energy available in a water column at the inlet to the turbine. In a pumped storage hydropower plant, it is proportional to the height difference between the upper and the lower reservoirs.

and $2,530/kW for an 8-hour discharge power plant. The 0.8 euro to dollar conversion rate was the exchange rate used in the paper.

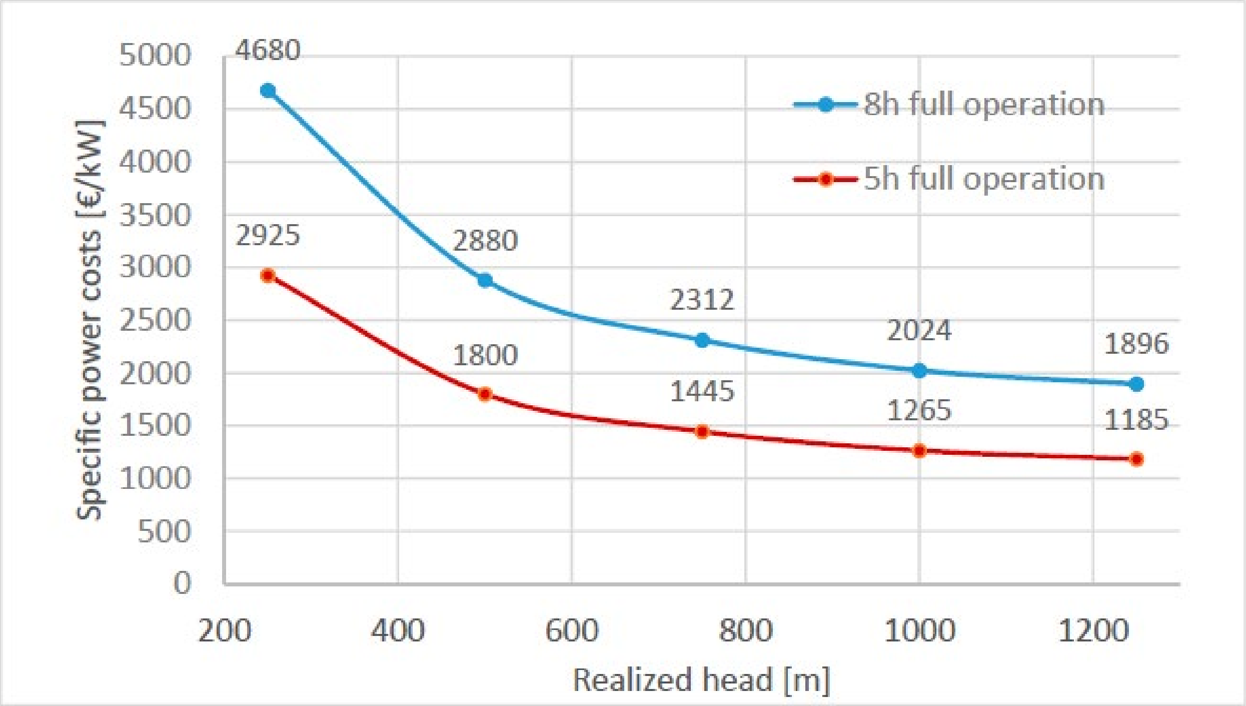

Figure 8-3: Capital cost of underground pumped storage hydropower plant in an abandoned coal mine in Germany (Source: Madlener et al. [4])

R Alvarado Montero, T. Wortberg, J. Binias and A Nieman (2016) While the Madlener and Specht study presented above was based on a generic mine in the Ruhr region of Germany, the study presented in the Montero et al. paper presents an investigation that went a step further to do a technical and economic assessment of building an underground pumped storage power plant in a particular mine, the Prosper-Haniel mine in the same Ruhr region in Germany. This study brings to even clearer focus the wide range of the potential cost that even when one narrows it down to one mine, the cost will vary widely depending on how much of the mine infrastructure is usable and how much more work (excavation, etc.) needs to be done to house the reservoir, pump house, etc.

In the case of the Prosper-Haniel mine, the capital cost of the power plant was estimated to range from a low of €760/kW to a high of €2,750/kW, depending on how much of the mine tunnels system was usable for water storage. Using the 0.8 euros to a dollar exchange rate explained earlier this translates to a low cost of $950/kW and a high cost of $3,480/kW. In the lowest cost option, the existing open tunnels in the mine are assumed usable while in the high-cost case only the mine shafts are deemed usable and new tunnels have to be excavated to hold the water as the lower reservoir [7].

Peter Schubert, Afshin Izadian, and JW Wheeler, in a paper published in October 2019 is the one study that is based on abandoned coal mines in Indiana. The study envisages a modular underground pumped storage hydropower plant design that can be scaled to fit different sizes of mines. The conceptual power plant used for cost estimates is a 200 MW, 1400 MWh (7-hour discharge) plant with the lower reservoir at a depth such as to have a 400 ft of water head.

A unique design feature in this power plant is the use of hydraulic wind turbines to supplement the pumping of the water from the lower reservoir to the upper reservoir. A hydraulic wind turbine differs from the more common electricity-generating wind turbines in that instead of a turbine-generator, the rotors in a hydraulic turbine drive a hydraulic pump, which can then be used to drive a water pump. The authors estimated the cost of this power plant at $1,494/kW [8].

Roman Sidortsov, Shardul Tiwari, Timothy Scarlett, Ana Dyreson, and David Watkins of Michigan Technological University, in a draft technical report written in 2021, details a landscaping study of repurposing of decommissioned metal mines (not coal) generally in the U.S., with a specific case study involving the use of a decommissioned copper mine in the Upper Peninsula of Michigan.

Their preliminary results estimated that the chosen mine, the Mather B mine in Negaunee, Michigan had the technical and economic feasibility to house an underground pumped storage hydropower plant in either of the two configurations: in a daily cycling configuration with a power capacity of 295 MW and an energy storage capacity of 1,666 MWh, or in a long-term (seasonal) storage configuration with a power capacity of 73 MW and an energy storage capacity of 52,188 MWh. Their estimated capital cost for the facility in the Mather B mine is $1,340/kW.

The study further concluded that the United States had metal mines with the potential to host 285 GW of partially underground UPS hydropower plants or 137 GW fully underground UPS hydropower plants operating in a daily cycling mode with an energy storage capacity of 564,441 GWh or 271,040 GWh for partial or fully underground UPS hydropower plants respectively. In comparison, according to the 2021 U.S. Department of Energy hydropower market report, there were 43 pumped storage hydropower plants operating in the U.S. at the end of 2019, all of them with surface-level reservoirs, with a combined power capacity of 22 GW and a combined energy storage capacity of 553 GWh. All other utility-scale energy storage technologies combined had a total power capacity of 1.6 GW and an energy storage capacity of 1.75 GWh [1, 9, 10].

8.3 State of underground pumped storage hydropower nationally

Although several technical and feasibility studies have been done showing the technical viability of underground pumped storage hydropower plants, SUFG is not aware of any such power plant that has been constructed anywhere in the world so far. The cost and the uncertainty associated with a new technology have been too high a barrier to surmount thus far [11].

There was a flurry of activity in the 1970s and 1980s in the U.S. around the concept of building underground pumped hydropower plants including feasibility studies conducted by utilities such as Commonwealth Edison and Potomac Electric Company. The state of the research in that period is summarized in a 1984 U. S. Department of Energy (DOE) report [6]. During this period, the focus was not on using abandoned mines but rather the excavation of underground reservoirs at locations close to cities where the load was located where they would serve to complement base-load nuclear generation and were considered more economical than running coal-fired power plants on cycling duty. Some of the more prominent studies in that period include.

The Potomac Electric Power Study (1981). According to the 1984 DOE report this study was the most comprehensive and rigorous of the techno-economic and feasibility studies that had been carried out in that period. The design specification was for a 2,000 MW, 10-hour discharge (20,000 MWh) underground pumped storage in close proximity to Washington, D.C., with a 5,000 feet operating head. Seismologic studies were done, and a site with the appropriate rock formation to host the underground reservoir was identified in Maryland 20 miles North of Washington D.C. and 20 miles Southwest of Baltimore, Maryland. Like the other proposed underground projects in this period, Potomac Electric Power did not proceed with the project.

Commonwealth Edison Study (1975-1981). This proposal was for a 3,000 MW, 10-hour discharge (30,000 MWh), underground pumped storage in close proximity to the city of Chicago to complement Commonwealth Edison's nuclear and coal power plants. Seismic studies were done, and a site with the appropriate rock formation to host the lower reservoir was identified in Northwest Illinois, within the Commonwealth Edison service territory. This project was suspended when a revised load forecast set back substantially the date the capacity would be needed.

In more recent times, the attention of the underground pumped storage industry globally has focused on the use of abandoned underground mines. Much more investigation has been going on in Europe than in the U.S. The major studies outside the U.S. encountered in literature include

- The 2013 (revised in 2020) Madlener et al techno-economic study of the potential for using underground coal mines in the Ruhr region of Germany [4]

- The 2016 Alvarado et al. of one of the mines, the Prosper-Haniel mine in the Ruhr region of Germany (200 MW) [7]
- The 2017 Menendez et al study of the use of mines in the Asturian Central Coal Basin in northern Spain [12]

In spite of this heightened interest and studies in the European Union, none of these projects has proceeded to make any substantial progress toward implementation.

In the U.S., most of the proposed underground pumped storage hydropower projects utilizing abandoned mines encountered in literature appear focused not on underground mines but rather on abandoned open pit mines. In addition, none of these projects appear to have progressed beyond a preliminary FERC permit. Underground pumped storage hydropower projects found in literature in the U.S. include.

The 1,000 MW Riverbank Wiscasset project in Wiscasset, Maine (2009) This project uses the site of a decommissioned nuclear power plant (the Maine Yankee Nuclear Power Plant) to minimize the impact of the construction work involved. The project proposes to use for its upper reservoir the tidal water at the mouth of the Black River and for its lower reservoir a man-made cavern excavated 2,200 feet below the surface. It was first proposed in 2008 and issued with a preliminary Federal Energy Regulatory Commission (FERC) permit in 2009. The concept of using this site of a decommissioned nuclear power plant for large-scale renewable energy projects made it attractive to the local community. Like other proposed underground pumped storage powerplants, this project has not progressed beyond permitting [13, 14].

The Elmhurst Quarry project in Elmhurst, Illinois (2011) This project, proposed by the host county (Dupage County) in 2011, was to be located at a dolomite quarry and underground mine 20 miles west of downtown Chicago that had ceased to operate in 1980. The quarry is used for flood control storage, where flood water is stored during flood events and then pumped out into the adjacent creek when the floods subside. This site is unique in that it consists of a surface quarry and an underground mine 300 feet below the quarry, such that very minimal excavation would be needed to construct the pumped hydropower plant. It was estimated to have the volume to host a pumped storage power plant with 709 MWh and between 50 to 250 MW generating capacity. A preliminary permit for the proposed project was issued by FERC in 2011, but like other underground pumped storage projects, it has not progressed much beyond that [15, 16].

8.4 State of underground pumped storage hydropower in Indiana

Indiana has many surface and underground coal mines that are no longer active. According to the Indiana Department of Natural Resources (DNR), there are 701 underground and 388 surface mines in Indiana that are no longer active. Figure 8-4 shows the location of these mines as downloaded from the DNR Coal Mine System map geographic information system database on May 16, 2022.

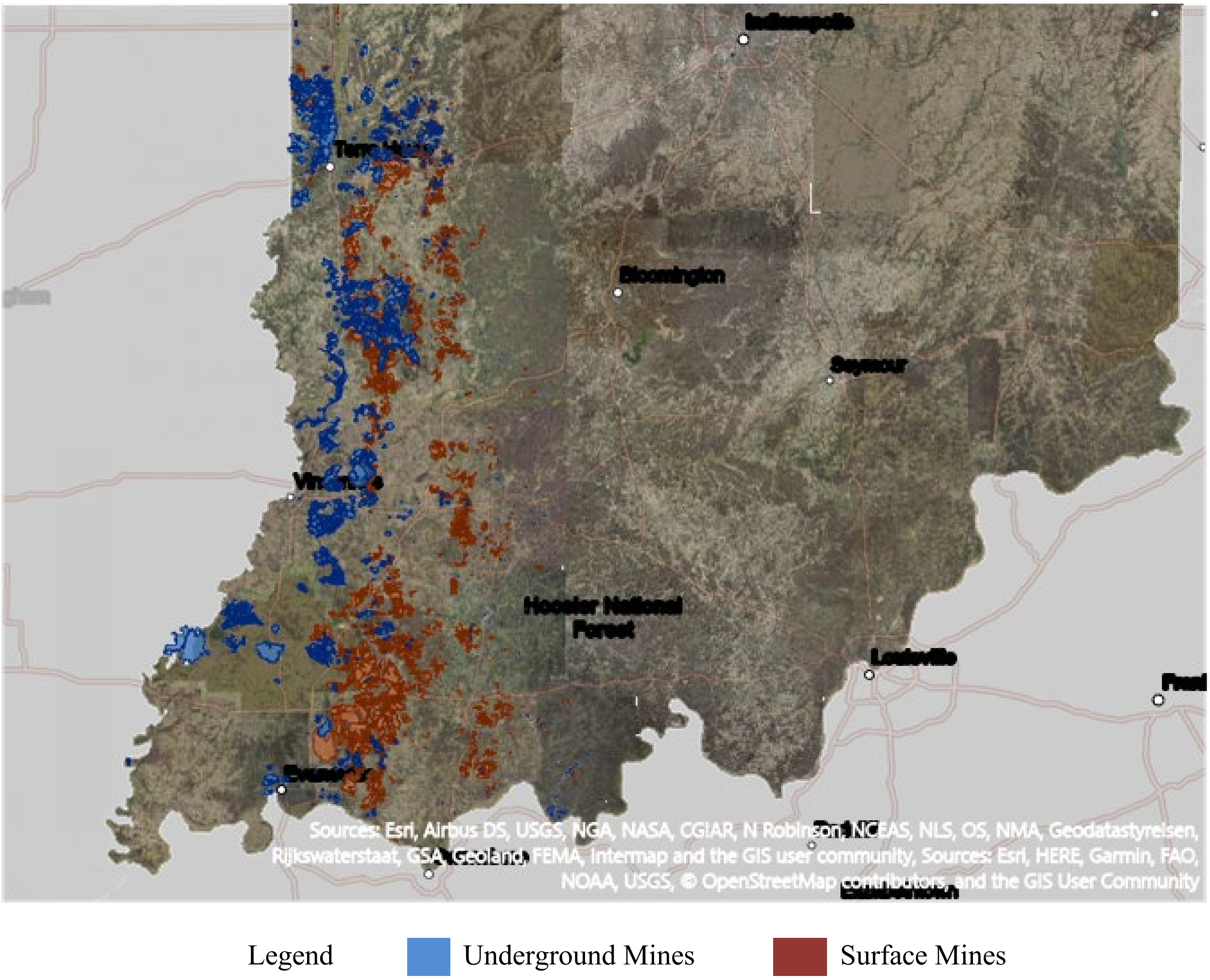

Figure 8-4: Location of inactive mines in Indiana (Source: DNR [17])

Each of these mines has the potential to host an underground pumped storage hydropower plant. Further investigation would need to be done on the suitability of each individual mine, including the condition of the chambers, the depth, the location relative to transmission lines, etc.

Peter Schubert, Afshin Izadian, and JW Wheeler, in their paper referred to earlier in this section, presents the cost estimate of a conceptual underground pumped storage hydropower plant that could be located in one of the many underground mines in Indiana. A modular power plant with the capacity to generate 200 MW for 7 hours (1,400 MWh) and a water head of 400 feet is modeled in the paper [8].

8.5 Incentives for underground pumped storage hydropower

No incentives or mandates specific to underground pumped storage hydropower plants exist currently in the U.S. or in Indiana, but since pumped storage hydropower is a form of hydropower, incentives where hydropower qualifies may also be applicable for underground pumped storage hydropower.

Federal Incentives

- Clean Electricity Investment Tax Credit (CEITC) enacted in the Inflation Reduction Act 2022 credits 30 percent of construction cost to all electricity generating technologies which have zero greenhouse gas emissions. The credit comes into effect in 2025 and expires either at the end of 2032 or whenever greenhouse emissions from the electricity industry reduce by 25 percent below the 2022 level.

  Also included in the Inflation Reduction Act 2022 is a provision that a power plant, such as an underground pumped storage hydropower plant, located in a retired coal mine would qualify for an extra 10 percent investment tax credit [18, 19].

- Clean Electricity Production Tax Credit (CEPTC) provides a 1.5 cents/kWh (1993 dollars) credit for electricity generated from all zero-carbon emitting technologies. The credit goes into effect in 2025 and expires at the end of 2032 or whenever greenhouse emissions from the electricity industry are reduced by 25 percent below the 2022 level [18, 19].

- 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 [20].

- Green Power Purchasing Goal requires that 7.5 percent of energy used by federal agencies must be obtained from renewable resources [20].

Indiana Incentives

- Renewable Energy Property Tax Exemption provides property tax exemptions for solar, wind, hydroelectric and geothermal systems [20].

- 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 [20].

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