Energy Assessment Report for the Commonwealth of Pennsylvania

April 2019

Prepared for:

pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION

Prepared by:

ICF

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Acknowledgments and Disclaimer

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Acronyms and Abbreviations

ACEEE American Council for an Energy-Efficient Economy
AEO Annual Energy Outlook
ARIPPA Anthracite Region Independent Power Producers Association
BAU Business-as-usual
Btu British thermal unit
BBtu Billion British thermal units
CH_4 Methane
CHP Combined heat and power
CMM Coal mine methane
CMOP Coalbed Methane Outreach Program
CO_2 Carbon Dioxide
DCNR Department of Conservation and Natural Resources
DEP Department of Environmental Protection
DOC Department of Commerce
DOE Department of Energy
EERS Energy efficiency resource standard
eGRID Emissions & Generation Resource Integrated Database
EIA Energy Information Administration
EPA Environmental Protection Agency
EV Electric vehicle
GHG Greenhouse gas
GMM ICF's Gas Market Model
GWh Gigawatt-hour
Hg Mercury
HVAC Heating, ventilation, and air conditioning
IECC International Energy Conservation Code
IoT Internet of things
IPCC Intergovernmental Panel on Climate Change
IPM ICF's Integrated Planning Model
LACE Levelized avoided cost of energy
LCOE Levelized cost of energy
LMOP Landfill Methane Outreach Program
LPG Liquefied petroleum gas
MATS Mercury Air Toxic Standards
MOVES MOtor Vehicle Emission Simulator
$MtCO_2e$ Metric tons of carbon dioxide equivalent
MW Megawatt
MWh Megawatt-hour
N_2O Nitrous Oxide
NEEP Northeast Energy Efficiency Partnerships
NOx Nitrogen Oxide
NRDC Natural Resources Defense Council
NREL National Renewable Energy Laboratory
PA Pennsylvania
PDA Pennsylvania Department of Agriculture
PEV Plug-in electric vehicle
PUC Public Utility commission
PV Photovoltaic
RFA Renewable Fuels Association
RFC Reliability First Corporation
RGGI Regional Greenhouse Gas Initiative
SEDS State Energy Data System
SO_2 Sulfur Dioxide
SWE Statewide Evaluator
TBtu Trillion British thermal units
USDA United States Department of Agriculture
WEF Water Environment Federation

Executive Summary

The Pennsylvania Department of Environmental Protection (DEP) aims to assist, educate, and encourage Pennsylvanians to advance conservation and efficient use of diverse energy resources to provide for a healthier environment and to achieve greater energy security for future generations. This report provides a comprehensive energy assessment for the Commonwealth of Pennsylvania, which builds upon previous work and analyses conducted by DEP and other organizations to consider energy resource utilization over the next several decades by leveraging new information, reflecting the realities of the rapidly changing energy profile in Pennsylvania, and using new data and methodologies. The results and discussion presented in this report will ultimately help Pennsylvanians improve the Commonwealth's environmental, energy, and economic sustainability.

The comprehensive energy assessment in this report characterizes current, future, and potential energy trajectories in Pennsylvania, providing readers with an overview of the Commonwealth’s energy picture and the potential opportunities for future energy development available to the Commonwealth. The report includes two main components:

1. **A business-as-usual (BAU) energy assessment** that provides a base case assessment of Pennsylvania’s energy trajectory from 2000 to 2050, given existing state and federal policies. The BAU assessment assumes that no additional action, in the form of new policy or regulations, will be taken. The report provides BAU trends in energy consumption, production, and imports and exports, as well as related economic (e.g., price) and environmental (e.g., pollutant and greenhouse gas [GHG] emissions) trends. Historical years of data are used for the years 2000 through 2015, while 2016 through 2050 represents projected data.
2. **An assessment of energy resource potential opportunities** that summarizes the technical and economic potential for various energy resource types for 2016 to 2050. These potentials represent the amount of resources that could be developed with known technologies and practices regardless of economic constraints or market barriers, and with economic constraints, respectively.[1]

When considered in combination, these assessments will enable policy makers at all levels of government, the energy industry, and other stakeholders to answer key questions that will drive the future of Pennsylvania’s environmental, energy, and economic sustainability. Specifically, the information in this report can help to answer the following key questions:

- What will Pennsylvania’s energy, economic, and environmental future look like in the absence of additional action?

[1] Potential is an indicator of untapped resources within the Commonwealth if no additional policy or regulatory action is taken, beyond what exists now.

- Does Pennsylvania have the in-state resources to meet energy demand now and in the future? Or will new action be needed to retain Pennsylvania's long-standing status as a net energy exporter?
- How and where should the Commonwealth focus its efforts to encourage clean, diverse energy sources and thus increase resilience and minimize contributions to climate change?
- What energy opportunities can the Commonwealth use to its economic advantage in the future?

The information in this report provides the foundation for a broader energy strategy for Pennsylvania and informed Pennsylvania's Climate Action Plan.

Approach

To develop the BAU energy assessment, the Analysis Team, comprising of ICF and DEP, compiled and integrated historical energy and economic data; projected data using the Energy Information Administration (EIA) Annual Energy Outlook (AEO) Reference Case; adjusted historical and future data to ensure consistency, capture Pennsylvania-specific data, address data gaps, and incorporate expert input; and applied emission factors to estimate GHG and criteria air pollutant emissions.

Building on the BAU assessment, the Analysis Team assessed both technical potential and economic potential of Pennsylvania's available energy resources. Resource potential estimates are based on the best available data at the time of analysis, as well as expert assumptions about the potential future energy landscape in Pennsylvania. The Analysis Team assessed scenarios and projections from various data sources, compared this information to the BAU projections, and then developed a comprehensive assessment of future resource potential in the Commonwealth based on all of the information considered. Similar to the BAU assessment, the Analysis Team applied emission factors to determine the GHG and criteria air pollutant emissions associated with the potential of the energy resources assessed.

The Analysis Team selected data and information sources (e.g., the EIA AEO) that are recognized at the national or state level, generally publicly available, and widely accepted in the government, industry, and academic communities. While using these sources promotes transparency and consistency in the analysis, it also introduces uncertainties. For example, AEO projections cannot predict all potential policy or technology scenarios. It also provides results at a regional-level, introducing uncertainties in this analysis when parsing regional data to the state-level. Additionally, the Analysis Team applied emission factors to state-level consumption estimates; these factors do not capture the variability in emission rates between different technology types and mitigation practices for sectors like transportation.

Organization of Results

The organization of the results presented in this report is illustrated in Table 1. This table will help readers navigate the report and understand what is included in each set of results.

Table 1: Report Results Organization

Section	Description and Included Fuels/Resource Types
BAU Energy Assessment	
Energy Consumption	Quantifies the electricity consumed and fuels combusted in Pennsylvania for electricity and non-electricity uses across the residential, commercial, industrial, and transportation sectors. Energy types consumed include: • Electricity • Fossil Fuels (for non-electricity uses) ○ Natural Gas ○ Coal ○ Motor Gasoline ○ Liquified Petroleum Gas ○ Distillate Fuel Oil ○ Residual Fuel Oil ○ Jet Fuel ○ Kerosene ○ Other Fuels • Renewable and Alternative Fuels (for non-electricity uses) ○ Biodiesel ○ Ethanol ○ Wood and Biogenic Waste ○ Biogas
Energy Production	Quantifies the fuels produced in Pennsylvania, including: • Fossil Fuels (for electricity and non-electricity uses) ○ Natural Gas ○ Coal ○ Crude Oil ○ Coal Mine Methane ○ Waste Coal • Renewable and Alternative Fuels (for non-electricity uses) ○ Landfill Gas Methane ○ Digesters (Wastewater and Agricultural) ○ Biodiesel ○ Ethanol ○ Wood and Biogenic Waste

Section	Description and Included Fuels/Resource Types
Electricity Generation	Quantifies the electricity generated in Pennsylvania from the following fuels and resources: • Fossil Fuels ○ Natural Gas ○ Coal ○ Waste Coal ○ Distillate Fuel Oil ○ Residual Fuel Oil ○ Petroleum Coke ○ Coal Mine Methane • Nuclear • Renewable and Alternative Fuels ○ Wood and Biogenic Waste ○ Wind ○ Hydroelectric ○ Landfill Gas Methane ○ Utility-Scale Solar PV ○ Building-Scale Solar PV ○ Digesters (Wastewater and Agricultural) ○ Pumped Storage • CHP
Energy Imports/Exports	Quantifies the electricity and fuels transported into and out of Pennsylvania. Imported and exported energy types include: • Electricity • Fossil Fuels ○ Coal ○ Natural Gas ○ Crude Oil ○ Coal Mine Methane • Renewable and Alternative Fuels (Non-electricity) ○ Landfill Gas Methane ○ Biodiesel ○ Ethanol
Energy Resource Potential Assessment	
Energy Conservation	• Encompasses behavioral and operational measures and programs, such as changing temperature settings, turning off unused devices, reducing the operation hours for energy systems, and changing industrial process operations • Estimates conservation potential for electricity and natural gas within the residential, commercial, and industrial sectors
Energy Efficiency	• Encompasses technology measures commonly used in residential, commercial, industrial, and transportation sectors in end uses such as lighting, heating, cooling, refrigeration, pumps, and motor systems • Estimates efficiency potential for ○ Electricity and natural gas within the residential, commercial, and industrial sectors ○ Motor gasoline within the transportation sector

Section	Description and Included Fuels/Resource Types
Energy Production	Estimates fuel production potential in Pennsylvania, including for: • Fossil Fuels (for electricity and non-electricity uses) ○ Coal ○ Natural Gas ○ Waste Coal ○ Crude Oil ○ Propane ○ Coal Mine Methane • Renewable and Alternative Fuels (for non-electricity uses) ○ Landfill Gas Methane ○ Digesters (Wastewater and Agricultural) ○ Biodiesel ○ Ethanol ○ Biomass Solids
Electricity Generation	Estimates potential electricity generation in Pennsylvania from the following fuels and resources: • Fossil Fuels ○ Coal ○ Natural Gas ○ Waste Coal • Nuclear • Renewable and Alternative Fuels ○ Wind ○ Hydroelectric ○ Landfill Gas Methane ○ Utility-Scale Solar PV ○ Building-Scale Solar PV ○ Digesters (Wastewater and Agricultural) ○ Biomass • CHP
Enabling Technologies	Discusses technologies that do not constitute energy resources in themselves, but rather enable higher-efficiency and/or lower-emission use of other energy resources. Enabling technologies include: • Battery Energy Storage • CHP/Microgrids • Hydrogen Fuel Cells • Electrification • Internet of Things

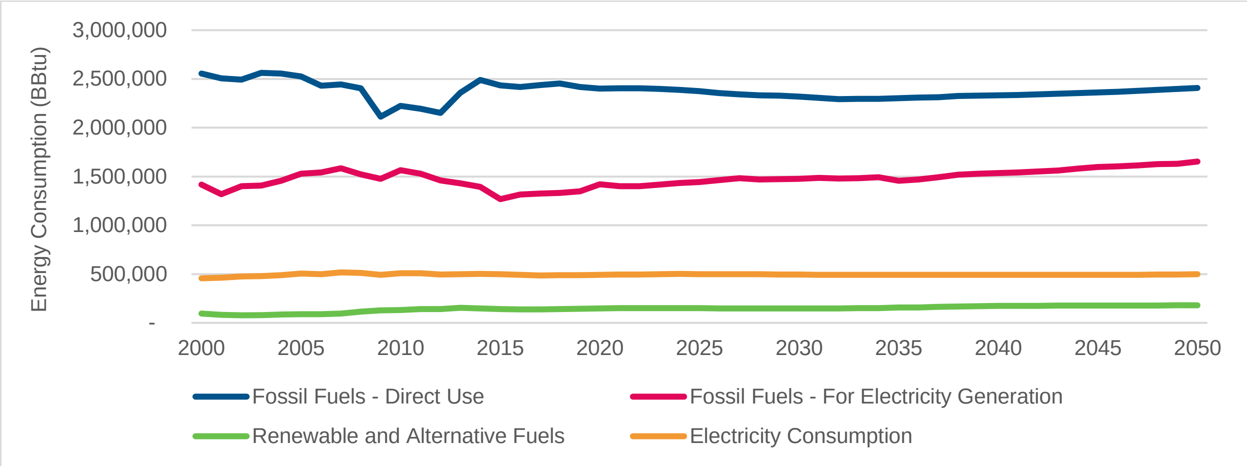
Key Business-as-Usual Results

The BAU energy assessment identifies a number of key trends in energy consumption, production, electricity generation, and imports and exports from 2005 to 2050. Key results and trends identified are presented here and explained further and in more detail (i.e., with more granular results by sector) in the report.

Energy Consumption

Figure 1 summarizes historical and projected trends in energy consumption by fuel type, showing a gradual increase in the consumption of most fuel types over time, and a slight decrease (5 percent decrease from 2005 to 2050) in the direct use of fossil fuels (fossil fuels not used for electricity generation). Overall, energy consumption in Pennsylvania is expected to increase across all sectors and fuel types by 2 percent from 2005 to 2050.

Figure 1: Energy Consumption by Fuel Type[a]



[a] Renewable and alternative fuels (the green line) includes consumption for direct use and electricity generation.

Key trends related to energy consumption include the following:

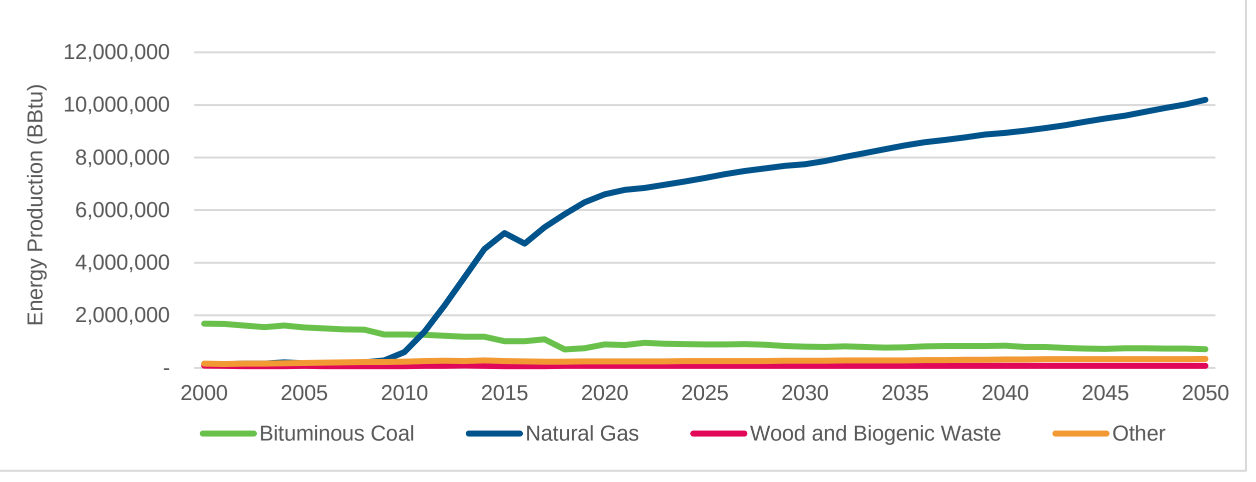
- Energy used to generate electricity is projected to increase 9 percent from 2005 to 2050. While overall end-use electricity consumption is projected to decrease 2 percent from 2005 to 2050, fuel use for generation is projected to increase due to increasing interstate electricity exports.
- Natural gas consumption is projected to increase 79 percent from 2005 to 2050, bringing both economic impacts (i.e., jobs and growth) and environmental risks associated with production (e.g., water contamination and fugitive methane emissions). Use of most other fossil fuels is expected to decline due to shifting market conditions.
- The transportation sector is electrifying and is projected to continue to do so, as the economic and environmental benefits of electric vehicles, particularly for passenger and fleet vehicles, become more compelling. Nearly a fourfold increase in transportation electricity use is expected between 2005 and 2050.
- Use of renewable and alternative fuels is projected to keep increasing, led by increases in biogas and corn ethanol, based on their economic and environmental benefits, rising 121 percent from 61,161 BBtu in 2005 to 135,384 BBtu in 2050.
- Economic growth and energy consumption are becoming increasingly decoupled, largely due to economic growth from energy exports. Total energy consumption per dollar of gross state product falls by more than half over the study period.

- GHG emissions are declining moderately, as coal use declines and natural gas and renewable energy use grow. GHG emissions are expected to decrease 14 percent between 2005 and 2050.
- Economic growth is projected to be decoupled from emissions, particularly for electricity generation, as lower-emission energy sources take larger shares of energy use markets. While electricity generation growth will likely bring economic growth with it (gross state product is projected to grow by 163 percent from 2005 to 2050), GHG emissions from the power sector are projected to decrease 10 percent and criteria air pollutant emissions are projected to decrease 25 percent from 2005 in 2050.

Energy Production

Figure 2 summarizes historical and projected trends in energy production by fuel type, showing a gradual increase in the production of renewable and alternative fuels (54 percent from 79,854 BBtu in 2005 to 123,020 BBtu in 2050; with a larger portion of this increase occurring from 2005 to 2018) and a dramatic increase in the production of fossil fuels over time (492 percent from 2005 to 2050).

Figure 2: Energy Production by Fuel Type *(not including renewable energy used for electricity generation)*[a]



[a] "Other" includes anthracite coal, crude oil, landfill gas methane, coal mine methane, digesters (wastewater, agricultural waste), biodiesel, corn ethanol, cellulosic ethanol, and waste coal. Renewable and alternative forms of electricity generation (e.g., solar, wind, hydro) are not included in "Other."

Key trends related to energy production include the following:

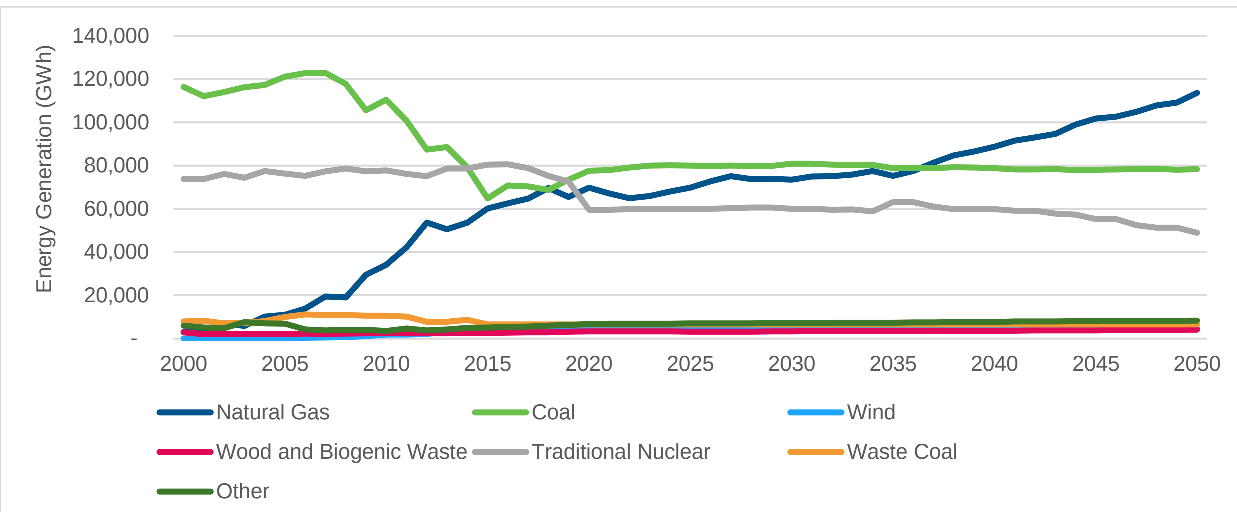
- Natural gas increasingly will be the Commonwealth's largest energy resource (in raw BBtu terms), as shale gas resources continue to be developed. Gas production is projected to exceed 10 quadrillion Btu by mid-century, increasing 5,675 percent from 2005 to 2050; this is about five times the total projected energy consumption in 2050.
- Coal production continues to fall, as competition from lower-cost, lower-emission natural gas continues to displace coal use for power generation. Total coal production in 2050 is projected to be just under half of 2005 levels, declining by 54 percent from 2005 to 2050.

- Oil production is projected to increase, due in large part to increased gas development activity, which encourages parallel oil resource development. Crude oil production is projected to double by 2050 from 2015 levels, with production rising 455 percent from 2005 to 2050, although it remains much smaller compared to coal and natural gas.
- Wood and biogenic waste shows the greatest renewable fuel growth, rising 15 percent from 2005 to 2050, albeit much smaller than fossil fuel growth in total BBtu terms.
- Fugitive methane emissions from natural gas drilling and transportation are projected to increase 110 percent from 2005 to 2050.
- Growth in biogas and biofuels production will be limited without further policy support.

Electricity Generation

Figure 3 summarizes historical and projected trends in electricity generation by fuel type, showing a 42 percent increase in generation from fossil fuels and renewable and alternative fuels (including solar, wind, and hydro) and a 36 percent decrease in generation from nuclear from 2005 to 2050.

Figure 3: Electricity Generation by Fuel Type[a]



[a] "Other" includes residual fuel oil, distillate fuel oil, digesters (wastewater, agricultural waste), building-scale solar PV, utility-scale solar PV, hydroelectric, and petroleum coke. Pumped storage is not shown in this figure.

Key trends related to electricity generation include the following:

- Natural gas is rapidly becoming the Commonwealth's primary electricity generation fuel, and is projected to continue to grow, increasing 925 percent from 2005 to 2050.
- The role of coal generation is decreasing, due primarily to its weak competitive position with respect to natural gas, but remains significant during the study period. Electricity generation from coal declines by 33 percent over the study period, but ultimately retains about a 29 percent share of total generation in 2050.
- Residual fuel oil is phased out over time, due to its environmental and economic characteristics.

- Pumped storage generation remains a relatively small generation resource, limited to managing daily load curve variations.
- Renewables (mainly solar, wind, hydroelectric, and wood and biogenic waste) increase during the study period but fall short of coal and natural gas generation as a percentage of total electricity generation. By 2050 renewable power is expected to account for about 6 percent of total generation in the Commonwealth, which represents a major increase of 230 percent from 2005 to 2050. While new policies and changing market conditions could increase renewable generation growth, this BAU estimate remains necessarily conservative.
- Nuclear generation decreases 39 percent from 2015 to 2050, based on the retirement of a portion of Pennsylvania's nuclear assets and other market factors, but remains significant.

Energy Imports and Exports

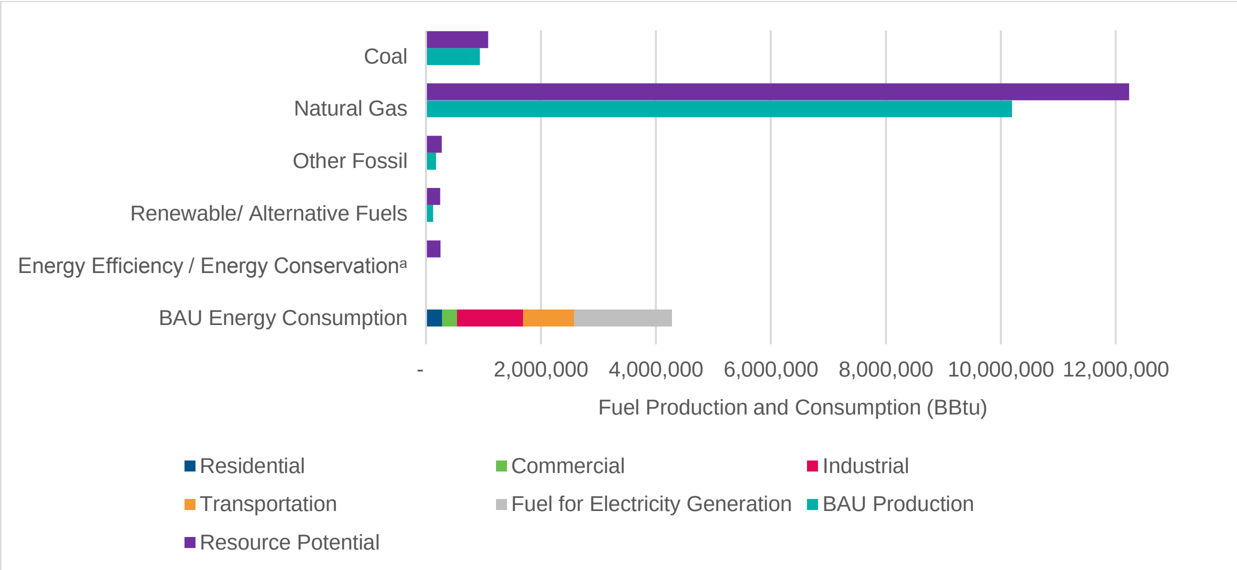
Key trends related to energy imports and exports include the following:

- Total electricity exports are projected to grow 83 percent from 2005 to 2050, as Pennsylvania-based generation remains competitive in the regional PJM market.
- Natural gas exports are increasing substantially, as shale gas production and pipeline development continue to grow. Exports are projected to increase 115 percent between 2015 and 2050.
- Domestic coal exports are decreasing dramatically, as demand for coal continues to decrease in most U.S. markets; net exports are projected to decrease 92 percent from 2005 to 2050. From 2020 onward, Pennsylvania's coal production is expected to stay about even with consumption.
- Crude oil imports are projected to decline 43 percent from 2005 to 2050, as Pennsylvania oil and gas production increases.
- Ethanol imports are growing and are projected to increase by 1,095 percent from 2005 to 2050. Meanwhile, biodiesel imports are estimated to decrease 94 percent from 2005 to 2050, as the Commonwealth increases biodiesel production, mostly from soybean oil feedstocks.

Key Energy Resource Potential Results

The assessment of energy resource potential opportunities shows that the Commonwealth has significant long-term potential for resource production from fossil fuels, renewable and alternative energy resources, and energy conservation and energy efficiency. Figure 4 compares the 2050 economic potential for major fuel categories against projected 2050 BAU production levels to show the incremental increase in production compared to BAU levels. It shows that all resources have greater economic potential in 2050 than projected production levels in 2050. The figure also compares these resources against the projected 2050 BAU fuel consumption by sector and shows that the economic potential for resource production in Pennsylvania far outweighs the Commonwealth's projected energy needs.

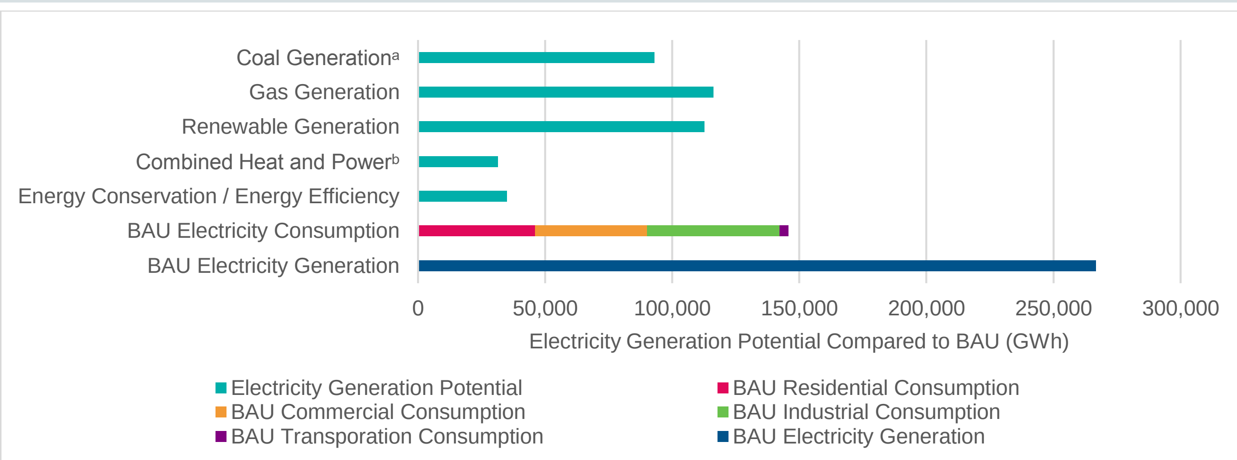
Figure 4: Energy Production Economic Potential Compared to BAU Production and Consumption for 2050[a]



[a] Direct fuel consumption savings of natural gas and motor gasoline from energy efficiency and energy conservation are included as a resource in this figure to compare against other fuel resources and direct fuel consumption within the state.

The assessment of energy resource potential also shows that the projected reductions in nuclear and coal generation could substantially transform the power sector. Natural gas, renewables, and CHP all show the potential to play a more significant role in the grid mix by 2050. Figure 5 shows the economic potential for in-state electricity generation from major sources compared to both projected 2050 BAU electricity consumption (by sector) and projected 2050 BAU electricity generation. Gas and renewables each show the potential to serve almost all of Pennsylvania's own electricity consumption.

Figure 5: Economic Potential for Electricity Generation by Fuel Type in 2050 Compared to BAU Electricity Consumption and Generation



[a] Coal generation includes coal and waste coal.

[b] Combined heat and power includes coal, gas, and renewable energy sources.

In addition to the summary information presented above, the assessment of energy resource potential opportunities identified the following key findings that have implications for Pennsylvania's energy future. Key findings are listed here and explained further in the report.

Energy Conservation

Energy conservation is defined for this report as changes in occupant behavior and facility operational practices, and is treated separately from energy efficiency, which is defined as choosing higher-efficiency technologies to serve specific end-uses.

- Energy conservation potential (from behavioral and operational measures) is generally less than energy efficiency potential, in part due to the length of the study period since conservation measures tend to show short-term effects that do not necessarily grow as large over time as do the effects of efficiency measures. The economic potential in 2050 for energy conservation across sectors is 4 percent of BAU electricity and natural gas consumption.
- Residential conservation measures show the greatest overall conservation potential in the short term, with potential in 2018 accounting for 1 percent of projected BAU residential electricity and natural gas consumption. Meanwhile, industrial conservation measures show the largest growth potential, with potential growing 297 percent from 2018 to 2050 and accounting for 2 percent of BAU electricity and natural gas consumption in 2050.

Energy Efficiency

Energy efficiency as applied in this report includes technology measures commonly used in residential, commercial, transportation, and industrial end-uses such as lighting, heating, cooling, refrigeration, pumps, and motor systems.

- Overall energy efficiency potential estimates in 2050 equal 15 percent of projected BAU electricity, natural gas, and motor gasoline consumption.
- The residential sector shows the greatest near-term efficiency potential, mainly driven by Act 129, with potential peaking in 2025. The industrial sector shows the greatest long-term efficiency potential, with potential increasing 529 percent from 2018 to 2050.
- When considering the economic potential of energy efficiency, over half of potential GHG emissions reductions are from the residential sector in the short term (51 percent of total 2020 energy efficiency potential), but potential emissions reductions from energy efficiency are spread out among sectors by 2050, with 23 percent of reduction potential in the residential sector, 23 percent in the commercial sector, 37 percent in the industrial sector, and 18 percent in the transportation sector.

Energy Production

- The Commonwealth has enough energy production economic potential to exceed projected BAU statewide energy demand by 101 percent in 2020 and by 226 percent in 2050.

- Fossil fuels within Pennsylvania's borders, particularly natural gas, hold enormous potential; the Commonwealth's cumulative economic fossil fuel potential is estimated at more than 200 times BAU annual consumption levels of natural gas.
- GHG emissions could increase with increased fossil fuel production. For example, GHG emissions resulting from total natural gas economic production potential could reach over 13 billion (metric tons of carbon dioxide equivalent) $MtCO_2e$. GHG emissions resulting from coal economic potential could reach over 20 billion $MTCO_2e$.
- Renewable fuels, such as biogases, ethanol, and biomasses, but excluding power generation resources such as solar, wind, and hydro, show high growth potential as replacements for conventional fossil fuel sources. These renewable fuel sources more than triple in annualized economic potential over the study period, but remain a small fraction (less than 3 percent) compared to fossil fuel resource potential.

Electricity Generation

- Fossil fuels could continue to provide more than half of Pennsylvania's electricity generation through 2050.
- Natural gas's projected increasing share of the power generation fuel mix could result in a moderate reduction in the emissions intensity of the generation fleet.
- Renewable power generation shows major growth potential; it has the economic potential to increase almost 12-fold by 2050 from 2015 levels if all renewable resources are developed to their potential. The economic potential of renewable power generation in 2050 would be equal to 77 percent of BAU electricity consumption and 42 percent of BAU electricity generation in 2050.
- Pennsylvania-specific resources (e.g., waste digester, waste coal-fired power plants) offer important diversity and competition contributions.
- Nuclear electricity generation shows expected declines.
- Combined heat and power (CHP) has the potential to almost double from 2015 to 2050, as both a resource and an enabling technology. CHP shows to be economical, with payback periods under 10 years or less.

Enabling Technologies

A number of technologies, such as those listed below, enable higher-efficiency and/or lower-emission use of other energy resources, but are not quantified in the energy resource analysis.

- **Battery Energy Storage**: enables electricity grids to integrate more renewables and other distributed energy resources
- **CHP/Microgrids:** enable efficient, low-emission, and resilient energy services
- **Hydrogen Fuel Cells:** enable resilient power supply, efficient and low-emission energy (especially as part of CHP systems), and additional energy resource choices
- **Electrification:** enables increased energy efficiency and reduced climate impacts when linked to reductions in the emission intensity of the grid

- **Internet of Things:** enables a variety of "smart" usage features, such as powering down devices when not in use or optimizing operational schedules, that can increase efficiency

Key Overall Trends and Results

Pennsylvania's energy markets continue to display significant development, diversity, and resource potential from the shale gas boom to the rise of renewables, as well as in smaller but meaningful markets such as waste coal and biofuels. The BAU analysis shows major shifts from coal to gas in power generation, rising renewable energy production, and increasing exports of natural gas and electricity. Energy consumption increases only modestly, as efficient technologies continue to flatten energy demand, assisted by policies such as Act 129. Policies such as the Alternative Energy Portfolio Standard continue to support and advance renewable resource development.

The energy resource potential analysis reveals major potential across the spectrum of demand and supply options, including energy efficiency and conservation as well as fossil fuel and renewable resources. Pennsylvania's energy resource choices will have significant implications for GHG and criteria air pollutant emissions, and for potential policies and actions. To the extent that lower-emission energy resources displace higher-emission resources, the Commonwealth could continue to grow its energy economy while reducing its emissions footprint. In 2015, Pennsylvania had already reduced its GHG emissions 12 percent as compared to 2005 emissions levels. Based on actions already in progress and low emissions resources already in use, GHG emissions are expected to continue to decrease 16 percent by 2025. A rough calculation using the results presented in Section 3 (Energy Resource Potential Opportunities) indicates that real resource potential opportunities (in the form of renewable and alternative fuels, renewable power generating resources, and demand-side energy conservation and energy efficiency resources) could further reduce GHG emissions to an estimated 30 percent below 2005 levels by 2025.

1. Introduction

1.1. Assessment Context

Since the start of the commercial oil production boom in the 1850s, Pennsylvania has been an energy leader in the United States and the world. The Commonwealth is rich in natural fossil resources, starting with oil and coal and now trending toward natural gas as well. In addition to having a wealth of carbon-based fuels, renewables and alternative energy resources are commonplace in Pennsylvania's energy landscape. Advances in renewables technologies and initiatives are allowing these low-carbon energy sources to play an increasingly pivotal role in Pennsylvania's energy story.

Because of its many resources, Pennsylvania is consistently one of the top energy-producing states in the United States and is one of the country's leading electricity exporters. This results in many economic benefits for the Commonwealth, but also comes with the serious responsibility of understanding and minimizing the associated environmental impacts. Pennsylvania has proven to embrace and rise to the challenge of meeting this responsibility through innovation and adaptability, while maintaining the energy sector as a key driver for its economy. Efficiency and conservation programs, such as those established through Act 129, continue to be integral in pushing the Commonwealth's energy trajectory. Other programs including the ongoing *Finding Pennsylvania's Solar Future*, as well as new initiatives to promote and enable the use of alternative energy options such as *Drive Electric Pennsylvania Coalition's Electric Vehicle Roadmap* are also starting to reshape Pennsylvania's energy future.

As Pennsylvania's energy landscape continues to shift and more energy resource solutions become unlocked, key stakeholders need to understand what future energy scenarios look like. This understanding will help guide DEP, government, policy makers, the energy industry, and interested citizens in making sound, forward-looking decisions about policy options and actions that balance the economic and environmental impacts of energy production and consumption in Pennsylvania. This report, prepared by an Analysis Team comprising ICF and DEP, presents an objective dataset and explanation of the data to support this understanding.

1.2. Purpose and Scope

DEP's Energy Programs Office aims to assist, educate, and encourage Pennsylvanians to advance conservation and efficient use of diverse energy resources to provide for a healthier environment and to achieve greater energy security for future generations. This report provides a comprehensive energy assessment for the Commonwealth of Pennsylvania, which builds upon previous work and analyses conducted by DEP and other organizations to consider energy resource utilization over the next several decades by leveraging new information, reflecting the realities of the rapidly changing energy profile in Pennsylvania, and using new data and methodologies. The results and discussion presented in this report will ultimately help Pennsylvanians improve the Commonwealth's environmental, energy, and economic sustainability.

The comprehensive energy assessment in this report characterizes current, future, and potential energy trajectories in Pennsylvania, providing readers with an overview of the Commonwealth's energy picture and the potential opportunities for future energy development available to the Commonwealth. The report includes two main components:

1. **A business-as-usual (BAU) energy assessment** that provides a summary of Pennsylvania energy consumption, energy production, electricity generation, and energy imports and exports, by energy resource type and sector,[2] from 2000 to 2050. This energy assessment provides a base case assessment of Pennsylvania's energy trajectory from 2000 to 2050, given existing state and federal policies. The BAU assessment assumes that no additional action, in the form of new policy or regulations, will be taken. The report provides BAU trends in energy consumption, production, and imports and exports, as well as related economic (e.g., price) and environmental (e.g., pollutant and greenhouse gas [GHG] emissions) trends. Historical years of data are used for the years 2000 through 2015, while 2016 through 2050 represents projected data.
2. **An assessment of energy resource potential opportunities** that summarizes the technical and economic potential for various energy resource types for 2016 to 2050. These potentials represent the amount of resources that could be developed with known technologies and practices regardless of economic constraints and market barriers, and with economic constraints, respectively. This resource potential assessment builds on and takes into account the BAU Energy Assessment and gives readers the ability to do first-order comparisons of potential estimates among resources. These potential estimates are based on available information compiled in a data source and literature review.[3]

When considered in combination, these assessments will enable policy makers at all levels of government, the energy industry, and other stakeholders to answer key questions that will drive the future of Pennsylvania's environmental, energy, and economic sustainability. Specifically, the information in this report can help to answer the following key questions:

- What will Pennsylvania's energy, economic, and environmental future look like in the absence of additional action?
- Does Pennsylvania have the in-state resources to meet energy demand now and in the future? Or will new action be needed to retain Pennsylvania's long-standing status as a net energy exporter?
- How and where should the Commonwealth focus its efforts to encourage clean, diverse energy sources and thus increase resilience and minimize contributions to climate change?
- What energy opportunities can the Commonwealth use to its economic advantage in the future?

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[2] Sectors include residential, industrial, commercial, and transportation.
[3] Potential is an indicator of untapped resources within the Commonwealth if no additional policy or regulatory action is taken, beyond what exists now.

The information in this report provides the foundation for a broader energy strategy for Pennsylvania and will inform Pennsylvania's Climate Action Plan.

1.3. Relationship to the 2013 Energy Analysis and Pennsylvania Planning and Potential Policy Efforts

In 2013, the DEP published an energy analysis titled *Energy in Pennsylvania: Past, Present, and Future* (Commonwealth Economics 2013). This Energy Assessment Report serves to update and expand upon much of the information in that 2013 report to reflect new and additional data sources and updated methods for allocating regional data to the Commonwealth level, as well as to provide a more detailed breakout of certain energy types. Given the continuing dynamism of Pennsylvania's energy markets since 2013, this update provides valuable new information that can serve multiple purposes, including informing Pennsylvania's Climate Action Plan and potential energy policies and regulatory actions, and helping leaders, businesses, and citizens prioritize actions and investments. For example, in updating the Climate Action Plan, the DEP used the BAU assessment to identify sectors and sources that constitute a large portion of Pennsylvania's energy consumption, energy production, or GHG emissions, and to identify strategies that can reduce emissions in key sectors and sources. The energy resource potential assessment was then used to quantify strategies that accelerate the deployment of low- and zero-emission resources.

1.4. Methodology Overview

To develop the BAU assessment, the Analysis Team took the following steps:

1. **Compiled and integrated historical energy and economic data**, primarily from the Energy Information Administration (EIA) State Energy Data System (SEDS).
2. **Projected future energy and economic data** primarily using the EIA Annual Energy Outlook (AEO) Reference Case, making adjustments to align AEO and SEDS geographies.[4]
3. **Adjusted historical and future energy and economic data** to ensure consistency, capture available Pennsylvania-specific data (e.g., to align with the *Finding Pennsylvania's Solar Future Plan*),[5] address existing data gaps, and incorporate the Analysis Team's expert input using resources such as ICF's Gas Market Model (GMM®).
4. **Applied emission factors when available** to estimate GHG and criteria air pollutant emissions.[6] The Analysis Team used emission factors from a variety of sources, including:
    - U.S. Environmental Protection Agency's (EPA) State Inventory and Projection Tool

[4] While SEDS data are provided at the state level, AEO data are forecasted at the regional level. To account for this geographical discrepancy, the Analysis Team applied the AEO regional growth rate for a particular energy resource to the historical SEDS data to project Pennsylvania Commonwealth-level energy resource data. Growth rates were indexed to 2015.

[5] For more detailed information, see *Finding Pennsylvania's Solar Future Plan* (PA DEP 2018).

[6] Where applicable and feasible, GHG emissions mainly include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) and criteria air pollutant emissions estimated by the Analysis Team including sulfur dioxide (SO_2), nitrogen oxide (NO_x), and mercury (Hg).

- EIA's State Energy Data Report, Consumption Estimates, 1960–2015
- EPA's U.S. Greenhouse Gas Inventory
- 2006 IPCC Guidelines for National Greenhouse Gas Inventories
- EPA's eGRID 2005, 2007, 2009, 2010, 2012, and 2014 state data files
- EPA's Emission Factors for Greenhouse Gas Inventories
- EPA AP-42 Fifth Edition Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources
- Emission Factor Supporting Documentation for the Final Mercury and Air Toxics Standards. Mercury Air Toxic Standards (MATS)

The projections take into consideration all of the policies in EIA's AEO, excluding the Clean Power Plan. The policies considered in the AEO forecast are summarized in Appendix D.

Building on the BAU assessment, the Analysis Team assessed both technical potential and economic potential of Pennsylvania's available energy resources. Resource potential estimates are based on the best available data at the time of analysis, as well as expert assumptions about the potential future energy landscape in Pennsylvania. The Analysis Team assessed scenarios and projections from various data sources, compared this information to the BAU projections, and then developed a comprehensive assessment of future resource potential in the Commonwealth based on all of the information considered. Similar to the BAU assessment, the Analysis Team applied emission factors to determine the GHG and criteria air pollutant emissions associated with the potential of the energy resources assessed.

Definition of Key Terms

Technical potential is the "time-dimensionless" amount of the energy resource that could be realized with known technologies and practices regardless of economic constraints or market barriers.

Economic potential is a subset of technical potential, defined as the maximum amount of the energy resource that could be developed under projected economic conditions, in both a "time-dimensionless" and annualized manner.

The Analysis Team selected data and information sources (e.g., the EIA AEO) that are recognized at the national or state level, generally publicly available, and widely accepted in the government, industry, and academic communities. While using these sources promotes transparency and consistency in the analysis, it also introduces uncertainties. For example, AEO projections cannot predict all potential policy or technology scenarios. It also provides results at a regional-level, introducing uncertainties in this analysis when parsing regional data to the state-level. Additionally, the Analysis Team applied emission factors to state-level consumption; these values do not capture the variability in emission rates between different technology types and mitigation practices for sectors like transportation.

1.5. Report Roadmap and Results Organization

This report is organized into two main sections following this introduction:

- Business-as-Usual Energy Assessment (Section 2)
- Energy Resource Potential Opportunities (Section 3)

References are included in Section 4.

The report also includes four appendices:

- **Appendix A** provides detailed historical and projected energy, environmental, and economic data associated with the BAU assessment.
- **Appendix B** provides detailed technical and economic potential data, as well as emissions data associated with the energy resource potential opportunities.
- **Appendix C** includes supply curves generated by the Analysis Team for the resource potential analysis.
- **Appendix D** summarizes the policies considered in the AEO forecast used for the BAU assessment.

The organization of the results presented in this report is illustrated in Table 2. This table will help readers navigate the report and understand what is included in each set of results.

Table 2: Report Results Organization

Section	Description and Included Fuels/Resource Types
BAU Energy Assessment	
Energy Consumption	Quantifies the electricity consumed and fuels combusted in Pennsylvania for electricity and non-electricity uses across the residential, commercial, industrial, and transportation sectors. Energy types consumed include: • Electricity • Fossil Fuels (for non-electricity uses) ○ Natural Gas ○ Coal ○ Motor Gasoline ○ Liquified Petroleum Gas ○ Distillate Fuel Oil ○ Residual Fuel Oil ○ Jet Fuel ○ Kerosene ○ Other Fuels • Renewable and Alternative Fuels (for non-electricity uses) ○ Biodiesel ○ Ethanol ○ Wood and Biogenic Waste ○ Biogas

Section	Description and Included Fuels/Resource Types
Energy Production	Quantifies the fuels produced in Pennsylvania, including: • Fossil Fuels (for electricity and non-electricity uses) ○ Natural Gas ○ Coal ○ Crude Oil ○ Coal Mine Methane ○ Waste Coal • Renewable and Alternative Fuels (for non-electricity uses) ○ Landfill Gas Methane ○ Digesters (Wastewater and Agricultural) ○ Biodiesel ○ Ethanol ○ Wood and Biogenic Waste
Electricity Generation	Quantifies the electricity generated in Pennsylvania from the following fuels and resources: • Fossil Fuels ○ Natural Gas ○ Coal ○ Waste Coal ○ Distillate Fuel Oil ○ Residual Fuel Oil ○ Petroleum Coke ○ Coal Mine Methane • Nuclear • Renewable and Alternative Fuels ○ Wood and Biogenic Waste ○ Wind ○ Hydroelectric ○ Landfill Gas Methane ○ Utility-Scale Solar PV ○ Building-Scale Solar PV ○ Digesters (Wastewater and Agricultural) ○ Pumped Storage • CHP
Energy Imports/Exports	Quantifies the electricity and fuels transported into and out of Pennsylvania. Imported and exported energy types include: • Electricity • Fossil Fuels ○ Coal ○ Natural Gas ○ Crude Oil ○ Coal Mine Methane • Renewable and Alternative Fuels (Non-electricity) ○ Landfill Gas Methane ○ Biodiesel ○ Ethanol

Section	Description and Included Fuels/Resource Types
Energy Resource Potential Assessment	
Energy Conservation	• Encompasses behavioral and operational measures and programs, such changing temperature settings, turning off unused devices, reducing the operation hours for energy systems, and changing industrial process operations • Estimates conservation potential for electricity and natural gas within the residential, commercial, and industrial sectors
Energy Efficiency	• Encompasses technology measures commonly used in residential, commercial, industrial, and transportation sectors in end uses such as lighting, heating, cooling, refrigeration, pumps, and motor systems • Estimates efficiency potential for ○ Electricity and natural gas within the residential, commercial, and industrial sectors ○ Motor gasoline within the transportation sector
Energy Production	Estimates fuel production potential in Pennsylvania, including for: • Fossil Fuels (for electricity and non-electricity uses) ○ Coal ○ Natural Gas ○ Waste Coal ○ Crude Oil ○ Propane ○ Coal Mine Methane • Renewable and Alternative Fuels (for non-electricity uses) ○ Landfill Gas Methane ○ Digesters (Wastewater and Agricultural) ○ Biodiesel ○ Ethanol ○ Biomass Solids
Electricity Generation	Estimates potential electricity generation in Pennsylvania from the following fuels and resources: • Fossil Fuels ○ Coal ○ Natural Gas ○ Waste Coal • Nuclear • Renewable and Alternative Fuels ○ Wind ○ Hydroelectric ○ Landfill Gas Methane ○ Utility-Scale Solar PV ○ Building-Scale Solar PV ○ Digesters (Wastewater and Agricultural) ○ Biomass • CHP
Enabling Technologies	Discusses technologies that do not constitute energy resources in themselves, but rather enable higher-efficiency and/or lower-emission use of other energy resources. Enabling technologies include: • Battery Energy Storage • CHP/Microgrids • Hydrogen Fuel Cells • Electrification • Internet of Things

2. Business-as-Usual Energy Assessment

This section provides a summary of Pennsylvania energy consumption, energy production, electricity generation, and energy imports and exports, by energy resource type and sector,[7] from 2000 to 2050. This energy assessment is intended to provide a base case assessment of Pennsylvania's energy landscape, given existing policies. It is organized into four sections:

1. Energy Consumption
2. Energy Production
3. Electricity Generation
4. Energy Imports and Exports

In each section, the report describes the methodology, sources, and assumptions used by the Analysis Team, and summarizes key results, including trends and relevant conclusions. Trends are generally discussed using a base year of 2005, as this ensures the trends discussed capture recent shifts in Pennsylvania's energy markets. Where feasible, the Analysis Team provides estimates of greenhouse gas (GHG) and criteria air pollutant emissions associated with each aspect of the energy system, as well as economic indicators such as prices and expenditures. Appendix A provides detailed historical and projected business-as-usual (BAU) energy, environmental, and economic data.

The BAU analysis shows major shifts over the 2005-2050 period from coal to gas in power generation, rising renewable energy production and use (especially in the 2015-2015 period), and increasing exports of natural gas and electricity. Energy consumption increases only modestly, as efficient technologies continue to flatten energy demand, assisted by policies such as Act 129. Policies like the Alternative Energy Portfolio Standard support renewable resource development, while fossil fuel production continues to play an important role.

2.1. Energy Consumption

2.1.1 Sources and Methodology

The Analysis Team estimated consumption, price, expenditures, GHG emissions, and criteria air pollutant emissions by fuel type and sector to the extent feasible, given available data sources.

[7] Sectors include residential, industrial, commercial, and transportation.

Electricity and Fossil Fuels

For electricity and the majority of fossil fuels, including natural gas,[8] coal, liquid petroleum gas [LPG,[9] motor gasoline, distillate fuel oil, residual fuel oil, jet fuel, kerosene, and others[10]) the Analysis Team used historical consumption, price, and expenditure data from SEDS. The Analysis Team applied price deflation factors from the Bureau of Economic Analysis to historical price and expenditure data (DOC 2018). The Analysis Team then applied emission factors to the consumption data to estimate criteria air pollutant and GHG emissions. The Analysis Team made the following exceptions and adjustments to the historical electricity and fossil fuel consumption data:

- For motor gasoline, the Analysis Team relied on SEDS data, but ensured ethanol was not included in the presented results for motor gasoline to prevent double counting. Ethanol is represented as a separate fuel.
- Similarly, biodiesel consumption was subtracted from transportation distillate to prevent double counting.
- Expenditures of distillate fuel oil are not provided in SEDS and therefore were calculated as consumption multiplied by price.
- Emissions of criteria air pollutants were not estimated for residual fuel oil and biodiesel consumption because multiple technical assumptions are needed to apply emission factors that are not conducive to statewide analyses.

Future trends in consumption and price data for electricity and fossil fuels (natural gas, LPG, motor gasoline, distillate fuel oil, residual fuel oil, jet fuel, and other fossil fuels) from AEO were applied to historical SEDS data to project from 2015 through 2050. Specifically, because AEO presents data regionally, the SEDS data for the historical year is scaled using the regional growth from the Middle Atlantic. Future expenditures are estimated as consumption multiplied by price. Emission factors described above in Section 1 were applied to the consumption data to estimate criteria air pollutant and GHG emissions. The exceptions to this method, and adjustments made to the data, included:

- For coal, the Analysis Team assumed:
    - Flat growth for residential and transportation coal consumption[11]
    - Growth in line with AEO growth for commercial coal consumption
    - Growth in line with AEO growth for metallurgical and other industrial coal consumption combined for industrial coal consumption
- Coal prices were projected for non-zero coal consumption sectors, including commercial and industrial, and are based on the weighted average of AEO-projected coal prices of metallurgical and other industrial coal.

[8] Coal mine methane is implicitly included in these figures because it is injected into natural gas pipelines.
[9] LPG is primarily made up of propane.
[10] Other fuel consumption is aligned between SEDS and AEO data to ensure consistency and for completeness. "Other fuels" include asphalt and road oil, aviation gasoline blending components, coking coal, naphthas, jet fuel, lubricants, motor gasoline blending components, pentanes plus, pet coke, still gas, unfinished oils, and waxes. The Analysis Team did not estimate anything other than consumption of these fuels.
[11] These are minimal or zero, based on SEDS data.

- Specifically, for consumption of kerosene in the industrial sector, the Analysis Team assumed a 2 percent annual decline in consumption due to lack of other data in AEO. The price of kerosene for all sectors was proxied to AEO prices of distillate for the relevant sectors.

Renewables

Compiling data on the consumption of renewables required reliance on multiple data sources. The approaches and data sources, by fuel type, are described below.

Historical biodiesel consumption was set equal to 2 percent of EIA-published data on distillate fuel oil used for transportation,[12] which is in line with requirements of Pennsylvania's Act 78 of 2008 – Biofuel Development and In-State Production Incentive Act (PDA 2018). Projected biodiesel consumption is in line with growth rates of distillate fuel oil consumed for the transportation sector in AEO, and therefore assumes that the mandated minimum 2 percent biodiesel content for all diesel fuels sold in Pennsylvania continues into the future. The Analysis Team proxied prices of biodiesel to distillate prices, and expenditures were estimated as consumption multiplied by price. Regarding GHG emissions from the use of biodiesel, the Analysis Team assumed carbon dioxide (CO_2) emissions were zero as it is a bio-based fuel; methane and nitrous oxide emissions are approximations that rely on commercial biodiesel emission factors from the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines.

SEDS and AEO data were used for consumption of ethanol, and AEO data were used to disaggregate consumption by corn and cellulosic.[13] Overall, ethanol prices are set equivalent to prices published by DOE (2018),[14] and expenditures were estimated as consumption multiplied by price. GHG emissions were estimated using the resources described in Section 1, however criteria air pollutant emissions were not estimated because multiple technical assumptions are needed to apply emission factors that are not conducive to statewide analyses.

Wood and biogenic waste consumption and price data come from SEDS for historical data and AEO for projection trends. The SEDS classification of wood and waste includes wood, municipal waste, landfill gas, combustible industrial byproducts, woodchips, industrial wood waste, and industrial waste gas (DOE 2017a). Expenditures were set equal to consumption multiplied by price. In using the AEO data for wood and biogenic waste, the Analysis Team needed to make some adjustments in order to arrive at a complete dataset for all sectors:

- AEO provided estimates of residential wood consumption.
- The Analysis Team proxied commercial and industrial wood and biogenic waste consumption to combined AEO-projected categories of wood and other biomass, and biogenic municipal waste consumption for these sectors.

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[12] Biodiesel data from EIA is published in the report *Pennsylvania Adjusted Sales of Distillate Fuel Oil by End Use* (EIA 2017g).

[13] The 2015 AEO values of ethanol from corn and from cellulose were used to determine a split between these two types of ethanol. Because commercial-scale cellulosic ethanol production was minimal before 2014, the 2015 cellulosic ethanol percentage was scaled down for 2014 based on the difference in commercial capacity (NREL 2017). All ethanol consumed before 2014 was assumed to be from corn.

[14] These data can be accessed in the table *Utilized U.S. Wholesale Ethanol Price Average to Scale*.

- The Analysis Team scaled projected prices for residential, commercial, and industrial wood and biogenic waste using a single forecasted AEO biomass price in the Middle Atlantic from AEO.

Biogas (including agricultural waste, wastewater, and landfill gas) estimates were only available for the industrial sector and only include consumption, GHG, and criteria air pollutant emissions estimates. The Analysis Team relied on biogas consumption information from a mix of sources, including the U.S. Environmental Protection Agency's (U.S. EPA's) Landfill Methane Outreach Program (LMOP) (EPA 2018d) and AgSTAR project databases (EPA 2018a), a listing of wastewater sites in Pennsylvania (WEF 2015), and a database of CHP projects maintained by ICF.

2.1.2 Summary of Results

This section summarizes key trends that emerge from examination of the energy consumption data, places these trends in context, and also discusses the environmental and economic effects associated with energy use. The summary figures and the more detailed tables[15] below reveal energy consumption trends that have implications for Pennsylvania's energy future. These trends include:

- **Energy used to generate electricity is projected to increase due to increasing power exports**. Power generation fuel use is represented in Figure 6 and shown in detail in Table 33 and Table 35 in Appendix A. These tables and the figure show a rise from 1,555,441 billion British thermal units (BBtu) in 2005 to 1,698,028 BBtu in 2050, an increase of 9 percent. However, end-use consumption of electricity in Pennsylvania falls by 2 percent overall in the same time period (see Table 3); this suggests that the growth in power generation will mostly be exported to other states. Pennsylvania has been a net exporter of electricity for many years, and that trend is projected to continue and expand.
- **Economic growth is projected to be decoupled from emissions.** While electricity generation growth will likely bring economic growth with it (gross state product is projected to grow by 163 percent from 2005 to 2050), GHG emissions from the power sector are projected to stay flat (132,246,404 metric tons of carbon dioxide equivalent [$MTCO_2e$] in 2005 to 118,719,884 $MTCO_2e$ in 2050) and criteria air pollutant emissions are projected to fall by 25 percent from 2,667,074 million metric tons (MT) in 2005 to 1,999,866 MT in 2050 (see Table 42, Table 43, Table 45, and Table 46). This decoupling of economic growth and emissions is an encouraging trend; however, achieving significant GHG emissions cuts will require additional advances in power sector emissions-reduction strategies.
- **The transportation sector is electrifying and will continue to do so**. Total energy use in the transportation sector falls over the study period, as shown in Figure 6. This is partly due to improved fuel economy in internal combustion vehicles, and increased market penetration of electric vehicles with their higher powertrain efficiencies. Table 3 shows a nearly fourfold increase in transportation electricity use between 2005 and 2050 (880 GWh to 3,402 GWh), which is primarily assigned to electric vehicles usage in passenger and fleet vehicles.

[15] Note total and percentage in tables may appear off due to rounding.

Figure 6: Energy Consumption by Sector

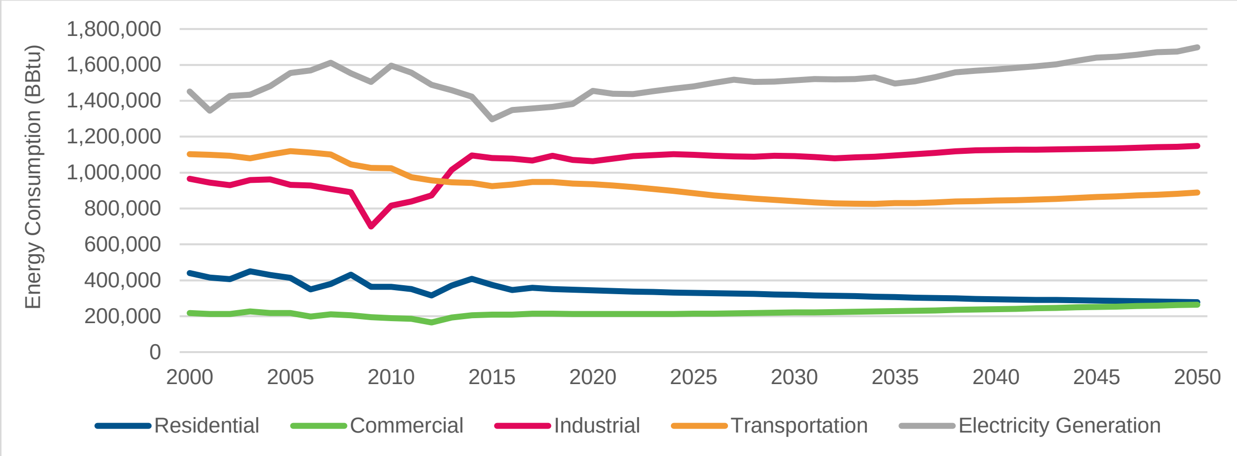


Table 3: Electricity Consumption by Sector (GWh)

Sector	2000	2005	2015	2018	2020	2025	2030	2050	Change from 2005 to 2050
Residential	45,008	53,661	54,419	51,878	50,348	49,216	48,949	45,981	-14%
Commercial	42,988	45,782	43,745	43,953	44,498	44,278	43,329	44,155	-4%
Industrial	45,449	47,950	47,404	46,215	47,814	51,417	50,298	52,096	9%
Transportation	401	880	776	910	1,042	1,621	2,166	3,402	287%
Total	**133,846**	**148,273**	**146,344**	**142,956**	**143,702**	**146,532**	**144,742**	**145,634**	**-2%**

- **Natural gas consumption is projected to increase significantly, bringing economic growth and environmental risks**. Gas is the only fossil fuel that shows significant growth in consumption, rising 79 percent from 635,724 BBtu in 2005 to 1,141,014 BBtu in 2050 (see Table 4 and Figure 7). It appears that most of this gas demand growth goes to electricity generation, although some is also used for residential, commercial, and industrial fuels. Shale gas development has become a major economic force in Pennsylvania, with a Penn State University report, "The Pennsylvania Marcellus Natural Gas Industry: Status, Economic Impacts and Future Potential" showing that the shale gas industry was supporting nearly 140,000 jobs with an estimated economic impact of $11 billion in 2010 (Penn State 2011). Economic impacts are projected to become even larger by 2020, with shale gas projected to support about 260,000 jobs and an economic impact of just over $20 billion (Penn State 2011). However, gas development does come with environmental risks, including groundwater and surface water contamination and fugitive methane emissions. Addressing fugitive methane emissions from natural gas development and consumption constitutes a significant opportunity to achieve meaningful total GHG emissions reductions.

Figure 7: Fossil Fuel Energy Consumption by Fuel

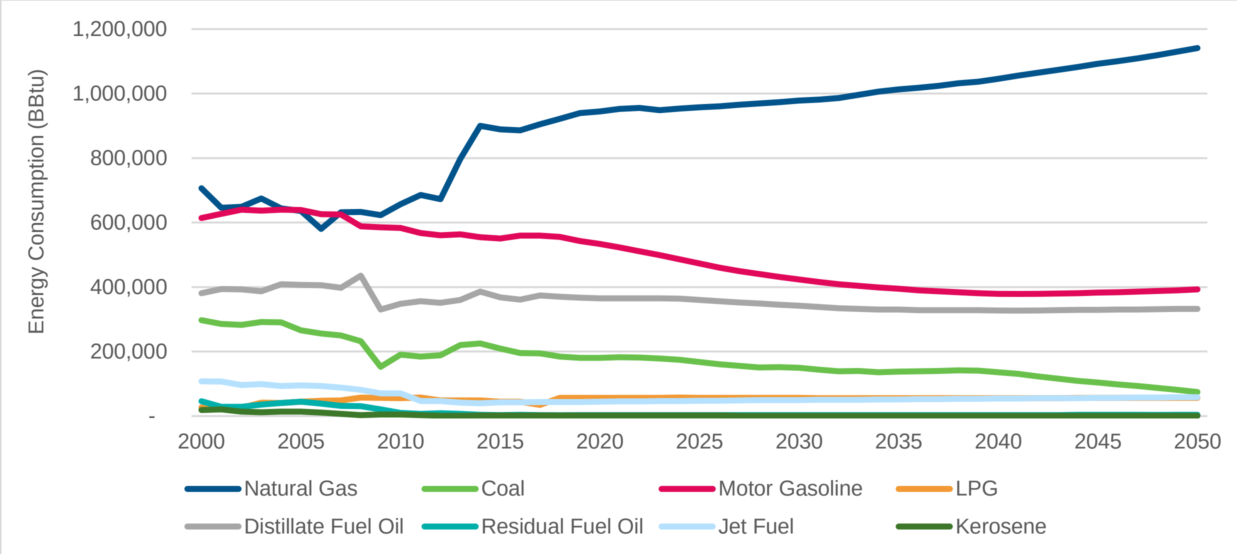


Table 4: Fossil Fuel Energy Consumption by Fuel Type (BBtu)

Fuel Type	2000	2005	2015	2018	2020	2025	2030	2050	Change from 2005 to 2050
Natural Gas	706,188	635,724	888,527	921,843	944,789	957,577	977,929	1,141,014	79%
Coal	297,454	265,925	209,585	184,657	180,379	168,032	149,404	74,567	-72%
Motor Gasoline	614,320	638,812	551,093	555,498	533,553	472,983	423,539	392,430	-39%
LPG	26,769	44,949	45,127	56,173	56,534	57,013	56,179	56,649	26%
Distillate Fuel Oil	380,548	406,428	367,862	369,847	365,143	360,556	341,835	332,793	-18%
Residual Fuel Oil	46,066	44,896	2,692	2,685	2,885	2,990	2,944	3,766	-92%
Jet Fuel	107,780	95,404	42,599	43,711	44,562	47,659	49,908	58,942	-38%
Kerosene	19,352	13,603	1,562	1,758	1,651	1,552	1,487	1,379	-90%
Other – Industrial[a]	349,272	372,394	318,309	310,868	263,150	297,731	308,656	340,416	-9%
Other – Transportation[a]	9,086	7,511	7,398	7,506	7,406	7,179	6,976	6,333	-16%
Total	**2,556,835**	**2,525,646**	**2,434,754**	**2,454,547**	**2,400,053**	**2,373,273**	**2,318,859**	**2,408,288**	**-5%**

[a] Other – Industrial and Other - Transportation contain asphalt and road oil, aviation gasoline blending components, coking coal, naphthas, lubricants, motor gasoline blending components, pentanes plus, pet coke, still gas, unfinished oils, and waxes.

Table 4 also illustrates a few unusual shifts in three petroleum product types: residual fuel oil, jet fuel, and kerosene. Available data sources do not fully explain the significant drops that appear in consumption of these fuels between 2000 and 2015. The Analysis Team's research indicate that residual fuel use fell primarily due to natural gas substitution, as gas became more available and affordable, and more environmentally preferable. It may also be that large fuel users with dual-fuel capability shifted their fuel choices to gas. Jet fuel usage data are subject to accounting anomalies as airlines have shifted their purchasing behavior; many airlines have shifted their procurement practices in the last decade, such that they buy in bulk using contract structures that may show sales in states different from the states in which the fuel is placed in aircraft tanks. Kerosene is declining in use for several possible reasons, among them health and safety concerns with portable kerosene heaters, and oil refinery practices as low-sulfur diesel regulations decreased the use of kerosene as a fuel blend element.

- **Use of biogas and corn ethanol use is rising**. Among the renewable and alternative fuels, these two fuels show significant percentage growth over the study period, rising 762 percent from 10,771 BBtu in 2005 to 92,859 BBtu in 2050 (see Table 5 and Figure 8). Corn ethanol consumption increased by a factor of 8 from 2005 to 2015, largely due to the ethanol mandate included in the Energy Independence and Security Act of 2007. While the total amounts in BBtu terms are not as large as for natural gas, these resources do offer the opportunity to diversify Pennsylvania's fuel resources with more renewable and lower-emission resources. However, these fuels do have associated environmental risks that should be managed, such as land and water quality degradation. Because most of the ethanol used in motor fuels will need to be imported (mostly pre-blended in fuels), water and electricity consumption impacts from ethanol production facilities would be incurred primarily in other states.

Figure 8: Renewable and Alternative Energy Consumption by Fuel Type

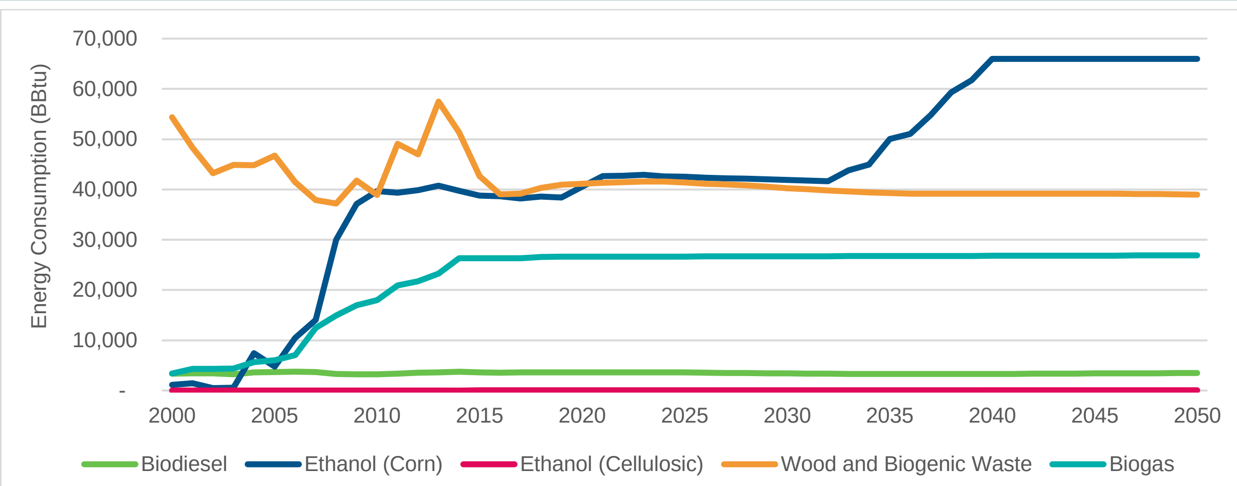


Table 5: Renewable and Alternative Fuels Energy Consumption by Fuel Type (BBtu)

Fuel Type	2000	2005	2015	2018	2020	2025	2030	2050	Change from 2005 to 2050
Biodiesel	3,338	3,690	3,589	3,623	3,587	3,584	3,397	3,486	-6%
Ethanol (Corn)	1,107	4,741	38,759	38,558	40,549	42,557	41,885	65,972	1292%
Ethanol (Cellulosic)	-	-	31	31	32	34	33	52	N/A
Wood and Biogenic Waste	54,369	46,700	42,638	40,280	41,156	41,387	40,230	38,987	-17%
Biogas	3,383	6,030	26,302	26,590	26,608	26,655	26,701	26,887	346%
Total	**62,196**	**61,161**	**111,319**	**109,082**	**111,933**	**114,216**	**112,246**	**135,384**	**121%**

- **Economic growth and energy consumption are becoming increasingly decoupled, largely due to economic growth from energy exports**. Total Btu consumption per dollar of gross state product falls by more than half over the study period, from 7.81 in 2005 to 3.04 in 2050 (see Table 33 and Table 35 in Appendix A). This decoupling of economic growth and energy consumption is an encouraging trend, and should make the Commonwealth's economy more resilient to outside energy market and policy forces. However, the intensity improvement also partially stems from the rising production and exports of major fuels like natural gas, which are projected to be increasingly exported. Increasing the Commonwealth's economic base creates significant benefits, but increasing reliance on exports also tends to overstate the economic efficiency effects of improved energy intensity. Energy efficiency also contributes to the energy intensity improvement, as a mix of technology advances, market forces, and policies such as federal appliance standards, state building energy codes, and utility-funded programs like those administered under Act 129, continue to drive end-use efficiency gains.
- **Emissions are declining moderately**. Continuing recent trends, GHG and criteria air pollutant emissions from fossil fuel energy consumption decrease over the study period. Reductions are greater in the non-power sector areas, which is understandable given the strong growth projected in fossil fuel power generation relative to other energy types. While these declines are encouraging, GHG emissions do not fall as rapidly as criteria air pollutant emissions, registering a 14 percent decrease from 149.6 million metric tons of carbon dioxide equivalent ($MTCO_2e$) in 2005 to 128.5 million $MTCO_2e$ in 2050 (see Table 33 and Table 35 in Appendix A). More significant GHG reductions may need to be achieved through potential new policy options.

At a high level, historical data findings on total consumption levels are consistent with those in the 2013 report, *Energy in Pennsylvania: Past, Present, and Future* (Commonwealth Economics 2013). The Analysis Team's top-level findings tend to be slightly higher than those in the 2013 report, which can be attributed mainly to the methods for allocating regional data to the Commonwealth level, the Analysis Team's consultation of additional data sources, and a more detailed breakout of certain energy types.

2.2. Energy Production

2.2.1 Sources and Methodology

The Analysis Team estimated production and GHG emissions for fossil fuels and renewable and alternative fuels by fuel type where feasible.

Fossil Fuels

Pennsylvania's DEP publishes historical information on bituminous and anthracite coal production. To estimate future trends in coal production in the Commonwealth, growth rates from AEO's Northern Appalachia bituminous and anthracite coal production were applied by the Analysis Team to historical DEP published data. Historical natural gas and crude oil data were available from SEDS; future natural gas and crude oil production were estimated by the Analysis Team using a mix of sources. To determine future production of natural gas and crude oil in Pennsylvania, the Analysis Team used historical SEDS data, ICF's Gas Markets Model (GMM®), and AEO projections to allocate AEO regional growth in natural gas production to Pennsylvania. GHG emissions estimates from natural gas production were based on the number of wells and associated emission factors, where the number of wells historically came from the EPA State Inventory Tool (EPA 2018a) and the future numbers of wells came from the GMM in the form of annual well completion numbers (assuming a well abandonment rate of 2 percent per year). Crude oil GHG emissions were estimated using the sources described in Section 1, above.

Energy production from byproducts of coal include coal mine methane and waste coal. Historical coal mine methane information was available from EPA's Coalbed Methane Outreach Program (CMOP) (EPA 2018b); the Analysis Team assumed production is the same for each year that CMOP-identified projects are in operation and that growth will be flat in future years, as compelling information to show increasing or decreasing trends in coal mine methane production was not available. For historical waste coal production, the Analysis Team equated production to waste coal consumption for electricity generation in EIA Form-923 under the assumption that generation facilities are located next to waste coal refuse piles, and waste coal is not imported or exported (EIA 2017e). Future waste coal production was set equal to 2015 levels under the assumption that no new waste coal-powered electricity generators come online in the future and existing generators will maintain their demand for local waste coal production.

Renewable and Alternative Fuels

Similar to consumption, the Analysis Team needed to use and integrate a mix of sources and methods to estimate production of renewable and alternative fuel production.

Historical landfill gas methane production and energy generated from digesters (wastewater and agriculture digesters) were set equal to the relevant quantities consumed and used to generate electricity. Future growth for landfill gas and wastewater digesters were assumed to be flat and were set equal to 2015, as compelling information to show increasing or decreasing trends in these areas were not available. Modest future growth in the agriculture digesters sector is expected, and therefore half of the historical annual growth from 2001 to 2015 in gas used in agriculture digesters was the basis for annual growth in this sector.

The Analysis Team relied on EIA's *Monthly Biodiesel Production Report* (EIA 2018) for historical biodiesel production estimates. The report provided capacity by state and production by the Petroleum Administration for Defense Districts, which was then allocated to states based on production capacity. For years where data were missing, the latest year's data were used until the date where the facility began operations (EIA 2018). Again, for this resource type, future growth was assumed to be flat and is set equal to 2015, assuming that biodiesel production levels continue to support the 2 percent minimum mandated statewide biodiesel content (PDA 2018).

Wood and biogenic waste production, which includes the production of wood and biogenic waste for residential, commercial, industrial, and electricity sector purposes, was set equivalent to wood and biogenic waste consumed and used to generate electricity for each sector in all years.

Lastly, the Analysis Team estimated ethanol production in Pennsylvania by using Renewable Fuels Association's (RFA's) *Ethanol Outlook for 2017* and holding the production constant back until the ethanol plant began production (RFA 2017). Future growth is flat and set equal to 2015, assuming the Commonwealth's one ethanol plant keeps running at its 110 million gallons per year capacity. The Commonwealth's ethanol production only includes corn ethanol; the Analysis Team assumed cellulosic ethanol was not produced in Pennsylvania, as there are no data sources indicating its production.

2.2.2 Summary of Results

Pennsylvania is one of the largest energy-producing states in the country as is evidenced by the analysis in this report and multiple studies (Penn State 2011, Pennsylvania Economy League of Greater Pittsburgh 2014, Berkman et al. 2016, Environmental Entrepreneurs et al. 2016). This energy production drives a lot of the Commonwealth's economy but also results in associated climate and other environmental impacts. This section summarizes key trends that emerge from examination of the energy production data, places these trends in context, and also discusses the environmental and economic effects associated with energy production.

The summary figures and the more detailed tables[16] below reveal energy production trends that have implications for Pennsylvania's energy future. These include:

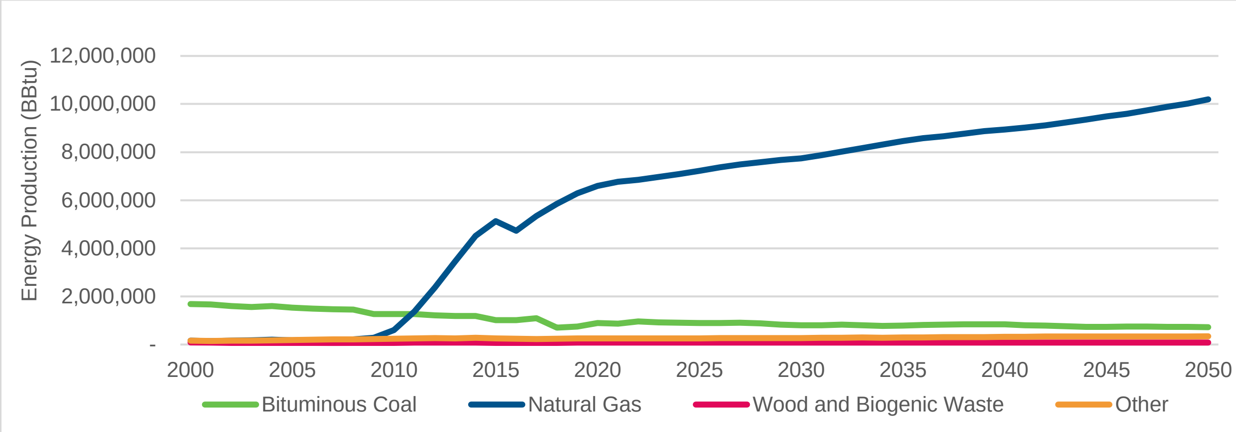
- **Natural gas is now and will increasingly be the Commonwealth's prime energy resource produced.** Gas production is projected to exceed 10 quadrillion Btu by mid-century, rising 5,675 percent from 177 trillion British thermal units (TBtu) in 2005 to 10,195 TBtu in 2050 (see Figure 9 and Table 6). This is more than double total projected energy consumption in 2050. While most of this gas will be exported, it makes this fuel the dominant energy resource for the Commonwealth. Expanded gas development in the Marcellus and Utica Shale comes with economic benefits from the development, transport, distribution, and sale of the commodity and its derivative products. This increased production and pipeline infrastructure also comes with environmental risks, including water consumption, water contamination, and fugitive

[16] Note total and percentages in tables may appear off due to rounding.

methane emissions. Fugitive methane and its mitigation could play a large role in Pennsylvania's climate policy future.

- **Coal production continues to fall.** Total anthracite and bituminous coal production in 2050 is projected to be just over half of 2005 levels, declining by 46 percent from 1,589 TBtu in 2005 to 858 TBtu in 2050 (see Table 6). Anthracite coal production does increase over this time period; however, this increase is overshadowed by declining bituminous coal production. Much of this decline is due to the rise of natural gas, which can be less expensive on a raw-Btu basis than other fuels, and can be used for power generation at greater efficiencies and with fewer emissions. Power and other energy markets have been choosing gas over coal for several years, and that trend is projected to continue. Coal production also comes with health and safety risks to miners, as well as land and water impacts such as acid mine drainage and waste piles. Moreover, because coal has the highest carbon content on a Btu basis out of any fossil fuel, its decline will help the Commonwealth achieve its GHG-reduction goals.
- **Oil production is rebounding.** More than 150 years after the first commercial oil well was drilled in Pennsylvania, and long after the Gulf states overtook it as leading oil producers, Pennsylvania oil production is making a comeback, spurred mainly by the same hydraulic fracturing technology that has driven the natural gas boom. Crude oil production, while not expected to produce more than a fraction of the total Btus of the natural gas sector, is projected to double by 2050 from 2015 levels, with production rising 455 percent from 14 TBtu in 2005 to 79 TBtu in 2050 (see Table 6). This may help rebuild the Commonwealth's refining industry and generate other economic benefits. Oil production also comes with its own set of environmental risks, including water consumption and contamination, land degradation, and spills.
- **Fugitive methane emissions are expected to increase significantly.** Production-related GHG emissions were not readily available for all fuels apart from natural gas and crude oil. Fugitive methane emissions from natural gas are expected to rise from 4.8 million $MTCO_2e$ in 2005 to 10.0 million $MTCO_2e$ in 2050, while emissions from crude oil production are expected to rise from 0.1 million $MTCO_2e$ in 2005 to 0.3 million $MTCO_2e$ in 2050 (see Table 38 and Table 41). Fugitive methane emissions regulations, currently under consideration in Pennsylvania, could alter these baseline projections. When using "best available technology" (e.g., leak detection and repair) to address methane emissions in natural gas systems, emission reductions could range from 50 percent to 60 percent (PA DEP 2017).

Figure 9: Energy Production by Fuel Type (BBtu)[a]



[a] "Other" includes anthracite coal, crude oil, landfill gas methane, coal mine methane, digesters (wastewater, agricultural waste), biodiesel, corn ethanol, cellulosic ethanol, and waste coal.

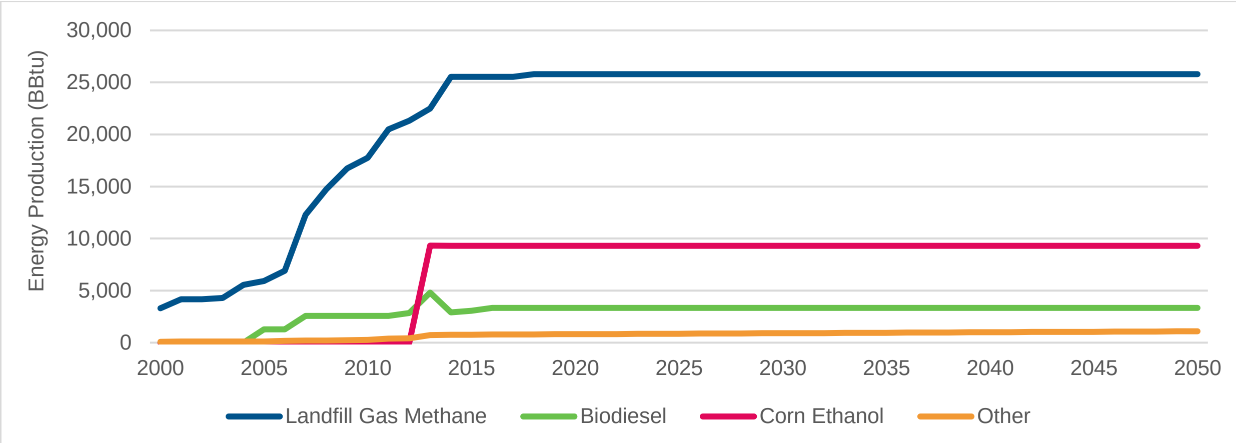
Table 6: Fossil Fuel Production by Fuel Type (TBtu)

Fuel Type	2000	2005	2015	2018	2020	2025	2030	2050	Change from 2005 to 2050
Bituminous Coal	1,682	1,539	1,015	702	896	895	802	715	-54%
Anthracite Coal	59	50	98	79	83	94	108	143	184%
Natural Gas	156	177	5,128	5,848	6,595	7,219	7,745	10,195	5675%
Crude Oil	9	14	40	41	48	45	43	79	455%
Coal Mine Methane	0.1	1.0	1.4	1.4	1.4	1.4	1.4	1.4	50%
Waste Coal	86	114	78	78	78	78	78	78	-32%
Total	**1,993**	**1,895**	**6,362**	**6,750**	**7,701**	**8,333**	**8,778**	**11,212**	**492%**

- **Wood and biogenic waste shows the greatest renewable fuel growth.** Wood and biogenic waste, which includes agricultural waste, other forest products such as cordwood and pelletized fuels, waste gas, and municipal waste, are projected to grow 15 percent, rising from 72,538 BBtu in 2005 to 83,466 BBtu in 2050 (see Table 7). Most of this fuel is expected to be used in the residential heating, industrial fuel use, and the power sector, with a large majority of the growth in demand coming from the power sector from increased usage of wood and biogenic municipal waste.
- **Limited growth expected in biogas and biofuels without further policy support.** While landfill gas methane and corn ethanol production has seen growth over the last decade, limited growth is expected for these and other biogas and biofuels under current market conditions (see Table 7 and Figure 10). Landfill gas methane production is projected to increase by 335 percent from

2005 to 2050 and corn ethanol production is projected to increase from 0 BBtu in 2005 to 9,319 BBtu in 2050.

Figure 10: Energy Production from Renewable and Alternative Fuels



"Other" includes digesters (wastewater, agricultural waste) and cellulosic ethanol. Wood and biogenic waste are not displayed on this chart for reasons of scale.

Table 7: Renewable and Alternative Fuels Production by Fuel Type (BBtu)

Fuel Type	2000	2005	2015	2018	2020	2025	2030	2050	Change from 2005 to 2050
Landfill Gas Methane	3,303	5,928	25,535	25,795	25,795	25,795	25,795	25,795	335%
Digesters – Wastewater	-	21	409	409	409	409	409	409	1812%
Digesters – Ag Waste	80	81	358	386	405	451	498	684	749%
Biodiesel	-	1,287	3,070	3,349	3,349	3,349	3,349	3,349	160%
Wood and Biogenic Waste	86,747	72,538	70,874	72,266	76,869	76,427	76,978	83,466	15%
Corn Ethanol	-	-	9,319	9,319	9,319	9,319	9,319	9,319	N/A
Cellulosic Ethanol	-	-	-	-	-	-	-	-	N/A
Total	**90,130**	**79,854**	**109,565**	**111,523**	**116,145**	**115,750**	**116,347**	**123,020**	**54%**

At a high level, historical data findings on total production levels are consistent with those in the 2013 report, *Energy in Pennsylvania: Past, Present, and Future* (Commonwealth Economics 2013). The Analysis Team's top-level findings tend to be slightly higher than were those in the 2013 report, which can be attributed mainly to the methods for allocating regional data to the Commonwealth level, the Analysis Team's consultation of additional data sources, and a more detailed breakout of certain energy types.

2.3. Electricity Generation

2.3.1 Sources and Methodology

The Analysis Team estimated electricity generation, capacity, prices, expenditures, GHG emissions, and criteria air pollutant emissions for each generating fuel type to the extent possible.

Fossil Fuels

Historical (2000–2015) trends in electricity generation and capacity for natural gas,[17] coal, waste coal, residual fuel oil, distillate fuel oil, and petroleum coke relied on EIA electricity data published by state (EIA 2017b) and on ICF's Combined Heat and Power (CHP) Database, while SEDS data were used by the Analysis Team for historical prices and expenditures for these fuels. The Analysis Team made exceptions as well as adjustments to the standard methods and sources of data, including:

- Data from the Anthracite Region Independent Power Producers Association (ARIPPA) was used for historical prices and expenditures for waste coal electricity generation (ARIPPA 2017).
- Only generation and capacity were estimated by the Analysis Team for pumped storage, and these values were taken directly from EIA electricity data published by state (EIA 2017b).
- The Analysis Team assumed zero historical electricity generation from coal mine methane, as coal mine methane typically is mixed in with natural gas in pipelines and therefore any generation stemming from coal mine methane production is included in natural gas electricity generation. Historical prices and expenditures are not estimated for the same reason.
- CHP data for historical generation, capacity, and consumption estimates from a variety of fuels, including natural gas, coal, waste coal, biogas, wood and biogenic waste, residual fuel oil, petroleum coke, and a variety of other fuels were taken from ICF's CHP Database. Prices and expenditures were not estimated.

Future (2016–2050) trends in electricity generation, capacity, and consumption from natural gas, coal, and distillate fuel oil were estimated by applying growth rates based on AEO's projections using the "Reference case without Clean Power Plan" for the Reliability First Corporation (RFC) electricity service areas RFC East and RFC West to the historical numbers. The Analysis Team projected prices of electricity from natural gas, coal, and distillate fuel oil using AEO's Middle Atlantic prices in the electricity sector and calculated forecasts for expenditures using price and consumption data. The Analysis Team made exceptions as well as adjustments to the standard methods and sources of data described here, including:

- ICF's CHP database was used for electricity generation, capacity, and consumption estimates from plants using natural gas expected to come on line after 2015. These estimates were added to historical levels, which otherwise remain constant from 2015 on. All other CHP fuel types are

[17] Energy consumption and electricity generation natural gas total may include some double-counting due to the inclusion of small CHP plants, which could not be isolated.

expected to remain constant from 2015 onward, as there were insufficient data to project these sources otherwise.

- The Analysis Team adjusted the AEO projections for electricity generation from coal to take into account an assumed increase in solar generation, capacity, and consumption for compliance with the Pennsylvania Alternative Energy Portfolio Standards Act (2004 Act 213),[18] as well as a more aggressive reference case scenario from the *Finding Pennsylvania's Solar Future Plan* (PA DEP 2018). This increased solar replaced some of the future generation, capacity, and consumption from coal.
- Future growth for waste coal generation, capacity, and consumption was assumed to be flat and was set equal to all values in 2015, as no new waste coal generators are expected to come online, and with uncertainty surrounding wholesale electricity prices, the Analysis Team assumed that waste coal generators would generate at 2015 levels into the foreseeable future (Ellis 2018). Similarly, prices and expenditures were assumed to be constant from 2015 on.
- Because residual fuel oil and petroleum coke were and are currently on a downward trend, the Analysis Team assumed they will not be used for electricity in projected years, beyond 2015.
- Generation and capacity from pumped storage were projected in the future using the relevant historical data from EIA (see above) and the related growth rates based on AEO's projections for Reliability First Corporation (RFC) East and RFC West.
- Future growth in generation and capacity for electricity generated from other fuels (see above) was assumed to be flat and was set equal to 2015 levels as information indicating their growth or decline was not available.

The Analysis Team calculated emissions for all years from fossil fuel electricity generation using the relevant emission factors presented in Section 1.

Renewable and Alternative Fuels

Most historical data for electricity generation and capacity were taken from SEDS and EIA state electricity tables, including for utility- and building-scale solar photovoltaic (PV),[19] hydroelectric, wind, and wood and biogenic waste. Future trends in electricity generation and capacity for renewable and alternative fuels mainly relied on growth rates based on AEO projections for RFC East and RFC West. Again, the Analysis Team made some exceptions and adjustments to fill in data gaps and to use Pennsylvania-specific information when available.

- For solar, both utility- and building-scale, future generation and capacity grew in line with the Commonwealth's Alternative Energy Portfolio Standard in the short term, rising to an equivalent of 0.5 percent of the Commonwealth's solar demand by 2021. Solar generation then rises in line

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[18] As Act 213 requires that 0.5% of electricity consumption is from solar sources, the AEO forecasts had to be adjusted and therefore the generation had to be reduced from other sources. The adjustment was made entirely in coal generation. More information is available at: http://www.legis.state.pa.us/cfdocs/legis/li/uconsCheck.cfm?yr=2004&sessInd=0&act=213.

[19] Historical SEDS and EIA data are split between utility and building-scale using data from EIA's *Electric Power Monthly* report. This historical split is applied to future data as well to disaggregate utility- and building-scale. More information is available at: https://www.eia.gov/electricity/monthly/archive/february2016.pdf.

with the reference case scenario in the *Finding Pennsylvania's Solar Future Plan* (PA DEP 2018), reaching a combined 1.2 GW of distributed and utility-scale solar by 2030. The continuing trend in solar capacity growth from 2021 to 2030 is then assumed to grow linearly through 2050.

- Historical price and expenditure data were available for electricity generation from wood and biogenic waste from SEDS, while future price data were available from AEO and could be used to estimate expenditures. Additionally, the Analysis Team estimated criteria air pollutant emissions from electricity generated from wood and biogenic waste using the needed emission factors presented in Section 1, above. Lastly, ICF's CHP Database was used to include historical generation, capacity, and consumption estimates from CHP using wood and biogenic waste; this growth was assumed to be flat beyond 2015.
- See discussion above in Section 2 on biogas (from landfill gas methane, wastewater, and agricultural digesters) for a discussion of methods and sources (e.g., ICF CHP Database, EPA AgStar, and LMOP data). In addition, the Analysis Team supplemented the estimates with information from a listing of wastewater sites in Pennsylvania (WEF 2015) for historical generation and capacity. Future growth was assumed to be flat and is set equal to 2015.

Nuclear

The Analysis Team used SEDS and EIA data for historical generation, capacity, price, and expenditures for nuclear generation, and estimated consumption in BBtu using heat rates published by EIA (2017c). The Analysis Team projected future nuclear generation using growth rates based on AEO's projections for RFC East and RFC West while adjusting for the closure of Three Mile Island; estimated consumption in BBtus using heat rates published by EIA (2017c); and assumed expenditures equal to price multiplied by consumption.

While nuclear power generation remains an active area of discussion in energy and climate policy circles, and does offer non-CO_2-emitting generation resource, current market and policy forces do not support a resurgence of nuclear power in the Commonwealth in the near future. The only states in which nuclear plants are under development are traditionally regulated, where state utility commissions can approve utility-proposed projects. Pennsylvania's electricity restructuring legislation placed all generation in the hands of private owners outside the Commonwealth's regulatory purview; so unless private entities take on the costs and risks of nuclear plants, they are unlikely to be built. Exelon, owner of the Three Mile Island nuclear unit, announced its closure is slated for 2019. In 2017, the Federal Energy Regulatory Commission rejected a proposed regulation from the U.S. Department of Energy (DOE) that would have provided price supports for nuclear and coal power plants based on their reliability value. In 2018, Beaver Valley nuclear plant owner First Energy requested U.S. Department of Energy to use its emergency authority to keep the facility operating. Because there have been no indications that that any nuclear units will be kept online through such policy actions, the baseline estimates in this section accordingly reflect current market-based action.

Advanced nuclear technologies do exist, at least in the research and development stage, such as liquid metal-cooled fast reactors, sodium-cooled fast reactors, and fluoride salt-cooled high-temperature reactors, as well as small modular reactor designs, all of which are included in DOE research plans.

However, none of these technologies has shown commercial uptake that would warrant inclusion in baseline projections for Pennsylvania-based power generation.

2.3.2 Summary of Results

This section summarizes key trends that emerge from examination of the electricity sector data, places these trends in context, and also discusses the environmental and economic effects associated with electricity generation.

The summary figures and the more detailed tables[20] below reveal electricity generation trends that have implications for Pennsylvania's energy future. These include:

- **Natural gas is rapidly becoming and is projected to continue to be the Commonwealth's primary electricity generation fuel.** Electricity generation from natural gas rises 925 percent from 11,088 GWh in 2005 to 113,649 GWh in 2050 (see Table 8). By 2050, gas is projected to rise from less than 10 percent in 2005 to more than half of fossil fuel generation, (see Figure 11 and Figure 12), and more than a third of total generation. Especially when burned in combined-cycle systems whose efficiencies can approach 50 percent, gas is a very cost-competitive fuel. Its relatively low emissions profile also gives gas an advantage relative to coal and other fossil fuels; however, it is important to address the associated GHG and nitrogen oxide (NO_x) emissions in air quality compliance and climate policy contexts.
- **Retiring nuclear generation leaves a large gap for other generating sources to fill.** BAU nuclear generation decreases 31,562 GWh from 2015 to 2050 (see Table 8). In order for emissions-free generation to break even given the expected reduction in emissions-free nuclear generation, renewable generation would need to quadruple from 2015 to 2050 (see Table 10).

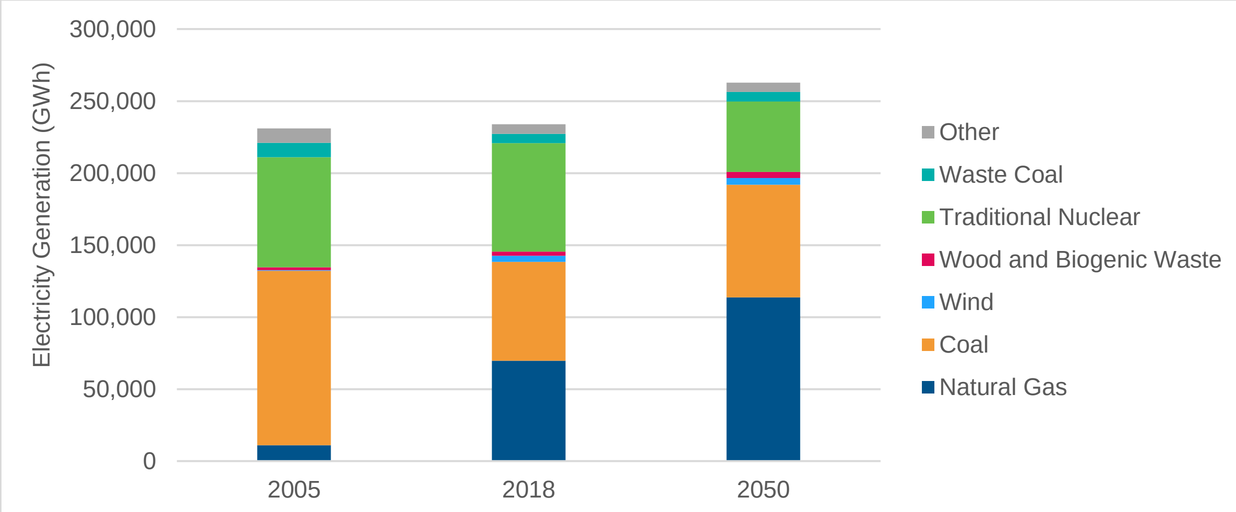
[20] Note total and percentage in tables may appear off due to rounding.

Table 8: Electricity Generation from All Fuel Types (GWh)

Fuel Type	2000	2005	2015	2018	2020	2025	2030	2050	Change from 2005 to 2050
Natural Gas	2,971	11,088	60,102	69,669	69,800	69,830	73,491	113,649	925%
Coal	116,403	121,124	64,828	68,769	77,608	80,076	80,874	78,352	-35%
Traditional Nuclear	73,771	76,289	80,517	75,246	59,546	60,058	60,044	48,955	-36%
Wood and Biogenic Waste	2,852	2,176	2,582	2,940	3,295	3,231	3,394	4,131	90%
Waste Coal	7,999	9,972	6,551	6,551	6,551	6,551	6,551	6,551	-34%
Wind	10	284	3,353	4,075	4,139	4,140	4,161	4,621	1527%
Hydroelectric	2,290	2,232	2,604	3,523	4,128	4,128	4,128	4,410	98%
Other Fuel (CHP)	2,231	2,231	2,471	2,471	2,471	2,471	2,471	2,471	11%
Landfill Gas Methane	304	396	1,621	1,648	1,648	1,648	1,648	1,648	316%
Utility-Scale Solar PV	-	-	33	125	186	364	542	1,255	3687% [a]
Building-Scale Solar PV	-	-	178	370	498	520	542	631	255% [a]
Distillate Fuel Oil	1,255	667	729	278	305	306	304	304	-54%
Digesters – Ag Waste	7	7	32	34	36	40	44	60	749%
Digesters – Wastewater	-	2	40	40	40	40	40	40	2154%
Residual Fuel Oil	2,514	4,031	34	34	34	34	34	34	-99%
Petroleum Coke	22	275	-	-	-	-	-	-	-100%
Coal Mine Methane	-	-	-	-	-	-	-	-	N/A
Pumped Storage	(411)	(711)	(509)	(419)	(419)	(419)	(423)	(426)	-40%

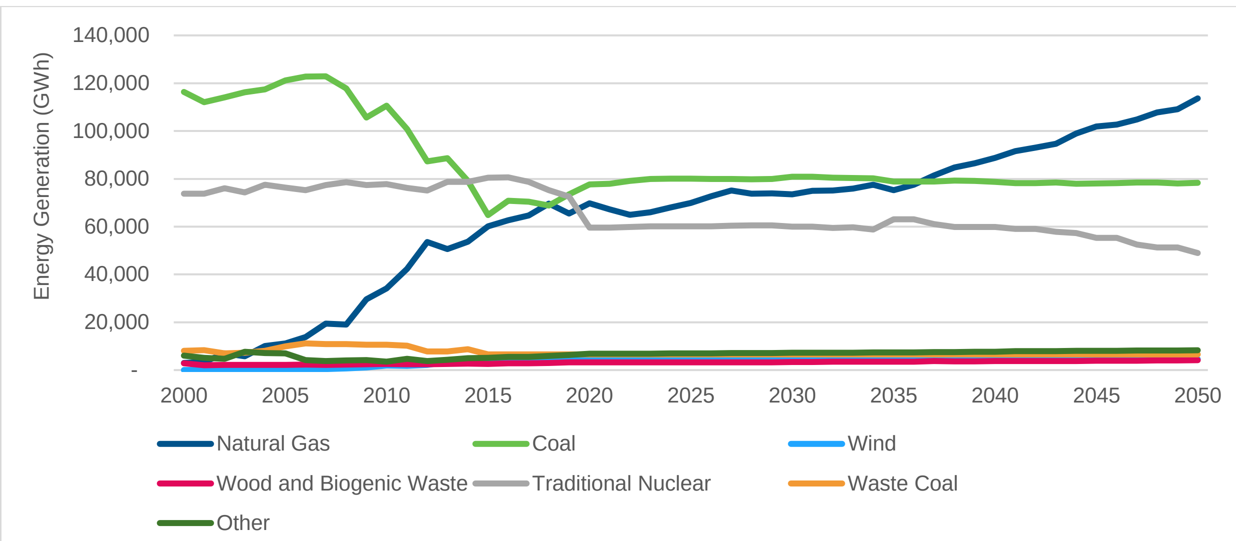
[a] This value reflects the percent change from 2015 to 2050 because there was no generation from this source in 2005.

Figure 11: Electricity Generation by Fuel[a]



[a] "Other" includes residual fuel oil, distillate fuel oil, petroleum coke, pumped storage, hydroelectric, landfill gas methane, building- and utility-scale solar PV, digesters – wastewater, and digesters – agricultural waste.

Figure 12: Total Electricity Generation by Fuel Type (GWh)[a]



[a] "Other" includes residual fuel oil, distillate fuel oil, digesters (wastewater, agricultural waste), building-scale solar PV, utility-scale solar PV, hydroelectric, and petroleum coke. Pumped storage is not shown in this figure.

- **The role of coal generation is decreasing but remains significant during the study period.** From 2005 to 2050, coal falls from about 80 percent to about 40 percent of fossil fuel generation (see Table 9 and Figure 13 and Figure 14), but retains about a 29 percent share of total generation. Electricity generation from coal declines by 35 percent from 121,124 GWh in 2005 to 78,352 GWh in 2050. This largely is driving the decreasing trend seen in GHG emissions from fossil fuel generation over the study period (see Figure 15) as it is the most carbon-intensive fuel. Coal carries other environmental risks; it also emits sulfur dioxide (SO_2), nitrogen oxide

(NO_x), particulates, and airborne toxics such as mercury, and coal ash presents water quality risks.

- **Residual fuel oil is phased out over time.** As shown in Table 9, residual fuel oil is nearly phased out by 2015, dropping from 2,514 GWh in 2000 to 34 GWh in 2015, as cheaper and cleaner burning natural gas generators increase their share of the market.
- **Pumped storage generation, while relatively small, shows a spike in 2005 before settling down.** Pumped storage shows an increase from 411 GWh in 2000 to 711 in 2005 before settling back down to 509 GWh in 2015, after which generation stabilizes (see Table 9). This pattern follows a similar rise and fall in wholesale electricity prices from 2000 to 2015 (Monitoring Analytics 2017). Since 2005 showed both high peak demand and high wholesale peak-hour prices in the PJM market during this period (through 2015), it is possible that pumped storage became a more economically viable resource in that timeframe.

Table 9: Electricity Generation from Fossil Fuels by Fuel Type (GWh)

Fuel Type	2000	2005	2015	2018	2020	2025	2030	2050	Change from 2005 to 2050
Natural Gas	2,971	11,088	60,102	69,669	69,800	69,830	73,491	113,649	925%
Coal	116,403	121,124	64,828	68,769	77,608	80,076	80,874	78,352	-35%
Waste Coal	7,999	9,972	6,551	6,551	6,551	6,551	6,551	6,551	-34%
Residual Fuel Oil	2,514	4,031	34	34	34	34	34	34	-99%
Distillate Fuel Oil	1,255	667	729	278	305	306	304	304	-54%
Petroleum Coke	22	275	-	-	-	-	-	-	-100%
Coal Mine Methane	-	-	-	-	-	-	-	-	N/A
Other Fuel (CHP)	2,231	2,231	2,471	2,471	2,471	2,471	2,471	2,471	11%
Pumped Storage	(411)	(711)	(509)	(419)	(419)	(419)	(423)	(426)	-40%
Total	**132,985**	**148,678**	**134,205**	**147,352**	**156,349**	**158,848**	**163,302**	**200,934**	**35%**

Figure 13: Fossil Fuel Electricity Generation by Fuel

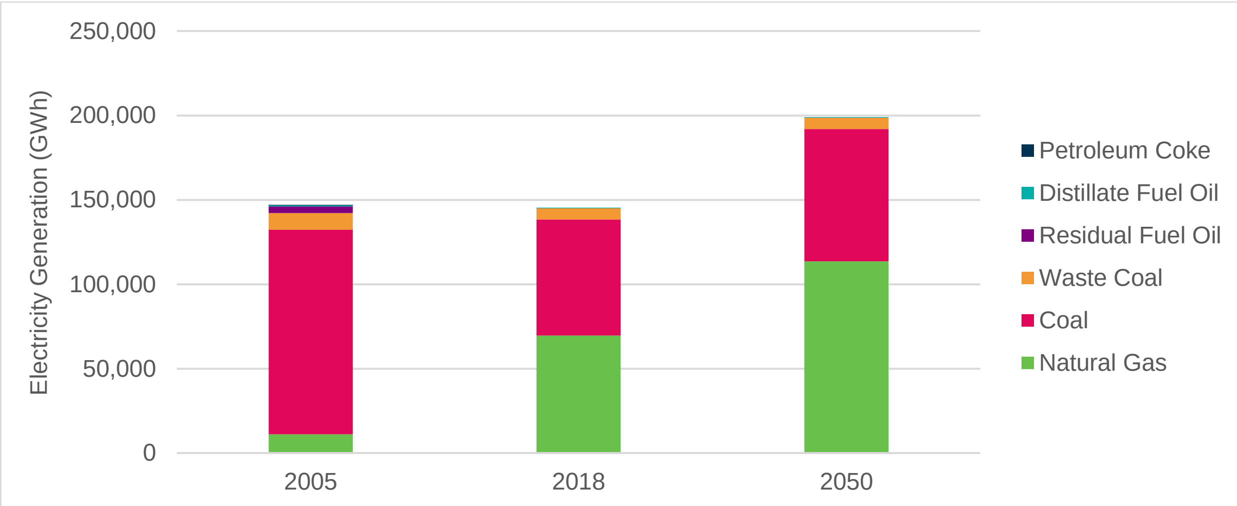
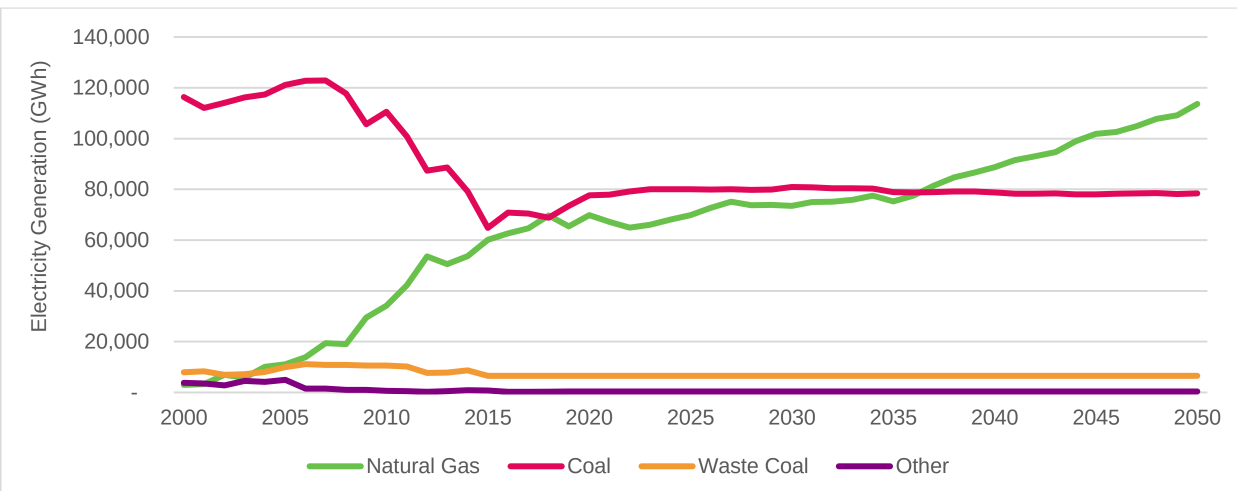
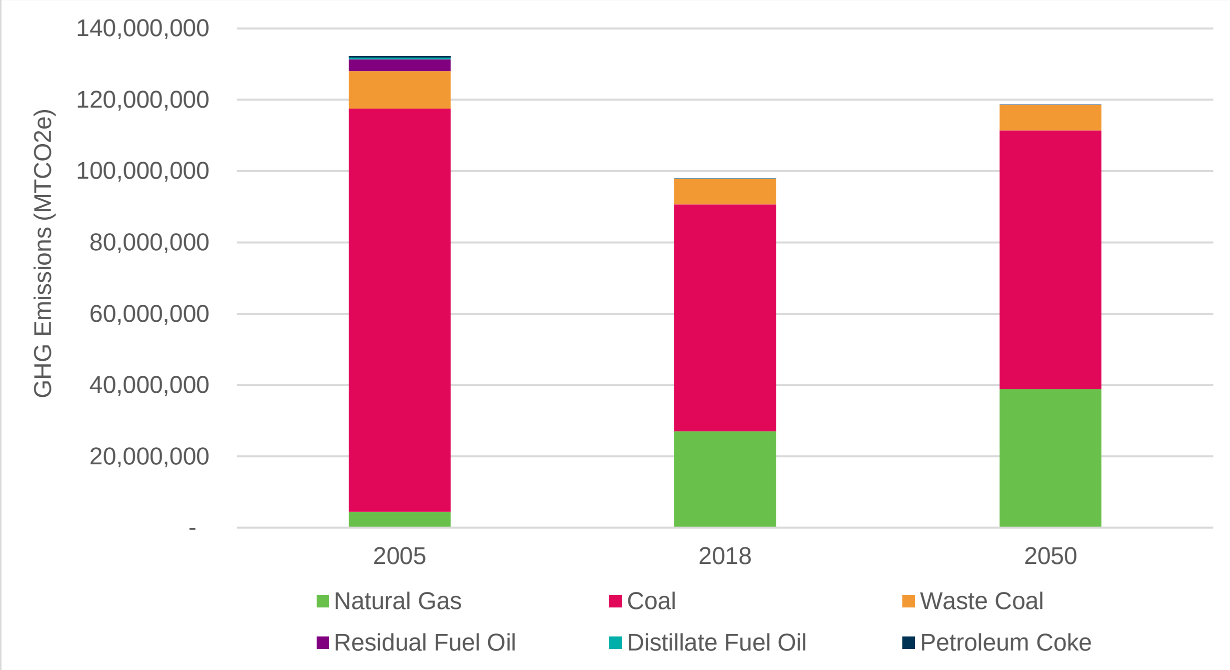


Figure 14: Electricity Generation from Fossil Fuels by Fuel Type (GWh)[a]



[a] "Other" includes residual fuel oil, distillate fuel oil, and petroleum coke. Pumped storage is not shown in this figure.

Figure 15: GHG Emissions from Fossil Fuel Electricity Generation by Fuel



- **Renewables increase during the study period but still fall short of coal and gas generation.** By 2050, renewable power is expected to account for about 6 percent of total generation in the Commonwealth, lower than the expected contribution from coal and natural gas. While emerging market forces and new policies could accelerate renewable generation growth, this BAU remains necessarily conservative based on available information. However, major increases are seen over the study period (see Figure 16 and Figure 17); renewable electricity generation increases 230 percent from 5,097 GWh in 2005 to 16,796 GWh in 2050 (see Table 10). Although solar PV generation increases dramatically in percentage terms, wind, hydroelectricity, and wood and biogenic waste also significantly increase their total generation, rising between about 1,200 to 1,600 GWh each from 2015 to 2050. These renewable resources have the great advantage of generating power with little or no GHG or criteria pollutant emissions. However, they do bear some other environmental risks: Wind power can impact sensitive bird and bat populations, and wood harvesting can be associated with land and water degradation from improper harvesting practices, and can also produce particulates and other criteria pollutants. The rising role of distributed resources such as energy efficiency, renewable generation, CHP, and battery storage in concert with other technology advances such as electric vehicles and grid-connected devices will also affect structural and operational dimensions of Pennsylvania's power system. These developments could drive future investments needed for required modernization/expansion of transmission and distribution system infrastructure. Such issues will become even more important if 10 percent of in-state consumption is provided from solar PV by 2030, as outlined in the *Finding Pennsylvania's Solar Future Plan*.

Table 10: Electricity Generation from Renewable and Alternative Fuels by Fuel Type (GWh)

Fuel Type	2000	2005	2015	2018	2020	2025	2030	2050	Change from 2005 to 2050
Utility-Scale Solar PV	-	-	33	125	186	364	542	1,255	3687%[a]
Building-Scale Solar PV	-	-	178	370	498	520	542	631	255%[a]
Hydroelectric	2,290	2,232	2,604	3,523	4,128	4,128	4,128	4,410	98%
Wind	10	284	3,353	4,075	4,139	4,140	4,161	4,621	1527%
Wood and Biogenic Waste[b]	2,852	2,176	2,582	2,940	3,295	3,231	3,394	4,131	90%
Landfill Gas Methane	304	396	1,621	1,648	1,648	1,648	1,648	1,648	316%
Digesters – Wastewater	-	2	40	40	40	40	40	40	2154%
Digesters – Ag Waste	7	7	32	34	36	40	44	60	749%
Total	**5,462**	**5,097**	**10,442**	**12,753**	**13,968**	**14,110**	**14,498**	**16,796**	**230%**

[a] This value reflects the percent change from 2015 to 2050 because there was no generation from this source in 2005.

[b] Wood and Biogenic Waste represents the "Wood and Waste" category from SEDS, which is not broken out into individual fuels.

Figure 16: Renewable Generation by Fuel Type

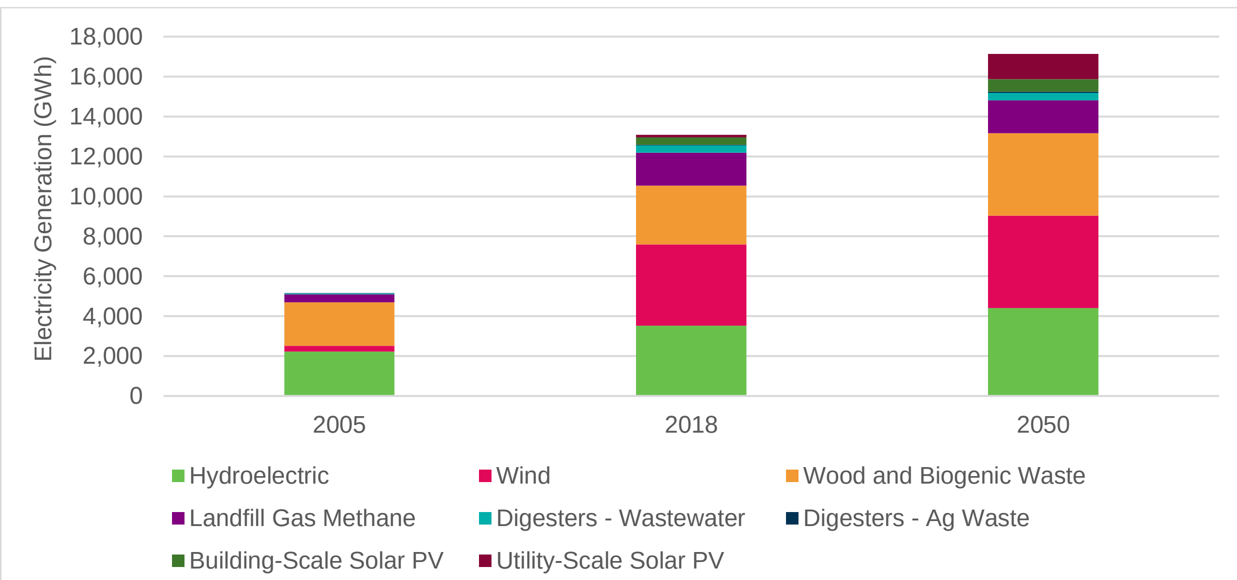
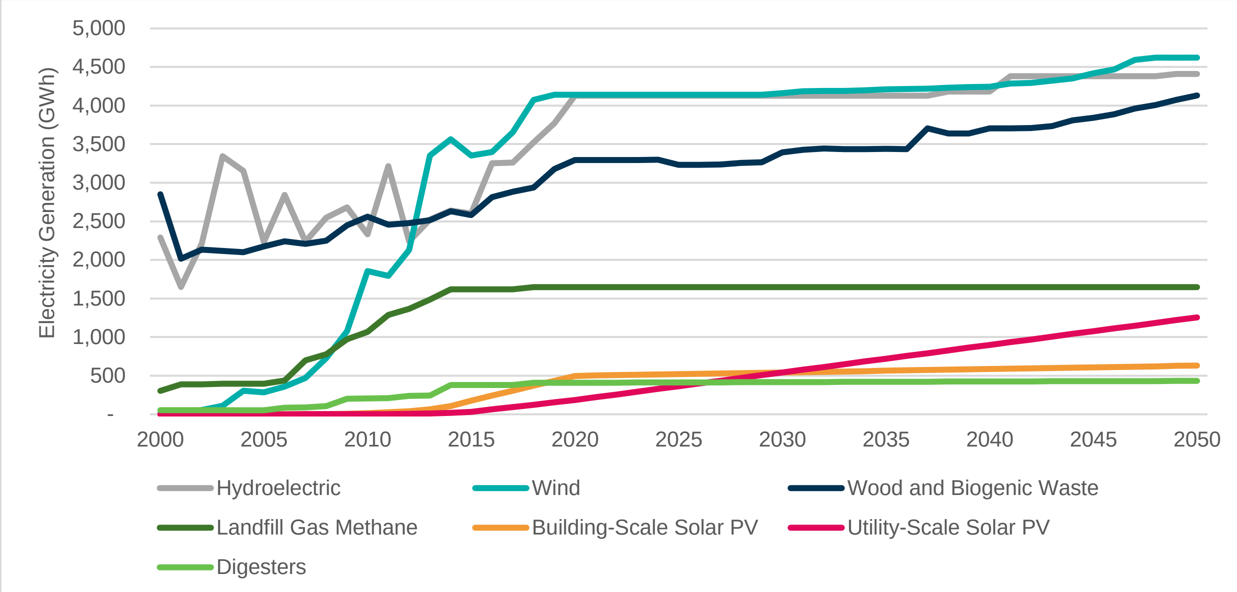


Figure 17: Electricity Generation from Renewable and Alternative Fuels by Fuel (GWh)



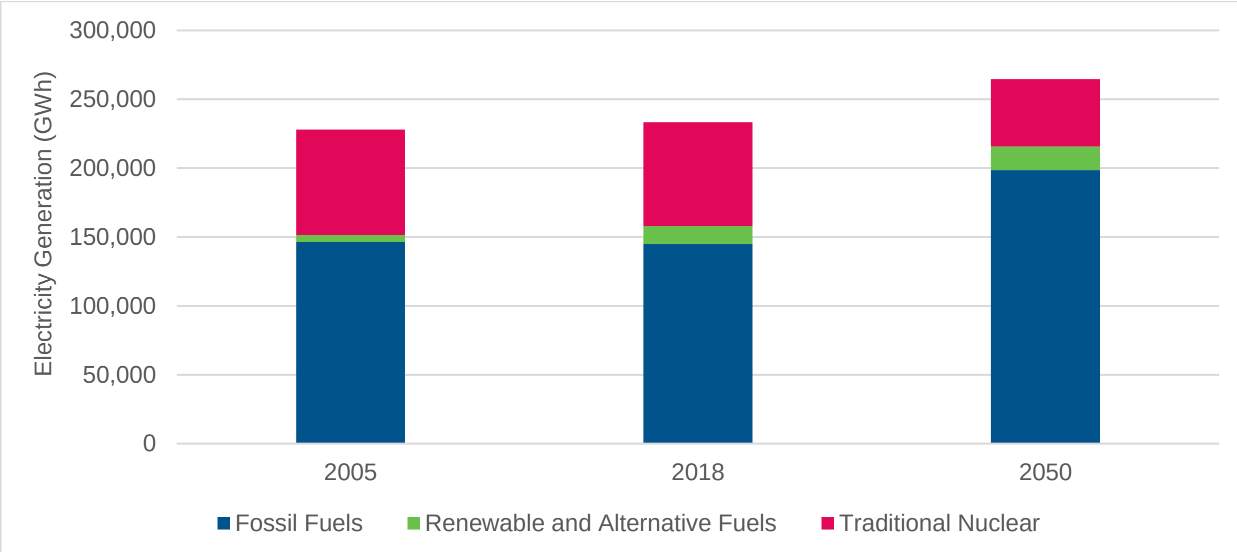
- **Nuclear generation decreases but remains significant.** The planned closures of the Three Mile Island nuclear plant in 2019 is a primary cause of the decrease of in-state nuclear generation by 26 percent from 80,517 GWh in 2015 to 59,546 GWh in 2020. Nuclear then continues its modest decline to 48,955 GWh in 2050, based partly on the expected license expiration of other nuclear units, dropping 36 percent overall from 2005 levels to 2050 (see Table 11 and Figure 18). Nuclear generation capacity is expected to decrease by 35 percent over the same time period, from 9,860 MW in 2005 to 6,383 MW in 2050. Together with coal, these traditional baseload generation fuels are projected to provide about 40 percent of the 2050 generation mix. Nuclear carries environmental risks; it is a low-emission technology at the smokestack, but its total fuel cycle is energy intensive, and the transport and storage of waste fuel remains an environmental challenge for state and federal governments.

Table 11: Electricity Generation from Traditional Nuclear (GWh)

	2000	2005	2015	2018	2020	2025	2030	2050	Change from 2005 to 2050
Traditional Nuclear	73,771	76,289	80,517	75,246	59,546	60,058	60,044	48,955	-36%

- **Renewables see substantial growth but are overshadowed by the increase in fossil fuel generation and a decrease in nuclear generation.** Renewable and alternative fuels increase by 4,043 GWh from 2018 to 2050, but this increase is overshadowed by an increase in fossil fuel generation of 53,582 GWh and a decrease in nuclear generation of 26,291 GWh during the same timeframe (see Figure 18). These trends are in line with the increase in emissions from power generation, which are expected to rise 21 percent over the same timeframe under BAU conditions (see Figure 15).

Figure 18: Total Generation by Fossil Fuels, Nuclear, and Renewables



At a high level, historical data findings on electricity generation levels are consistent with those in the 2013 report, *Energy in Pennsylvania: Past, Present, and Future* (Commonwealth Economics 2013). The reasons for any small discrepancies are attributed to the Analysis Team's methods for allocating regional data to the Commonwealth level, and consultation of additional data sources.

2.4. Energy Imports and Exports

2.4.1 Sources and Methodology

The Analysis Team estimated energy imports and exports for electricity and select fossil and renewable fuels that play a large economic and energy role in the Commonwealth.

Electricity

International and net state historic import and export electricity data came directly from a variety of EIA and DOE sources:[21]

- Energy Information Administration, Form EIA-923, "Power Plant Operations Report" and predecessor forms
- Energy Information Administration, Form EIA-860, "Annual Electric Generator Report"
- Energy Information Administration, Form EIA-861, "Annual Electric Power Industry Report"
- DOE, Office of Electricity Delivery and Energy Reliability, Form OE-781R, "Annual Report of International Electric Export/Import Data," predecessor forms

[21] Estimates likely do not reflect the soon-to-occur Regional Greenhouse Gas Initiative (RGGI) compliance period extension and emissions cap reduction; net power exports will likely increase from these changes.

Electricity losses (transmission and distribution[22] and generation) were estimated by sector (residential, commercial, industrial, and transportation).

International imports were held constant from 2015 through 2050. As U.S. interstate trade data was only available as net exports, the analysis only considers international imports. The Analysis Team used the following equation to calculate exports for 2016–2050:

$$G_c + I_c - [(G_p + I_p) - (C_p + E_p)] / (C_p * C_c) - C_c$$

Where:

G_c = Current year generation
I_c = Current year imports
G_p = Previous year generation
I_p = Previous year imports
E_p = Previous year exports
C_p = Previous year consumption
C_c = Current year consumption

Fossil Fuels

For natural gas, the Analysis Team pulled import/export data for Pennsylvania interstate natural gas receipts (imports) and deliveries (exports) directly from Form EIA-176, *Annual Report of Natural and Supplemental Gas Supply and Disposition* and then applied the following equations to calculate future imports/exports (EIA 2017f):

Imports:[23] *2015 imports – (current year – 2015) * 0.01*

Exports: current year production + current year imports – current year exports

Imports and exports of coal, crude oil, and coal mine methane are calculated simply using production less consumption for each year across the 2000–2050 time-series (see Sections 2 and 3, above, for how the Analysis Team estimated production and consumptions). For coal mine methane consumption, the Analysis Team assumed there was no out-of-state consumption, so coal mine methane produced was scaled by the natural gas production-to-consumption ratio to obtain in-state coal mine methane consumption.

Renewable and Alternative Fuels

Estimates of landfill gas methane imports and exports were zero for all years; the Analysis Team assumed all landfill gas methane produced in the Commonwealth was consumed in state in the same

[22] The Analysis Team used the eGRID regional factor to account for transmission and distribution losses. Transmission and distribution losses could be accounted for using a national loss factor that both EPA and DOE use: The annual 2016 U.S. transmission and distribution losses are determined as ((Net Generation to the Grid + Net Imports – Total Electricity Sales)/Total Electricity Sales) i.e., (3,940 + 57 – 3,727)/3,727 = 7.26%). This percentage considers all transmission and distribution losses that occur between net generation and electricity sales. The data are from the Annual Energy Outlook 2017, Table A8, available at: http://www.eia.gov/forecasts/aeo/. The Analysis Team is currently using the eGRID regional factor for this.

[23] The Analysis Team assumes a 1 percentage point reduction in natural gas imports each year from 2015.

year. Biodiesel and ethanol imports and exports were calculated using the same method described immediately above for coal and crude oil across the entire time-series of 2000–2050.

2.4.2 Summary of Results

Accounting for imports and exports can be challenging, especially for fuels like natural gas and coal. For gas, huge volumes pass through the Commonwealth in interstate pipelines, and new pipeline construction is a very dynamic activity, making projections challenging. Coal shipments by truck, rail, and barge can be even more complex to account for. Moreover, different EIA sources treat import and export data in somewhat different ways. For these reasons, the Analysis Team chose to take a relatively simple net-export approach, with specific details varying by energy type. In general, the approach netted out consumption from production, accounting for transmission losses for electricity and other factors as appropriate.

The detailed tables[24] below reveal energy import and export trends that have implications for the Commonwealth's energy future. These include:

- **Total electricity exports are growing.** As shown in Table 12, Pennsylvania has been a net exporter of electricity since before 2000 and net electricity exports are projected to more than double from 180,263 GWh in 2005 to 329,982 GWh in 2050.

Table 12: Net Imports of Electricity (GWh)

	2000	2005	2015	2018	2020	2025	2030	2050	Change from 2005 to 2050
Net Imports	(176,156)	(180,263)	(185,485)	(233,732)	(212,039)	(211,525)	(235,128)	(329,982)	83%

- **Natural gas exports are increasing substantially.** Natural gas became a net export between 2005 and 2015, with gas exports accounting for the great majority of production volume in 2015. As a result of increasing exports driven by shale gas development, net imports decline from 540,509 BBtu in 2005 to 8,390,679 BBtu in 2050 (see Table 13).
- **Coal exports are declining dramatically.** Coal, which once was Pennsylvania's largest energy export commodity to other states, is projected to decline dramatically in terms of export volumes as well as total production. From 2020 onward, Pennsylvania's coal production is expected to stay about even with consumption, with net exports falling from 108,905 BBtu in 2005 to 8,688 BBtu in 2050 (see Table 13). The rise of other producing regions, such as the Powder River Basin in the western U.S., driven by their abundant low-sulfur coal resources, helps to explain the decline in Pennsylvania exports.
- **Crude oil imports are decreasing.** While Pennsylvania remains a net importer of crude oil over the study period due to economic and market conditions, net imports decline by 43 percent

[24] Note total and percents in tables may appear off due to rounding.

from 1,239,807 BBtu in 2005 to 711,831 BBtu in 2050 (see Table 13). Shale gas development has encouraged parallel growth in oil production, using some of the same hydraulic fracturing techniques, and taking advantage of the increased availability of drilling equipment and associated labor and infrastructure.

Table 13: Net Imports of Fossil Fuels by Fuel Type (BBtu)

Fuel Type	2000	2005	2015	2018	2020	2025	2030	2050	Change from 2005 to 2050
Coal	(243,785)	(108,905)	(245,417)	82,554	(32,672)	(29,644)	38,995	(8,688)	-92%
Natural Gas	534,304	540,509	(3,885,490)	(4,487,460)	(5,211,778)	(5,823,939)	(6,304,474)	(8,390,679)	-1652%
Crude Oil	1,204,530	1,239,807	931,939	933,977	902,207	842,606	778,524	711,831	-43%
Coal Mine Methane	-	-	(1,071)	(1,095)	(1,127)	(1,151)	(1,161)	(1,174)	N/A
Total	**1,495,049**	**1,671,411**	**(3,200,039)**	**(3,472,023)**	**(4,343,371)**	**(5,012,127)**	**(5,488,116)**	**(7,688,709)**	**-560%**

- **Ethanol imports are growing while the Commonwealth is becoming more self-sufficient in biodiesel.** The increase in net imports of renewable and alternative fuels over the study period is driven by growing net imports of ethanol, which increase by 1,095 percent from 4,741 BBtu in 2005 to 56,653 BBtu in 2050 (see Table 14). This is somewhat offset by biodiesel, with the Commonwealth becoming nearly self-sufficient in biodiesel between 2005 and 2015. Net imports of biodiesel decrease from 2,403 BBtu in 2005 to 519 BBtu in 2015. This decrease in biodiesel imports is driven by increasing in-state production as new plants began operating and consumption remained relatively stable. Biodiesel imports are expected to continue decreasing to 137 BBtu in 2050 as in-state consumption increases slightly (see Table 14).

Table 14: Net Imports of Renewable and Alternative Fuels by Fuel Type (BBtu)

Fuel Type	2000	2005	2015	2018	2020	2025	2030	2050	Change from 2005 to 2050
Landfill Gas Methane	-	-	-	-	-	-	-	-	N/A
Biodiesel	3,338	2,403	519	274	238	235	48	137	-94%
Ethanol	1,107	4,741	29,441	29,240	31,230	33,238	32,566	56,653	1095%
Total	**4,445**	**7,144**	**29,959**	**29,514**	**31,469**	**33,473**	**32,614**	**56,790**	**695%**

3. Energy Resource Potential Opportunities

This section provides an assessment of technical and economic energy resource potential estimates in Pennsylvania by energy resource type for the 2016-2050 period, using 2015 as the most recent year for historical data. This assessment builds on and takes into account the BAU Energy Assessment and gives readers the ability to do first-order comparisons of potential estimates among resources. The resource potential estimates are based on available information compiled in a data source and literature review.

Definition of Key Terms

Technical potential is the "time-dimensionless" amount of the energy resource that could be realized with known technologies and practices regardless of economic constraints or market barriers.

Economic potential is a subset of technical potential, defined as the maximum amount of the energy resource that could be developed under projected economic conditions, in both a "time-dimensionless" and annualized manner.

The annualized results presented in this section represent a time-series of economic potential from 2016 through 2050. Depending on the resource, the annualized results either come directly from the source data, or are estimated based on resource-specific methods described in Table 15 and the subsections below. Because the Analysis Team assessed each resource independently, the energy resource potentials are not necessarily additive since the economic conditions for reaching a given resource potential may differ. While only one annualized and time-dimensionless potential estimate for each resource is provided, the Sources and Methodology sections in Section 3 provide assumptions and other context behind the technical and economic potentials, and benchmark estimates when possible.

Time-dimensionless economic and technical potentials are also characterized differently depending on whether a fuel production resource, an electricity resource, or a demand-side resource is being assessed:

- **For fuel production resources**, the Analysis Team typically characterized time-dimensionless potential by the total amount "in the ground" that could be technically or economically extracted, regardless of time.
- **For electricity generation resources**, where technical and economic potential were practical to quantify, the Analysis Team typically characterized potential in annual generation or capacity terms, because electricity is not a long-term storable commodity like fossil fuels.
- **For demand-side resources** (energy efficiency and energy conservation), the Analysis Team characterized economic and technical potentials as the annualized consumption savings, because efficiency and conservation are not storable commodities.

For these reasons, the time-dimensionless technical and economic potential of electricity and demand-side resources may appear similar in magnitude to their annualized values, while the values for time-dimensionless fuel production potential appear much higher than any annualized production estimate.

Given the data limitations on certain resources, and because there are a variety of ways to characterize resource potential based on resource characteristics, time-based characteristics, and the type of potential, Table 15 summarizes how the Analysis Team characterized resource potential for each resource type. This information can help readers properly interpret and apply the resource potential results. In some instances, the Analysis Team did not estimate potentials. These cases are noted in Table 15 and described further in the subsections below.

Table 15: Description of Types of Potential Presented in this Report by Resource Type

Resource Type	Time-Dimensionless Technical and Economic Potential	Annualized Economic Potential
Energy Efficiency	Based on maximum values from a meta-analysis of multiple potential studies; technical represents the maximum annual technical potential value; economic represents the maximum annual economic potential value across the 2016-2050 time-series	Cumulative annual savings using a 10-year (buildings) to 12-year (vehicles) measure lifetime to carry forward incremental savings
Energy Conservation	Technical represents the most aggressive technical potential value in a given year based on ACEEE data; economic represents the greatest annual economic potential value across the 2016-2050 time-series	Cumulative annual savings using a 5-year (residential) or 10-year (commercial and industrial) measure lifetime to carry forward incremental savings
Fossil Fuel Production – Coal, Natural Gas, Crude Oil, Propane	Technically recoverable resource base established using Energy Information Agency (EIA) data; economic potential established by taking production from maximum price from supply curves	Annual production using most aggressive EIA forecast scenario
Fossil Fuel Production – Waste Coal	Technical represents current resource base plus expected coal refuse additions from coal mining through 2050; economic represents the sum of annual potential across the 2016–2050 time-series	Equated to potential fuel use for waste coal electricity generation
Fossil Fuel Production – Coal Mine Methane	Technical based on current and potential projects identified in Pennsylvania; economic represents the sum of annual potential across the 2016–2050 time-series	Based on historical coal mine methane production and projected coal production
Renewable and Alternative Fuel Electricity Generation – Solar and Wind	Technical and economic based on National Renewable Energy Laboratory (NREL) potential, and Nature Conservancy sources	Based on interpolation between historical 2015 generation values and time-dimensionless economic potential being met by 2050
Renewable and Alternative Fuel Production – Biogas	Technical and economic based on annual potential from current and potential projects identified in Pennsylvania	Based on historical production and potential projects identified in Pennsylvania

Resource Type	Time-Dimensionless Technical and Economic Potential	Annualized Economic Potential
Renewable and Alternative Fuel Production – Biofuels	Economic based on taking the highest annual value of Department of Energy (DOE) forecast scenarios for feedstocks; technical not estimated	Based on economically available feedstocks for each year from DOE forecast scenarios
Renewable and Alternative Fuel Production – Biomass Solids – Low-Use Wood	Technical based on overall wood on timberland; economic represents the sum of potential across the 2016–2050 time-series	Based on sustainable yield of low-use wood on timberland
Fossil Fuel Electricity Generation – Coal and Natural Gas	Not estimated due to regional market for sourcing these fuels for generation; technical potential for these resources is the entire Pennsylvania generating fleet, which is detailed in the BAU assessment	Annual generation from most aggressive EIA forecast scenario
Fossil Fuel Electricity Generation – Waste Coal	Technical not estimated; economic represents existing plants running at average historical capacity factor rates for 1 year	Annual generation based on existing plants running at average historical capacity factor rates
Renewable and Alternative Fuel Electricity Generation – Hydro	Technical based on NREL report and listed as an annual value; economic based on most aggressive EIA forecast scenario	Annual generation from most aggressive EIA forecast scenario
Nuclear Electricity Generation	Not estimated, as technical potential is theoretically the entire generation capacity, and BAU projections capture known economic potential based on regional market factors	Annual generation from most aggressive EIA forecast scenario

This energy resource potential assessment will help policy makers, citizens, businesses, and other stakeholders gain a comprehensive grasp of the energy resource potentials that could be available to the Commonwealth and can help guide policy and action decisions in the context of a statewide energy plan, Climate Action Plan updates, or for other purposes. It is organized into six subsections:

1. Overview of Resource Potential by Resource Type
2. Energy Conservation
3. Energy Efficiency
4. Energy Production
5. Electricity Generation
6. Enabling Technologies

The first section provides a high-level overview of total resource potential by resource type and compares resource potential to BAU numbers. Each of the following sections describes the methodology, sources, and assumptions used by the Analysis Team, and summarizes key results. The Analysis Team calculated potential estimates for the period 2016–2050, and generally presents trends starting with 2018 as the current year. Where feasible, the Analysis Team developed estimates of greenhouse gas (GHG) and criteria air pollutant emissions associated with potential estimates.

Appendix B provides detailed technical and economic potential data, as well as emissions data. Appendix C provides supply curves generated by the Analysis Team for this analysis.

3.1. Overview of Resource Potential by Resource Type

The energy resource potential analysis reveals major potential across the spectrum of demand and supply options, including energy efficiency and conservation as well as fossil fuel and renewable resources. Pennsylvania's energy resource choices will have significant implications for GHG and criteria air pollutant emissions. To the extent that lower-emission energy resources displace higher-emission resources, the Commonwealth could continue to grow its energy economy while reducing its emissions footprint.

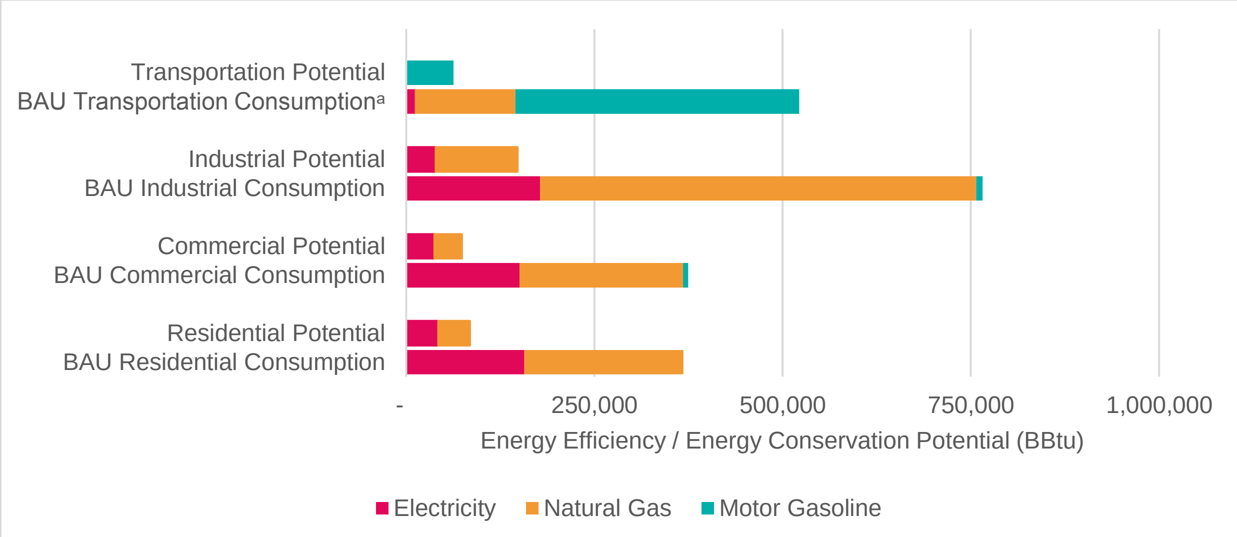
In 2015, Pennsylvania had already reduced its GHG emissions 12 percent as compared to 2005 emissions levels. Based on actions already in progress and low emissions resources in use, GHG emissions are expected to continue to decrease 16 percent by 2025. A rough calculation using the results presented in Section 3 indicates that real resource potential opportunities in the form of renewable and alternative fuels and power generating resources, as well as demand-side energy conservation and energy efficiency resources, exist for the Commonwealth and could further reduce GHG emissions to an estimated 30 percent below 2005 levels by 2025.

3.1.1 Energy Conservation and Energy Efficiency Potential

On the demand side of Pennsylvania's energy markets, Figure 19 shows the economic potential for energy conservation and energy efficiency within the Commonwealth to reduce electricity demand, natural gas consumption, and motor gasoline consumption and compares this potential to projected 2050 BAU consumption of these resources. (Note that energy conservation and energy efficiency are also included in the summary graphs below).

Energy efficiency and energy conservation show significant economic potential to offset both electricity and natural gas demand in the residential, commercial, and industrial sectors. The efficiency of electric motors is also a factor in the potential to accelerate the transition from internal combustion to electric vehicles in the transportation sector. While demand-side resource potential represents a smaller fraction of total projected BAU consumption than the potential of supply-side resources, the cost-effectiveness of demand-side resources continues to make them a priority. In addition, it is important to note that the estimates in this report are based on economic potential rather than achievable potential. Achievable potential, defined as the subset of economic potential that can be achieved in specific markets and timeframes with the constraints of market barriers, is typically lower than economic potential estimates. Achievable potential becomes more of an applicable concern when developing specific policy and program scenarios, such as analyses that support Climate Action Plan updates.

Figure 19: Energy Efficiency and Energy Conservation Potential in 2050 Compared to BAU Sectoral Fuel Consumption

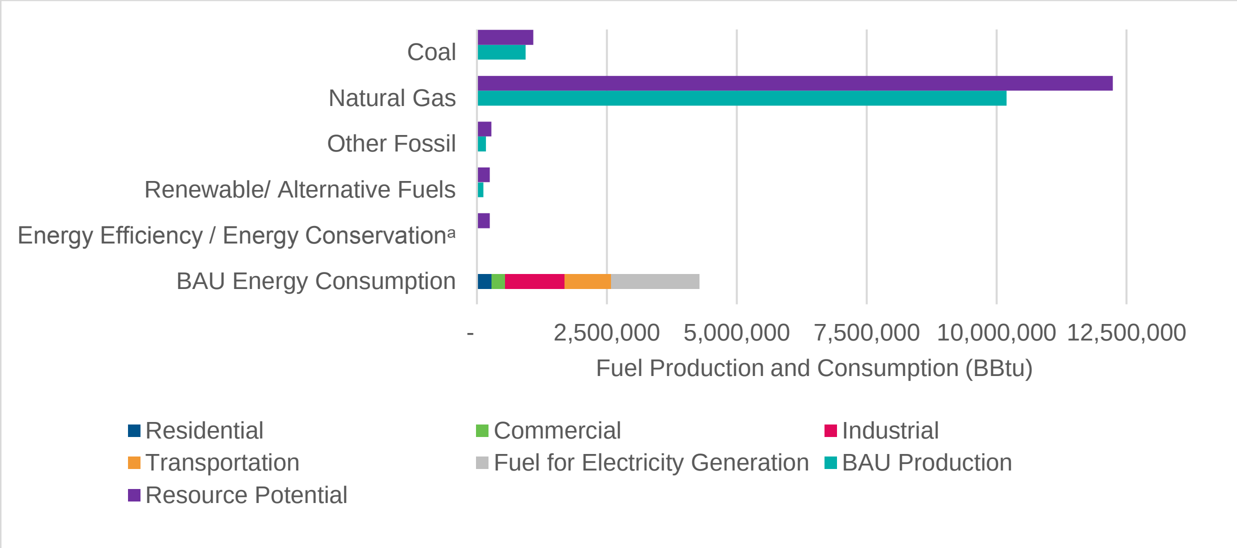


[a] Data sources used for BAU transportation-related natural gas consumption include natural gas consumed in pipeline operations (primarily in compressors) and for distribution use, and natural gas consumed as vehicle fuel.

3.1.2 In-State Fuel Production Potential

On the supply-side, the Commonwealth has significant long-term potential for resource production from fossil fuels, renewable and alternative energy resources, and energy conservation and energy efficiency. Figure 20 compares the 2050 economic potential for major fuel categories against projected 2050 BAU production levels to show the incremental increase in production compared to BAU levels. It shows that all resources have greater economic potential in 2050 than projected production levels in 2050. The figure also compares these resources against the projected 2050 BAU fuel consumption by sector and shows that the economic potential for resource production in Pennsylvania far outweighs the Commonwealth's projected energy needs.

Figure 20: Energy Production Economic Potential Compared to BAU Production and Consumption for 2050[a]



[a] Direct fuel consumption savings of natural gas and motor gasoline from energy efficiency and energy conservation are included as a resource in this figure to compare against other fuel resources and direct fuel consumption within the state.

The following two figures (Figure 21 and Figure 22) show the economic potential of fossil and renewable fuel production compared to the projected BAU consumption of those fuels. While some of the fuels shown are part of a regional market (e.g., natural gas, coal, ethanol) and therefore can be imported into the state and exported out of the state, these charts give an idea of whether the Commonwealth can be self-sufficient in certain fuels.

Figure 21 shows that the annual economic potential in 2050 for natural gas production is over three times the projected 2050 BAU in-state demand for natural gas, while coal also has the potential to supply more than the entire projected 2050 BAU demand for coal. Other fossil fuel production potential, which includes crude oil, propane, and coal mine methane, is limited compared to projected BAU demand, indicating the Commonwealth will still need to rely on out-of-state crude oil production to meet its petroleum product needs if shifts are not made to change the energy trajectory. For example, policy options that address reduced travel demand or alternative fuel vehicles could be considered to reduce consumption of motor gasoline for the transportation sector.

Economic potential for renewable and alternative fuel production is smaller than potential for fossil fuel production, but still is projected to make an impact on the state resource mix (see Figure 22). Low-use wood[25] from the Commonwealth's timberlands has the greatest economic potential to be developed, followed by corn ethanol, cellulosic ethanol, and landfill methane.

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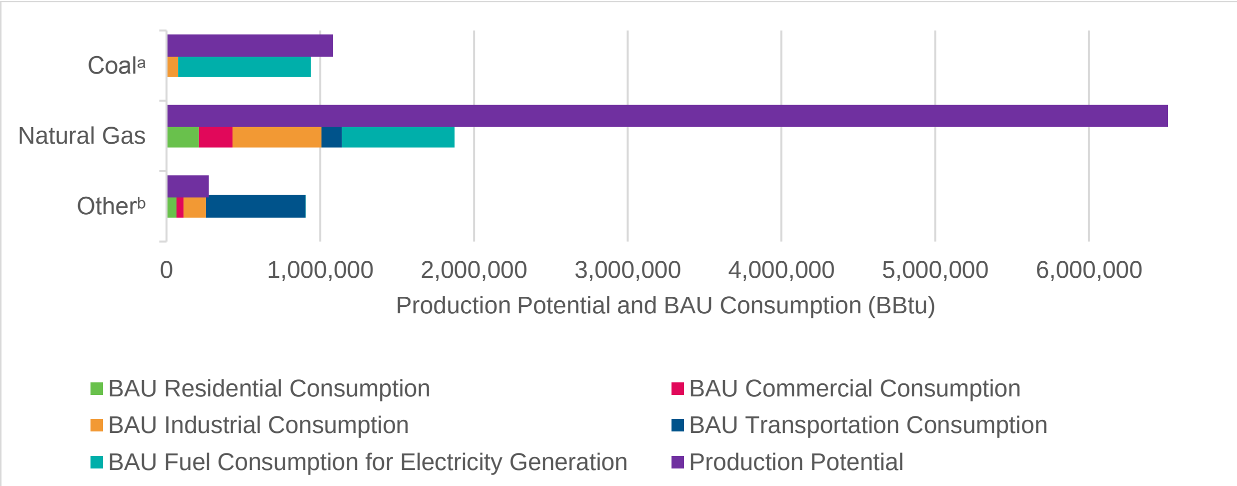
[25] For this assessment, low-use wood is defined as all trees greater than one inch in diameter.

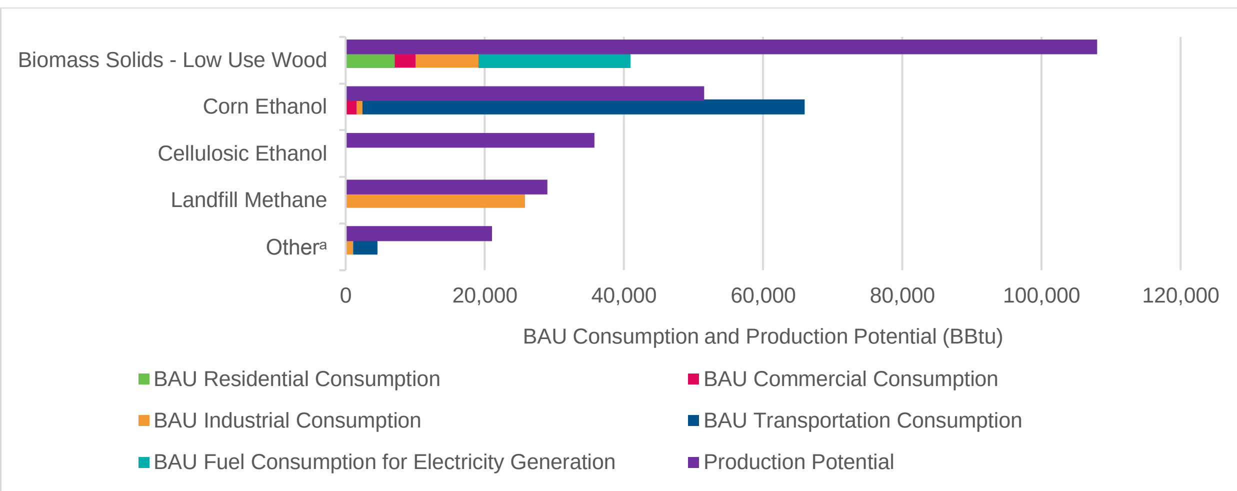
Figure 21: Fossil Fuel Economic Production Potential in 2050 Compared to BAU Fossil Fuel Consumption



[a] Includes coal and waste coal production.

[b] "Other" includes crude oil, propane, and coal mine methane. Because crude oil is refined and then consumed, BAU crude oil consumption within the other category is represented by in-state petroleum product consumption. Much of the Commonwealth's crude oil and propane comes from out of state, which is why BAU consumption in the "Other" category is higher than production.

Figure 22: Renewable and Alternative Fuel Economic Production Potential in 2050 Compared to BAU Renewable and Alternative Fuel Consumption

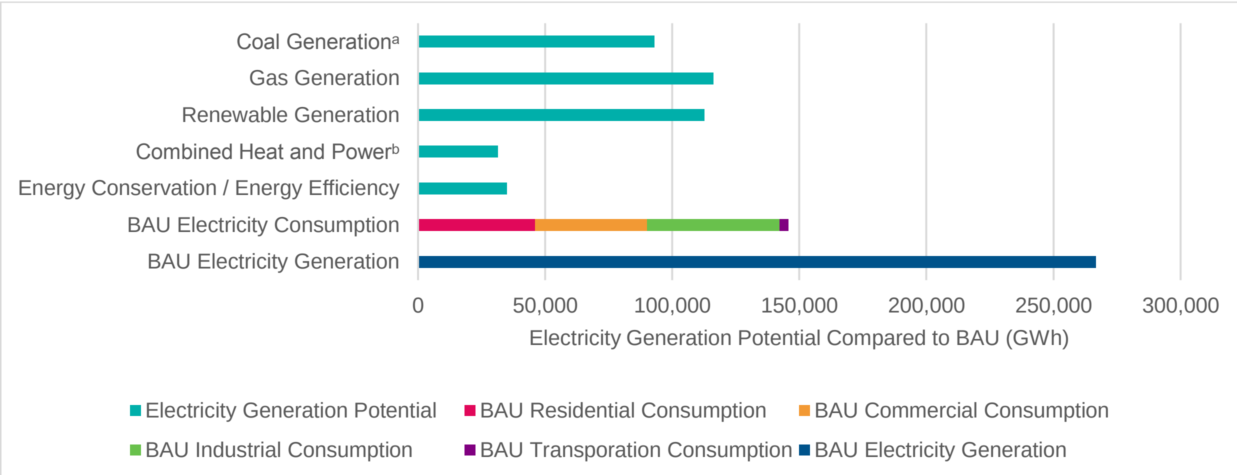


[a] "Other" includes wastewater digesters, agricultural waste digesters, and biodiesel.

3.1.3 In-State Electricity Generation Potential

The power sector could be transformed substantially as the projected reductions in nuclear and coal generation make way for increased use of natural gas, renewables, and CHP resources, all of which show the potential to play a more significant role in the grid mix by 2050. Figure 23 shows the economic potential for in-state electricity generation from major sources compared to both projected 2050 BAU electricity consumption (by sector) and projected 2050 BAU electricity generation. Natural gas and renewables each show the potential to serve almost all of Pennsylvania's own electricity consumption demands.

Figure 23: Economic Potential for Electricity Generation by Fuel Type in 2050 Compared to BAU Electricity Consumption and Generation



[a] Coal generation includes coal and waste coal.

[b] Combined heat and power includes coal, gas, and renewable energy sources.

The sections that follow elaborate on the resource potential estimates by type in greater detail.

3.2. Energy Conservation

For purposes of this analysis, energy conservation includes behavioral and operational measures and programs, such changing temperature settings, turning off unused devices, reducing the operation hours for energy systems, and changing industrial process operations.

3.2.1 Sources and Methodology

Technical Potential. For energy conservation technical potential, the Analysis Team relied primarily on the most comprehensive recent technical review of energy conservation/behavior change program results, ACEEE's 2016 *Behavior Change Programs: Status & Impact* report (ACEEE 2016). Fuel-specific measure savings were derived from documented results in the study; the Analysis Team also applied documented savings from the U.S. DOE Better Plants Challenge for industrial savings (DOE 2016c). All incremental annual savings were calculated as percentages of BAU projections. A 2-year measure lifetime was applied, with measures continuously implemented each year (ACEEE 2016).

- Transportation energy conservation
    - Transportation conservation estimates were based on the EPA's 2011 analysis of emission reduction potential from travel efficiency improvements (EPA 2011). It provides 2030 and 2050 estimates of vehicle miles traveled (VMT) and emissions reductions associated with seven progressively ambitious scenarios. The most

aggressive scenario shows a 2030 VMT reduction of 3.4 percent and a 2050 reduction of 8.8 percent. The Analysis Team assumed fuel savings equal to VMT reductions as estimates of technical and economic potential.

- Residential Energy Conservation
  - An 11.8 percent savings for electric measures and 8.9 percent savings for gas measures were assumed, which are the averages of high-end savings from multiple measures analyzed by ACEEE including home energy reports, real-time feedback, competitions, and in-person messaging (ACEEE 2016). The Analysis Team only used measures with a “quality of evaluation” rating of moderate or high and assumed a 100 percent participation rate in behavioral programs.
- Commercial Energy Conservation
  - The Analysis Team assumed a 17 percent savings for electric measures, and 19 percent savings for gas measures, which are the high-end averages from multiple measures analyzed by ACEEE (ACEEE 2016), including real-time feedback, persuasive messaging, competitions, in-person messaging, and strategic energy management. The Analysis Team only pulled in measures with a “quality of evaluation” rating of moderate or high,[26] and assumed a 100 percent participation rate.
- Industrial Energy Conservation
  - The Analysis Team applied the savings seen from industrial strategic energy management programs, and assumed a 4.4 percent savings for electric measures and 15.2 percent savings for gas measures based on documented high-end savings from strategic energy management programs (ACEEE 2016). The Analysis Team assumed a 100 percent participation rate.

Economic Potential. Estimating energy conservation economic potential is not as straightforward as for technology-based measures, because conservation measures typically have little to no capital costs, and thus are often nominally cost-effective. However, it is appropriate to differentiate between higher vs. more limited estimates; in this context, technical potential is estimated at the higher end of available sources. For economic potential, the analysis relied on the same sources but took the average of mid-range savings, instead of the high-end savings used for technical potential.

- Residential Energy Conservation
  - The Analysis Team assumed a cumulative 7.2 percent savings for electric measures and 4.7 percent savings for gas measures per year, which are the low-end averages from the same measures in the residential technical potential (ACEEE 2016). The Analysis Team assumed a 5-year measure life (Cadmus 2017) and 20 percent annual participation rate, consistent with ACEEE and Analysis Team expert judgment.

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[26] Quality of evaluation is a term used in ACEEE's *Behavior Change Programs: Status and Impact* report (2016). The report notes that "quality of evaluations ranged from basic (a simple pre–post measurement of energy consumption without a control group) to very rigorous (e.g., a large, randomized control trial evaluated by a third party)." Given that more robust measurement options were available, the Analysis Team used moderate and high evaluations and omitted low from this analysis.

- Commercial Energy Conservation
    - The Analysis Team assumed a cumulative 5 percent savings for electric measures and 1 percent savings for gas measures per year, based on the low-end averages from the same measures in commercial technical potential (ACEEE 2016). These numbers align with achieved savings from the EPA Data Trends resource, which documents approximately 7 percent annual savings from commercial building benchmarking efforts by the fourth year of involvement in benchmarking programs (EPA 2016). ACEEE offered more comprehensive analysis of multiple behavioral measures, as well as consistency across all sectors. Additionally, the Analysis Team assumed a 10 percent annual participation rate and 10-year measure life, based on documented success from corporate energy management programs at companies such as Dow and IBM.
- Industrial Energy Conservation
    - The Analysis Team assumed a cumulative 2 percent savings for electric measures and a 4 percent savings for gas measures per year based on documented mid-range savings from both ACEEE and industrial participants in DOE's Better Plants Challenge (DOE 2016c). The Analysis Team assumed a 10 percent annual participation and measure life of 10 years.

3.2.2 Summary of Results

This section summarizes key trends that emerge from the assessment of energy conservation technical and economic potential, places these trends in context, and also discusses the environmental effects associated with energy conservation potential as shown in the tables in Appendix B. The summary figures and table below reveal energy conservation potential estimates and trends that have implications for Pennsylvania's energy future. Table 16 shows the annualized economic potential and time-dimensionless economic and technical potential by sector for energy conservation resources. Figure 24 shows the annualized economic potential for energy conservation resources by sector broken down by fuel type, while Figure 25 shows the annualized economic potential for energy conservation by fuel type for the full time-series.

Key Results: Energy Conservation

- The economic potential in 2050 for energy conservation across sectors is 58,395 BBtu, or 4 percent of BAU electricity and natural gas consumption.
- The residential sector shows the greatest potential for energy conservation initially, making up 1 percent of total BAU electricity and natural gas consumption in 2018. The industrial sector shows the greatest potential over the longer term, making up 2 percent of total BAU electricity and natural gas in 2050.
- The industrial sector shows the greatest technical potential for energy conservation (73,362 BBtu), which is equivalent to 4 percent of total BAU electricity and natural gas consumption in 2050.

- **Energy conservation potential is generally less than energy efficiency potential, in part due to the length of the study period.** Conservation measures tend to show short-term effects that do not necessarily grow as large over time as do the effects of efficiency measures. It is also difficult to predict behavioral effects over long time-series, even though such effects could potentially be large. Efficiency measures typically show longer lives than conservation measures; moreover, efficiency gains tend to dampen the effects of conservation measures through the "rebound effect," in which the reduced cost of an energy service tends to increase use of that service.

- **Residential conservation measures show the greatest overall conservation potential while industrial conservation measures show the largest growth potential.** Table 16 shows that residential conservation measures, estimated to have a potential of 14,329 BBtu in 2018, or 3 percent of 2018 BAU residential electricity and natural gas consumption,[27] show the greatest overall potential in the short term. This is in part because households are not typically as capable of sustained focus on energy-saving behaviors as are organizations, which have shown the ability to institute and sustain fundamental energy management practices. In keeping with this observation, industrial conservation shows the largest growth potential over the study period, growing from 6,438 BBtu in 2018 to 25,579 BBtu in 2050, based in part on the ability of industrial enterprises to measure, manage, and continuously improve energy system operations practices and sustain year-over-year gains.

Table 16: Energy Conservation Economic and Technical Potential by Sector (BBtu)

Sector	Annualized Economic Potential[a]					Economic Potential[b]	Technical Potential[b]
	2018	*2020*	*2025*	*2030*	*2050*		
Residential	**14,329**	**23,674**	**22,927**	**22,722**	**21,372**	**23,699**	**43,904**
Commercial	**3,173**	**5,333**	**10,751**	**10,836**	**11,444**	**11,669**	**55,990**
Industrial	**6,438**	**10,965**	**22,551**	**23,150**	**25,579**	**25,579**	**73,362**
Transportation	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**
Total	**23,941**	**39,972**	**56,229**	**56,708**	**58,395**	**60,946**	**173,257**
Comparison to BAU							
Total BAU Electricity and Natural Gas Consumption	**1,409,609**	**1,435,099**	**1,457,544**	**1,471,786**	**1,637,913**	**NA**	**NA**
Efficiency Potential – Percent of BAU Consumption	**2%**	**3%**	**4%**	**4%**	**4%**	**NA**	**NA**

Note: "NE" indicates that the value was not estimated.

[a] Annualized economic potential for energy conservation represents the cumulative annual savings compared to BAU energy consumption, accounting for the lifetime of energy conservation measures.

[b] Because energy efficiency is not a finite fuel stock like coal or gas, time-dimensionless potential for energy conservation is represented by the greatest annualized potential value throughout the time-series (e.g., the economic potential for the industrial sector is equivalent to the 2050 annualized value which happens to be the highest annualized value in the 2016 to 2050 time-series). Technical potential is characterized similarly to economic potential, only with more aggressive assumptions on participation rates and savings potential per customer. Time-dimensionless economic and technical potential were presented in this way to show a more relevant comparison with annual values in the BAU time-series.

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[27] Based on 2018 residential electricity and natural gas consumption of 410,790 BBtu from the BAU Energy Assessment.

Figure 24: Energy Conservation Economic Potential by Sector

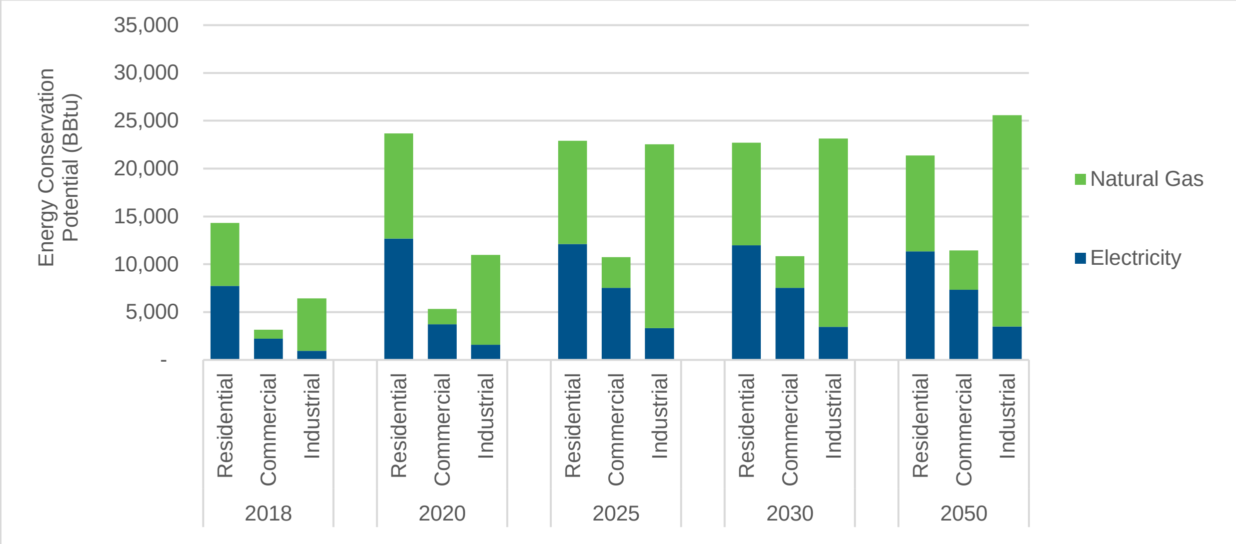
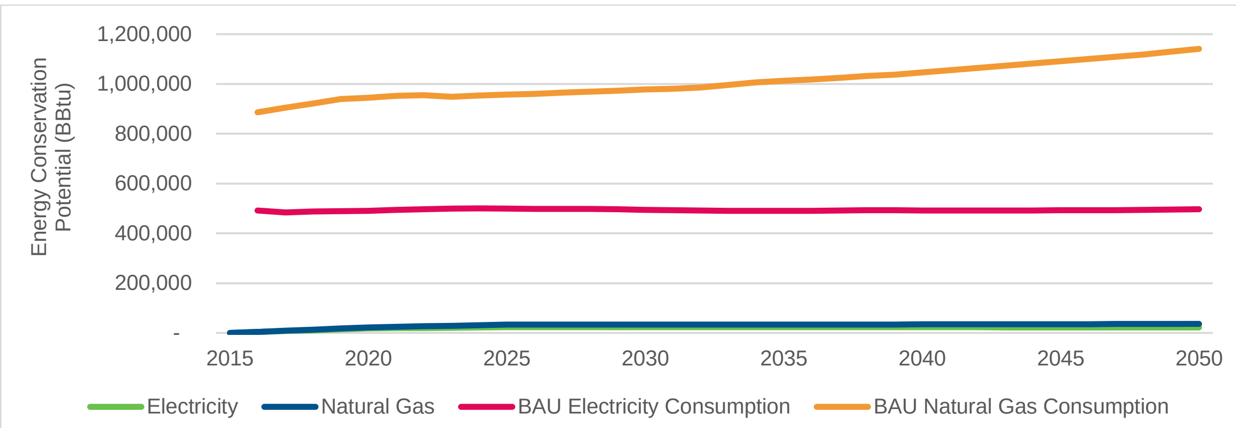


Figure 25: Energy Conservation Economic Potential by Fuel Type (BBtu)



3.3. Energy Efficiency

For the purposes of this analysis, energy efficiency encompasses technology measures commonly used in residential, commercial, transportation, and industrial end-uses such as lighting, heating, cooling, refrigeration, pumps, and motor systems. Efficiency in power generation was not separately estimated, as it was assumed that BAU numbers capture market-driven efficiencies over the study period, and because generation efficiencies are also included in the CHP analysis. Energy efficiency technical and economic potential estimates are presented in terms of potential energy savings.

3.3.1 Sources and Methodology

Technical Potential. The Analysis Team determined technical potential for energy efficiency using different methodologies for each sector (residential, commercial, industrial, transportation). For all building energy efficiency measures, the Analysis Team assumed a measure lifetime of 10 years, based on ICF's experience with weighted-average measure lifetimes in utility energy efficiency program portfolios. The measures mix was regenerated every 10 years through the study period, so that energy-using equipment stock is replaced with more efficient models through 2050.

- Residential Energy Efficiency
  - *Electricity.* Because the Act 129 potential study does not project potential past 2025, the Analysis Team used ICF's Energy Code Calculator to project maximum technical energy efficiency for the residential building stock. This approach projects potential based on all housing stock, both new and existing, attaining energy performance levels equal to progressively more stringent versions of the International Energy Conservation Code (IECC) through 2050. While the limits of code adoption and enforcement could limit realization of these savings, this approach is sufficient for estimating technical potential.
  - *Natural gas*. The Analysis Team developed a method to estimate resource potential by applying the ratio of electricity technical to economic potential from Act 129 (PA PUC 2015) to derive economic potential. Then, the Analysis Team applied the rate of change between ACEEE's and the Statewide Evaluation Team (SWE) report's 2025 gas potential figures (PA PUC 2015), to account for the more ambitious projections from ACEEE (ACEEE 2009) compared to the SWE report.
- Commercial Energy Efficiency
  - *Electricity.* Due to limitations on commercial square footage data for Pennsylvania, the Analysis Team did not use the ICF Energy Codes Calculator to estimate technical potential for electricity. Instead, the Analysis Team used the Act 129 study's projected electric technical potential through 2025 (PA PUC 2015), and then applied a 4 percent EERS, double that used for economic potential below and consistent with technical-economic ratios found in the Chandler and Brown 2009 meta study (more on EERS below).
  - *Natural gas.* The Analysis Team estimated gas savings technical potential using the same method applied for the residential sector through 2025. For post-2025, the Analysis Team applied the same method as commercial electricity using a 3 percent EERS (Chandler and Brown 2009).
- Industrial Energy Efficiency
  - *Electricity.* Electric savings technical potential was estimated using the same method applied for the commercial sector.
  - *Natural gas.* Gas savings technical potential was estimated using the same method applied for the commercial sector.
- Transportation Energy Efficiency
  - For the technical potential, the Analysis Team assumed 100 percent of gasoline-powered vehicles was displaced by phasing in electric vehicles. Other studies are also

available that provide more narrowly defined estimates of technical potential (NRDC 2016, NEEP 2017, and DOE, EPA 2011).

Economic Potential. Estimating economic potential for energy efficiency also used different sources for electricity and natural gas projections. The Analysis Team made the same measure lifetime and measure regeneration assumptions as with technical potential: 10-year lifetime and regeneration of the measure mix every 10 years through the study period. Cumulative annual savings were pulled directly from sources and interpolated for any missing years between 2016 and 2025.

Because the Act 129 potential study was a bottom-up analysis relying on current data, and was necessarily limited by constraints on the current and future avoided costs of energy and capacity—by a ten-year study period and by lack of information on the performance and cost of future efficiency technologies—the Analysis Team complemented this source with top-down estimates, based on the maximum required energy savings targets in state Energy Efficiency Resource Standard (EERS) policies. After reviewing ACEEE's state energy policy database, the Analysis Team used the new Maryland EERS target of 2 percent annual incremental savings to estimate savings as a proxy representative of economic potential; this annualized level of savings is consistent with a meta-analysis of efficiency potential studies across the United States (Chandler and Brown 2009).

- For residential, commercial, and industrial electricity economic potential, Act 129's *Statewide Evaluator Energy Efficiency Potential Study* (PA PUC 2015) was used for projections of 13,143 GWh, 6,805 GWh, and 6,997 GWh savings potential, respectively, through 2025. The Analysis Team then applied 2 percent annual incremental savings beyond 2025, cumulating over a measure lifetime of 10 years.
- For residential, commercial, and industrial gas economic potential, the Analysis Team relied on projections of 91,000 BBtu, 46,000 BBtu, and 37,000 BBtu of cost-effective energy efficiency potential, respectively, from the ACEEE study *Potential for Energy Efficiency, Demand Response, and Onsite Solar Energy in Pennsylvania* (2009). Energy savings between 2016 and 2025 were ramped up using the same annual incremental changes as used for residential electricity from the SWE report (PA PUC 2015). Beyond 2025, the Analysis Team applied 1.5 percent annual incremental savings beyond 2025, cumulating over a measure lifetime of 10 years.
- For transportation economic potential, the Analysis Team built off baseline vehicle projections from the Motor Vehicle Emission Simulator (MOVES) model, with baseline fuel consumption from the BAU Energy Assessment. The Analysis Team used NRDC's "plausibly optimistic" scenario, modeled on the Zero Emission Vehicles Memorandum of Understanding's (NRDC 2017) projections for PEV uptake: 0.9 percent on road by 2025, 5 percent by 2030, and 12 percent by 2035. Beyond 2035, the Analysis Team tied on-road growth to the "plausibly optimistic" rate of EV sales in NEEP's *Regional Assessment of Strategic Electrification* (NEEP 2017). Similar to the technical potential estimates, a 42 percent efficiency gain from gasoline internal combustion engines to PEV (DOE 2011, EPA 2011) was then assumed. Again, the Analysis Team also assumed a 12-year vehicle lifetime, and only included light-duty vehicles in these calculations as projections on heavy duty EVs are uncertain, at best.

3.3.2 Summary of Results

This section summarizes key trends that emerge from the assessment of energy efficiency technical and economic potential, places these trends in context, and also provides the environmental effects associated with energy efficiency potential where available. The summary figures and table below reveal energy efficiency potential estimates and trends that have implications for Pennsylvania's energy future. Table 17 shows the annualized economic potential and time-dimensionless economic and technical potential by sector for energy efficiency resources. Figure 26 shows the annualized economic potential for energy efficiency resources by sector broken down by fuel type, while Figure 27 shows the annualized economic potential for energy conservation by fuel type for the full time-series.

Key Results: Energy Efficiency

- The economic potential in 2050 for energy efficiency across sectors is 310,823 BBtu, or 15 percent of BAU electricity, natural gas, and motor gasoline consumption.
- The residential sector shows the greatest economic potential for energy efficiency in 2018 (4 percent of total BAU electricity, natural gas, and motor gasoline consumption). The industrial sector shows the greatest economic potential for energy efficiency in 2050 (6 percent of BAU consumption).
- The transportation sector shows the greatest technical potential for energy efficiency (551,093 BBtu), equivalent to 27 percent of total BAU electricity, natural gas, and motor gasoline consumption in 2050.

- **Overall potential estimates are large in comparison with BAU consumption.** Total economic potential for energy efficiency, represented by the highest annual potential throughout the time-series for a given sector, is shown in Table 17 and is equivalent to about 19 percent of overall 2015 electricity, natural gas, and motor gasoline consumption.[28]
- **Residential potential shows the greatest near-term efficiency potential, with industrial showing the greatest long-term efficiency potential.[29]** Driven mostly by estimates from the Act 129 study (PA PUC 2015), residential savings peak at 107,766 BBtu by 2025 and then decline somewhat, as the methodology takes a relatively conservative approach to estimating longer-term incremental savings. In the industrial sector, the expectation is that technology advances, process redesign, and company-wide strategic energy management programs will drive total efficiency gains beyond other sectors over the long term to 122,405 BBtu in 2050. In the transportation sector, electrification of passenger and fleet vehicles drives efficiency gains based on the relative efficiency of electric-drive compared to internal combustion technology. These efficiencies show up most strongly toward the end of the study period, as EV sales and infrastructure expansion drive significant market transformation.

[28] This value excludes natural gas consumption for electricity generation and is based on consumption of 1,938,945 BBtu from 2015 in the BAU Energy Assessment.

[29] The Analysis Team did not evaluate diesel fuel because projections on heavy duty EVs are very uncertain. While some EV trucks are currently being manufactured, there are none on the road. An electric bus option is currently available for purchase but at a significant markup that does not make it cost-competitive with traditional diesel buses.

- **By 2050, all sectors are showing significant potential emissions reductions compared to BAU.** The residential sector accounts for about 62 percent of total $MtCO_2e$ potential GHG reductions relative to BAU from energy efficiency across all sectors in 2018. By 2050, the industrial sector still shows the greatest potential (37 percent) but the residential (23 percent), commercial (23 percent), and transportation sectors (18 percent) all show the potential to drive significant emissions reductions. If the power sector's emissions intensity declines, potential GHG and criteria air pollutant emissions reductions from the electrification of the transportation sector would be even larger.

Table 17: Energy Efficiency Economic and Technical Potential by Sector (BBtu)

Sector	Annualized Economic Potential[a]					Economic Potential[b]	Technical Potential[b]
	2018	*2020*	*2025*	*2030*	*2050*		
Residential	71,932	78,400	107,766	64,164	63,057	107,766	203,856
Commercial	26,955	41,479	69,205	55,689	62,658	76,114	104,268
Industrial	19,475	31,430	60,860	82,044	122,405	122,405	244,810
Transportation	944	991	1,096	5,897	62,703	62,703	551,093
Total	**119,306**	**152,300**	**238,927**	**207,795**	**310,823**	**368,987**	**1,104,027**
Comparison to BAU							
Total BAU Electricity, Natural Gas, and Motor Gasoline Consumption	1,965,107	1,968,652	1,930,527	1,895,326	2,030,343	NA	NA
Conservation Potential – Percent of BAU Consumption	6%	8%	12%	11%	15%	NA	NA

[a] Annualized economic potential for energy efficiency represents the cumulative annual savings compared to BAU energy consumption, accounting for the lifetime of energy efficiency measures. See Section 3.2.1 for more detail.

[b] Because energy efficiency is not a finite fuel stock like coal or gas, time-dimensionless potential for energy efficiency is represented by the greatest annualized potential value within the time-series (e.g., the economic potential for the residential sector is equivalent to the 2025 annualized value which happens to be the highest annualized value in the 2016 to 2050 time-series). Technical potential is characterized similarly to economic potential, only with more aggressive assumptions on participation rates and savings potential per customer. Time-dimensionless economic and technical potential were presented in this way to show a more relevant comparison with annual values in the BAU time-series.

Figure 26: Energy Efficiency Economic Potential by Sector (BBtu)

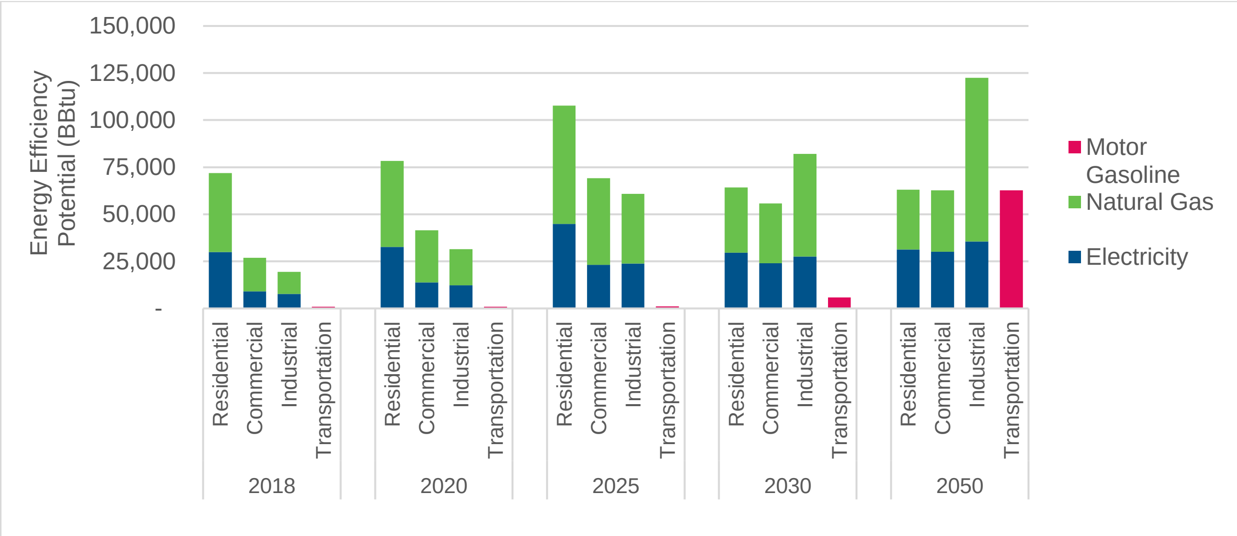
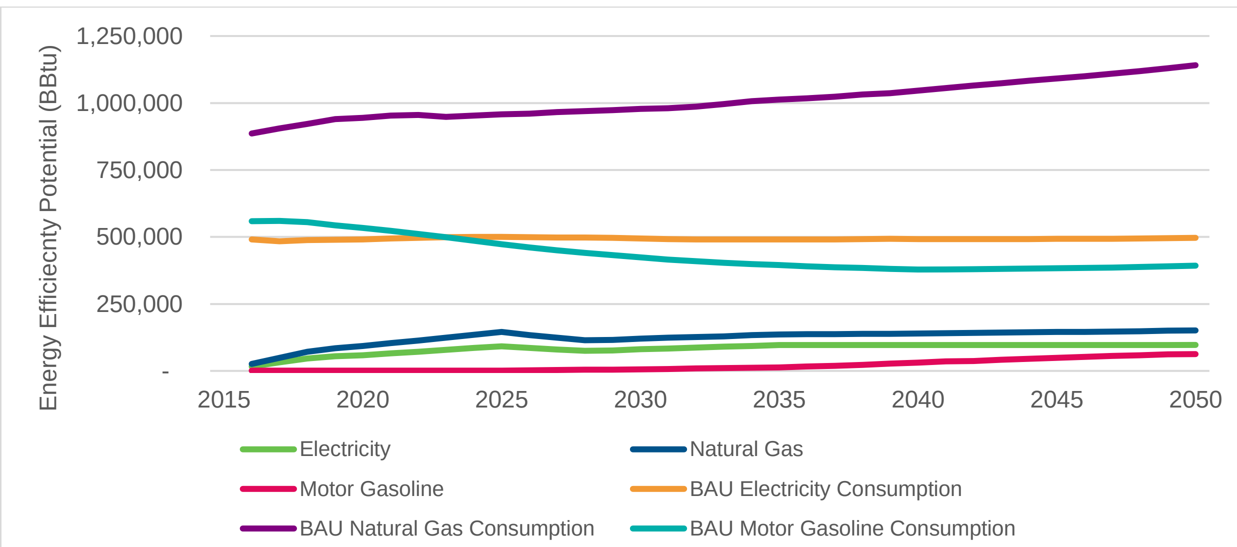


Figure 27: Energy Efficiency Economic Potential by Fuel Type (BBtu)



3.4. Energy Production

3.4.1 Sources and Methodology

The sections below present the Analysis Team's approach and sources for determining technical and economic potential for energy production in the Commonwealth of Pennsylvania.

Fossil Fuels

The fossil fuels the Analysis Team assessed for this report include natural gas, coal, waste coal, coal mine methane, crude oil, and propane.

Energy resource potential from coal, natural gas, crude oil, and propane. The technical potential was first determined by establishing a "technically recoverable resource" base (see Table 18). This is defined as the volume that is technically recoverable using existing technology without regard for economic feasibility. This quantity is considered "time-dimensionless," given that this volume represents what is currently recoverable regardless of energy market price. Technical potential estimates for each resource were determined using the following data sources:

- For coal, the Analysis Team relied on recoverable coal reserve data published by the Energy Information Administration, which is available by state (EIA 2017e). The estimated recoverable reserves volume is used here as it does not consider any specific economic feasibilities, but does exclude coal inherently unavailable due to land use.
- For natural gas and crude oil, the Analysis Team relied on the "Technically Recoverable Resource" volume published in the 2017 EIA Annual Energy Outlook (AEO) documentation where proven and unproven reserve volumes are provided at the regional level (EIA 2017a). For Pennsylvania-specific information, the Analysis Team considered the East region and allocated volumes per expert judgment based on what amount of each play is found within Pennsylvania. EIA also provides an estimated proven reserves volume of natural gas plant liquids, of which approximately 33 percent was considered propane (EIA 2018) with the remainder being hydrocarbons such as ethane, butane, and isobutane, which have other typical usages such as plastic products or refrigerants. To determine unproven reserves of natural gas plant liquids, the Analysis Team relied on a ratio of proven and unproven reserves of natural gas.

Table 18: Resource Bases established for Coal, Crude Oil, Natural Gas, and Natural Gas Plant Liquids

Coal Reserves (MM short tons)	
	Total
Pennsylvania:	10,350

Natural Gas Plant Liquids (billion barrels)			
	Proved	Unproved	Total
East Region	2.42	12.90	15.32
Pennsylvania	0.57	2.79	3.36
PA as % of East	*23.4%*	*21.7%*	*21.9%*
Note: Propane is approximately 33% of NGPL production in PA.			

Crude Oil & Lease Condensate (billion barrels)			
	Proved	Unproved	Total
East Region	0.60	4.80	5.40
Pennsylvania	0.10	0.72	0.82
PA as % of East	*17.0%*	*15.0%*	*15.2%*

Natural Gas (Tcf)			
	Proved	Unproved	Total
East Region			
Tight Gas	1.2	54.0	55.2
Shale and Tight Oil	92.6	450.4	543.0
Coalbed Methane	2.5	3.7	6.2
Other	6.3	29.4	35.7
All Natural Gas	102.6	537.5	640.1
Pennsylvania			
Tight Gas	0.4	17.8	18.2
Shale and Tight Oil	56.6	238.7	295.3
Coalbed Methane	0.2	0.5	0.7
Other	2.0	9.2	11.2
All Natural Gas	59.2	266.2	325.4
Pennsylvania as % of East			
Tight Gas	*31.0%*	*33.0%*	*33.0%*
Shale and Tight Oil	*61.1%*	*53.0%*	*54.4%*
Coalbed Methane	*8.5%*	*13.0%*	*11.2%*
Other	*32.0%*	*31.2%*	*31.3%*
All Natural Gas	*57.7%*	*49.5%*	*50.8%*

With resource bases determined, the Analysis Team then considered Pennsylvania-specific supply curves to determine economic potential estimates for each fossil fuel resource. These curves represent a "time-dimensionless" quantity of a particular resource base that is recoverable and economically feasible as a function of a particular market price. The economic potential is the maximum recoverable amount of the resource that is economically feasible, and is represented by the highest price expected between now and 2050. Supply curves were generated for each resource as follows:

- For coal, the Analysis Team utilized the EPA Pennsylvania-specific coal supply curve generated for use in the Integrated Planning Model (IPM) (EPA 2013).[30] This curve was developed using a detailed and comprehensive bottom-up approach based on resource base geological data and economic feasibilities. Because the EPA coal supply curve resource base did not match the estimated recoverable reserves volume from EIA in Pennsylvania for 2016, the curve was adjusted to match the EIA control total.
- For oil, natural gas, and propane, the Analysis Team generated its own supply curves. These curves were developed using an ICF-specific model that aggregates various data sources into recoverable resources and associated supply costs at a U.S. level. The resources considered include proven and unproven reserves, new fields, and growth while supply costs were determined by assessing factors such as the cost of discovering and developing new fields, further exploration, and the cost of extraction including well drilling, completion, and operation. The Analysis Team scaled these generated supply curves to match EIA volumes of crude oil, natural gas, and natural gas plant liquids for the Pennsylvania resource base developed above.

The supply curves generated are included in Appendix C.

Additionally, for each resource, the Analysis Team considered the AEO quantities used to project BAU Energy Assessment results in future years (EIA 2017a). For each quantity, the Analysis Team reviewed each AEO side case to provide both the overall maximum price of each resource expected between now and 2050 for consideration in the economic potential and for an annualized maximum production potential. The AEO side cases vary by underlying assumptions driving the calculations in the model. The side cases considered here include:

- **High/Low Oil and Gas Resource and Technology**: Underlying assumptions are changed based on the amount of future technology available. This change affects cost and resource availabilities, with the high and low cases representing optimistic and pessimistic outcomes respectively.
- **High/Low Oil Price**: Underlying assumptions are changed to represent the market where oil prices are highest or lowest respectively, causing impact on all resources.
- **High/Low Economic Growth**: Underlying assumptions are changed to represent a market with optimistic or pessimistic views on factors influencing economic growth.

One consideration is that in order to measure the increased supply of a resource under alternative pricing assumptions, the two AEO cases must be compared that use the same supply curve for that

[30] The IPM is an ICF proprietary model that provides true integration of wholesale power, system reliability, environmental constraints, fuel choice, transmission, capacity expansion, and all key operational elements of generators on the power grid in a linear optimization framework.

resource. Comparing the AEO cases allows the price elasticity of supply to be estimated (movement along the supply curve). This cannot be done if the supply curve is changing between the two cases (e.g., due to different assumptions about resource endowment or supply technologies). Because the AEO's High and Low Economic Growth cases only change demand-side assumptions, they can be used to estimate the supply response of all energy resources to higher/lower prices. One can also use the High and Low Oil and Gas Resource cases to estimate the supply response to non-oil/gas energy resources to higher/lower prices.

Given this, the highest overall price was first determined using relevant AEO side cases and was considered in conjunction with each resource's generated supply curve to determine economic potential. The case that presented the highest average production volumes from 2030 through 2039 was considered to have the highest production potential, as this timeframe would allow for assumptions reflected within each case to take effect. After determining the case with the maximum production potential, each BAU result was projected forward using both the AEO reference case and the identified case value with the highest production potential and a "differential" was determined for each future year. By applying this differential to BAU results, an annualized maximum production potential was determined.

Energy resource potential from coal mine methane and waste coal. Coal mine methane information was available from EPA's Coalbed Methane Outreach Program (CMOP). To determine technical potential, the Analysis Team assumed the continued operation of current projects as well as the addition of candidate projects identified by CMOP. The major driver for coal mine methane market share in the natural gas market was assumed to be the number of coal mines operating and projected natural gas prices in Pennsylvania. Given this assumption, the Analysis Team estimated economic potential to be the product of coal mine methane produced in the 2015 base year (the last historical year of data available for the BAU), the ratio of coal produced in forecast years compared to base years, the percent change in natural gas prices between forecast years and base years, and a constant supply elasticity. This calculation is illustrated in the formula below. Natural gas prices from the AEO Low Oil and Gas Resource and Technology scenario for the East region and projected coal production from the BAU were used for these calculations (EIA 2017a).

Coal Mine Methane (CMM)(y) = CMM(b) * [CoalProd(y)/CoalProd(b)] * [NGPrice(y) – NGPrice(b) / NGPrice(b) * 0.5]

Where:
CMM(y) = amount of coal mine methane produced in the forecast year y
CMM(b) = amount of coal mine methane produced in the base year b
CoalProd(y) = amount of coal produced in the forecast year y
CoalProd(b) = amount of coal produced in the base year b
NGPrice(y) = price of natural gas in the forecast year y
NGPrice(b) = price of natural gas in the forecast year b
0.5 = constant supply elasticity

For waste coal, the Analysis Team assumed that there would be no additional waste coal capacity built through 2050 (Ellis 2018). An average historical capacity factor based on 2000–2015 data (EIA 2017a) was applied to existing 2015 capacity to determine the economic potential for fuel production through 2050, with waste coal production assumed to be equal to fuel required for electricity generation. The historical ratio of waste coal to total coal production was used to estimate future waste coal production based on projected total coal production through 2050 (DEP 2015). This production was added to the 290 million tons of coal refuse that is estimated to be in the Commonwealth currently to determine total technical production potential (Econsult Solutions 2017).

Renewable and Alternative Fuels

The Analysis Team focused on a range of renewable and alternative fuels for this resource potential analysis, including landfill methane, wastewater methane, agricultural waste, biodiesel, solid biomass – low-use wood, and ethanol (corn and cellulosic).

Energy resource potential from biogas, including agricultural digesters, waste water digesters, and landfill methane gas. The Analysis Team relied on a mix of sources and methods to estimate the resource potential from biogas.

Agricultural digesters: To estimate the total technical potential of agricultural waste digesters, the Analysis Team used state-level data on cow and pig livestock populations from the U.S. Department of Agriculture's 2012 Census of Agriculture (USDA 2012). Estimates of the expected system size that waste from these animals can support were used to identify total capacity (Jones and Lamar 2015). This estimated capacity was then used to calculate total production based on assumptions from Oak Ridge National Laboratory's *Combined Heat and Power Market Potential for Opportunity Fuels* report (Jones and Lamar 2015). To estimate economic potential, the Analysis Team took the technical potential and applied the following assumptions:

- There will be no growth in cow and pig farms through 2050.
- Farms currently do not have anaerobic digesters installed and system installation costs are $2,000/kW (Jones and Lamar 2015).
- Siloxane removal is not required for digester projects, but gas pretreatment is required at a cost of $500/kW (Jones and Lamar 2015).
- Other cost and performance assumptions mirror the Analysis Team's assumptions for natural gas CHP projects detailed in this report.
- Utility electricity and gas purchases are displaced with the same prices and escalation rates as used in the Analysis Team's natural gas CHP analysis.
- Payback periods for projects are close to 5 years, improving to under 4 years by 2050.

For annualization, 100 percent of the total economic potential is realized by 2050, with results weighted toward 2050. Assumptions from the Opportunity Fuels Report were used to estimate economic production potential based on these results (Jones and Lamar 2015).

Wastewater digesters: Data on wastewater treatment plants with existing anaerobic digesters from the Water Environment Federation database were used to estimate the total technical potential of this source, with system capacities determined from average flow rates (WEF 2015 and Jones and Lamar 2015). Given that the AEO population growth forecast for Middle Atlantic Census Division was 0 percent, current wastewater flow estimates were used for forecasted technical and economic potential through 2050 (EIA 2017a). Based on the estimated technical potential, the Analysis Team applied several assumptions to projects to determine the expected economic potential.

- Siloxane removal costs are $500/kW for >1 MW systems, $1,000/kW for 500–999 kW systems, and $1,500/kW for <500 kW systems (Jones and Lamar 2015).
- Additional pretreatment costs are $300/kW for >1 MW systems and $500/kW for <1 MW systems (Jones and Lamar 2015).
- Other cost and performance assumptions mirror the Analysis Team's assumptions for natural gas CHP projects detailed in this report.
- Utility electricity and gas purchases are displaced with the same prices and escalation rates as used in the Analysis Team's natural gas CHP analysis.
- Payback periods are close to 5 years, improving to under 4 years by 2050.

For annualization, 100 percent of the total economic potential is realized by 2050 for both <1MW systems and >1 MW systems, with results weighted toward 2050. Assumptions from the Opportunity Fuels Report were used to estimate economic production potential based on these results (Jones and Lamar 2015).

Landfill methane gas: Data on candidate sites for landfill gas were available from EPA's Landfill Methane Outreach Program (LMOP) (EPA 2018d). Reported waste in place figures in the LMOP database for each site were used to estimate total technical potential in terms of capacity, with total fuel production being derived from those results (Jones and Lamar 2015). Based on the estimated technical potential, the following assumptions were applied to candidate projects to determine the expected economic potential in terms of system capacity:

- Projects require 5 miles of pipeline at $330,000 per mile (Jones and Lamar 2015).
- $1/MMBtu is charged for access to landfill gas (Jones and Lamar 2015).
- Siloxane removal and gas pretreatment are required for CHP. Siloxane removal costs are $500/kW for >1 MW systems, $1,000/kW for 500–999 kW systems, and $1,500/kW for <500 kW systems (Jones and Lamar 2015).
- Additional pretreatment costs are $300/kW for >1 MW systems and $500/kW for <1 MW systems (Jones and Lamar 2015).
- For direct use in boilers, it is assumed that no gas cleanup is required.
- Other cost and performance assumptions that mirror the Analysis Team's assumptions for natural gas CHP projects detailed in this report. Utility electricity and gas purchases are also displaced with the same prices and escalation rates as used in the Analysis Team's natural gas CHP analysis.
- Payback periods for projects are 7.5-year payback for CHP, improving to below 5 years by 2050.

For annualization, the Analysis Team assumed 100 percent of the total economic potential is realized by 2050, with 61.1 percent for CHP and 38.9 percent for direct use. LMOP database shows project potential for landfill sites that closed up to 30 years ago. This was accounted for in the annualization calculations by assuming that landfills can start projects 30 years after closure (with 15-year project lives) and after 45 years, landfills cannot support projects. Assumptions from the Opportunity Fuels Report were used to estimate economic production potential based on these results (Jones and Lamar 2015).

Energy resource potential from biofuels including corn ethanol, cellulosic ethanol, and biodiesel. The Analysis Team relied on the DOE *Billion Ton Report* (DOE 2016a), which provides projections of economically available biomass feedstocks for a range of scenarios and farm-gate prices. For each biofuel, the Analysis Team identified the scenario, or combination of scenarios, in the database that provided the greatest quantity of potential feedstocks. The DOE feedstocks database assumes in some scenarios that additional acreage of feedstocks will be produced compared to Pennsylvania's current production levels. For example, in 2017, Pennsylvania produced 148,120,000 bushels of corn (USDA 2018), and the DOE database projects a maximum annual production of 253,757,186 bushels of corn.

For corn ethanol, the Analysis Team converted the maximum amount of economically available corn feedstocks into the amount of ethanol that can produced from those feedstocks using a factor of 2.82 gallons of ethanol per bushel of corn (DOE 2016a). The Analysis Team then calculated the energy content of the potential ethanol produced. For biodiesel (B100), the Analysis Team converted the maximum amount of economically available soybean feedstocks into the amount of biodiesel that can be produced from those feedstocks using factors of 11 pounds of soybean oil per bushel of soybeans (Irwin 2017) and 267 gallons of biodiesel per ton of soybean oil (DOE 2016a). The Analysis Team then scaled this value up by a factor of 2 to account for total biodiesel potential, because roughly 50 percent of biodiesel produced in the United States is produced from soybean oil (EIA 2017d). The remaining 50 percent of biodiesel is produced from other vegetable- and animal-based feedstocks including yellow grease, canola oil, corn oil, white grease, tallow, recycled oils, poultry fat, vegetable oil, and palm oil (DOE 2016a). The Analysis Team then calculated the energy content of the potential biodiesel produced. For cellulosic ethanol, the maximum amount of economically available switchgrass, hay, corn stover,[31] yard trimmings, hardwood residue, mixed wood residue, softwood residue, other forest residue, primary and secondary mill residue, and tree nut residue was converted into the amount of ethanol that can be produced from those feedstocks using a factor of 85 gallons of ethanol per dry ton of biomass. The Analysis Team then calculated the energy content of the potential ethanol produced.

The total economic potential was calculated as the maximum of the annual economic potential estimates from 2016 through 2050. The total technical potential for biofuels was not estimated.

Energy resource potential from biomass solids – low-use wood. There is a range of estimates for biomass resource potential within the Commonwealth. The Analysis Team decided to use estimates from the Pennsylvania Department of Conservation and Natural Resources (DCNR) due to its well-documented methodology (PA DCNR n.d.). The DCNR report states that out of the 1,145.8 million green tons of wood biomass on Pennsylvania timberland, 657.8 million tons are classified as low-use wood, meaning all trees greater than one inch in diameter have low economic value. Further considerations such as slope of the land and density of tree stands refine this number down to 468.7 million green tons. Using a growth rate of 2.5 percent and a conversion factor of 0.5 to convert green tons to dry tons, the DCNR report estimates that 6 million dry tons would be available to harvest annually in a sustained yield over time, although this estimate does not consider further constraints such as social considerations,

[31] Corn stover is the stalks, leaves and cobs that remain in fields after the corn harvest

environmental protections, and a change in the regeneration rate of forests over time (PA DCNR n.d.). Therefore, for the purpose of this report, the Analysis Team used 1,145.8 million green tons (572.9 million dry tons) as the technical potential, and 6 million dry tons annually as the economic potential (or 210 million dry tons cumulatively from 2016 through 2050).[32] This estimate is about two to three times the amount of historical annual biomass consumption from forests, estimated at between 2.15 to 2.4 million dry tons (Pennsylvania State Wood Energy Team 2016, Partnership for Public Integrity 2012).[33]

The estimates of annual sustained yield are comparable to other studies, such as the Pennsylvania Wood Energy Prospectus, which estimates 8 million dry tons are available for harvest for energy after protected and inaccessible land is removed and wood for timber, paper, and other markets is removed (Pennsylvania State Wood Energy Team 2016). The Analysis Team limited the scope of reported values of biomass for energy consumption to low-use wood from forests, however additional sources of biomass exist within the state, including biomass from mill residues, agricultural residues, energy crops, and urban wood. A 2012 report estimates that wood generated in urban locations (primarily from construction and demolition sources) has the economic potential to supply between 0.4 and 0.7 million dry tons of wood each year, although these estimates may overestimate the amount of wood that is non-contaminated and in a suitable state for burning (Partnership for Public Integrity 2012).

3.4.2 Summary of Results

This section summarizes key trends that emerge from the assessment of energy production technical and economic potential, places these trends in context, and also discusses the climate effects and economic factors associated with energy production potential where available. The summary figures and tables below reveal energy production potential estimates and trends that have implications for Pennsylvania's energy future.

- **Fossil fuels within Pennsylvania's borders, particularly natural gas, hold enormous potential.** Table 19 and Figure 28 show that in terms of raw British thermal unit (Btu) potential, Pennsylvania has more than enough fossil energy resources within its

Key Results: Energy Production

- The Commonwealth has enough energy production economic potential to exceed projected BAU statewide energy demand by 101 percent in 2020 and by 226 percent in 2050.
- Energy production potential is led by natural gas, which accounts for 81 percent of annualized economic potential in 2020 and 88 percent in 2050.
- Renewable and alternative fuels have the economic potential to make up 4 percent of projected BAU statewide energy demand by 2020 and 6 percent by 2050.

[32] This estimate is also in line with the 2009 *Pennsylvania Climate Action Plan*, which references a range of 3 to 6 million dry tons of biomass availability from the same low-use wood study (Pennsylvania Department of Environmental Protection 2009).

[33] These historical estimates and the sustained yield estimate are not comparable to the Wood and Biogenic Waste estimates in the BAU Energy Assessment report because the Wood and Biogenic Waste category includes fuel sources beyond low-use wood from forests.

borders to supply all of its energy needs. Due primarily to shale gas development, by 2015, the Commonwealth was already producing more fossil fuels than its total energy consumption; by 2050, the economic potential of 13,594,508 BBtu exists to serve more than three times projected BAU consumption from the BAU Energy Assessment. The Commonwealth's total economic fossil fuel potential is estimated at more than 100 times annual consumption levels.

- **Significant emissions are embedded within the Commonwealth's fossil fuel reserves.** The large-scale extraction of fossil energy resources presents environmental risks along with energy and economic benefits. Environmental impacts could be significant if fossil resources are fully developed (see Table 20: Energy Production Potential for Fossil Fuels by Fuel Type and Figure 29 and Figure 30). For instance, GHG emissions tied to total natural gas economic production potential could reach over 13 billion $MTCO_2e$, and coal economic potential comes with over 20 billion $MTCO_2e$ (see Table 52). For context, in 2014, emissions from natural gas and coal consumption in Pennsylvania were about 66 million $MTCO_2e$ and 98 million $MTCO_2e$, respectively. Similarly, the estimated SO_2 emissions from the total economic potential for coal would reach over 350 million metric tons (MT) and NO_x emissions would reach over 73 million MT over the timeframe that these resources would be extracted.

- **Renewable fuels show high growth potential, but remain a small fraction of fossil fuel resource potential.** As Table 19 and Table 21 indicate, renewable fuels (which exclude electric power generation resources such as solar, wind, and hydro) show dramatic growth potential, more than tripling in annualized economic potential over the study period from historical production levels of 79,641 BBtu in 2015 to a potential of 245,331 BBtu in 2050 (see also Figure 32 and Figure 33). However, absolute resource potential levels for renewables remain a small fraction of those associated with fossil fuels: even with a tripling of annual production potential, renewable fuel potential remains less than 3 percent of fossil fuel potential through 2050.

Table 19: Energy Production Potential by Fuel Type

Fuel Type	Unit	Annualized Economic Potential					Economic Potential	Technical Potential
		2015[a]	*2020*	*2025*	*2030*	*2050*		
Production Potential								
Fossil Fuels	BBtu	6,426,489	7,797,764	8,822,209	9,795,424	13,594,508	483,839,463	581,480,254
Renewable and Alternative Fuels	BBtu	79,641	157,169	187,931	207,145	245,331	2,791,449	10,354,082
Total	**BBtu**	**6,506,130**	**7,954,933**	**9,010,140**	**10,002,569**	**13,839,839**	**486,630,913**	**591,834,336**
BAU Fuel Consumption (excluding electricity consumption)	BBtu	3,842,140	3,966,838	3,967,135	3,945,116	4,241,188	NA	NA

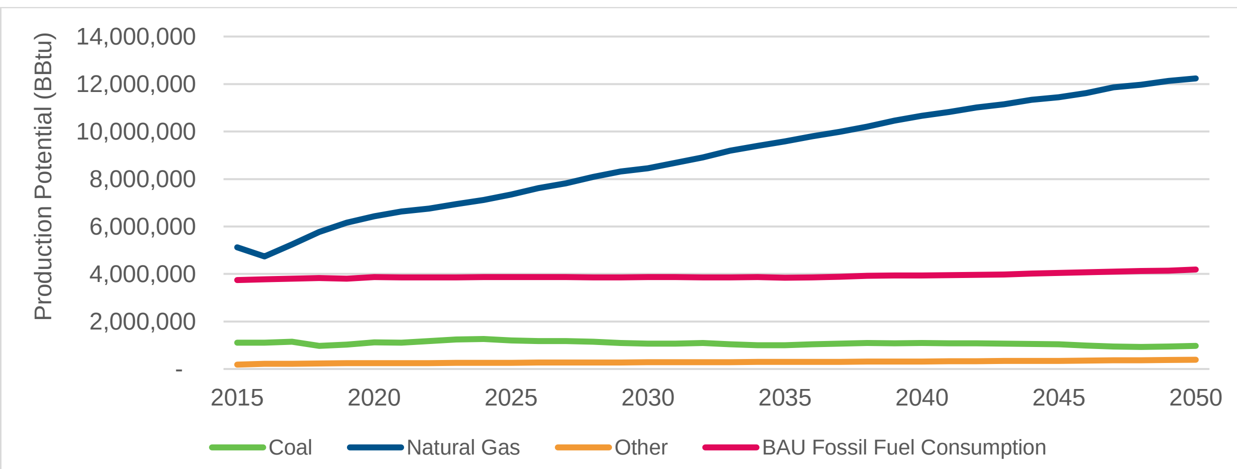
[a] 2015 is historical data and provided for reference. Potential projections begin after 2015.

Table 20: Energy Production Potential for Fossil Fuels by Fuel Type

Fuel Type	Unit	Annualized Economic Potential					Economic Potential	Technical Potential
		2015[a]	*2020*	*2025*	*2030*	*2050*		
Production Potential								
Coal	BBtu	1,113,859	1,117,838	1,208,110	1,065,734	969,148	218,012,036	220,651,650
Crude Oil	BBtu	39,979	50,437	55,163	57,328	118,624	4,694,604	4,699,376
Natural Gas	BBtu	5,128,439	6,432,482	7,349,875	8,449,250	12,235,472	252,814,761	346,690,201
Propane	BBtu	64,824	81,308	92,904	106,800	154,658	4,250,375	4,254,545
Waste Coal	BBtu	77,962	114,066	114,066	114,066	114,066	3,992,294	5,033,810
Coal Mine Methane	BBtu	1,427	1,634	2,091	2,247	2,541	75,392	150,672
Total	**BBtu**	**6,426,489**	**7,797,764**	**8,822,209**	**9,795,424**	**13,594,508**	**483,839,463**	**581,480,254**
BAU Fuel Consumption (excluding electricity)	BBtu	3,842,140	3,966,838	3,967,135	3,945,116	4,241,188	NA	NA

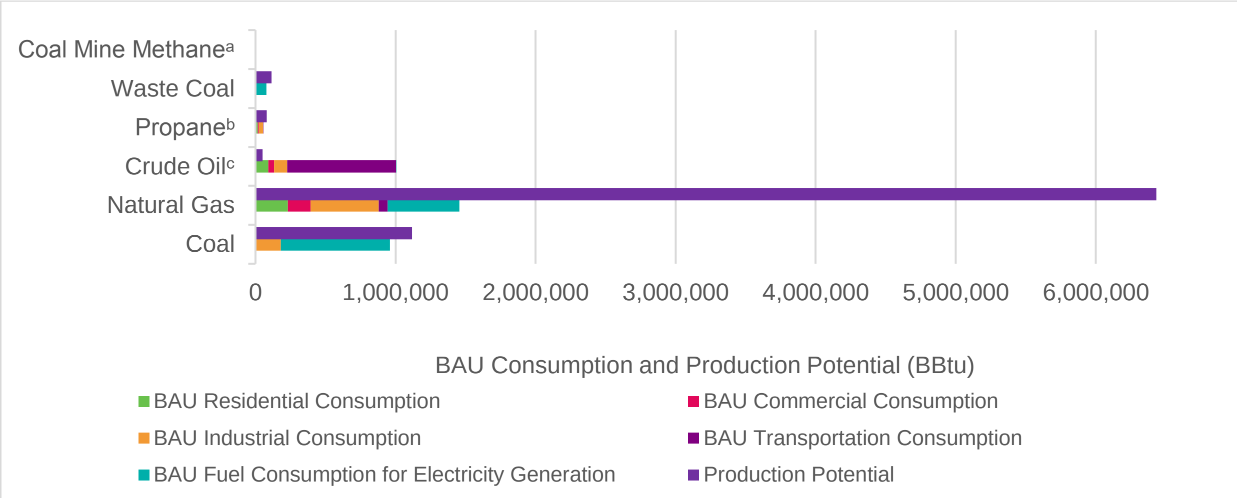
[a] 2015 is historical data and provided for reference. Potential projections begin after 2015.

Figure 28: Energy Production Economic Potential for Fossil Fuels by Fuel Type[a]



[a] "Other" includes crude oil, propane, waste coal, and coal mine methane. 2015 values are historical data for reference.

Figure 29: 2020 Energy Production Economic Potential and BAU Energy Consumption for Fossil Fuels by Fuel Type (and BAU by Sector)



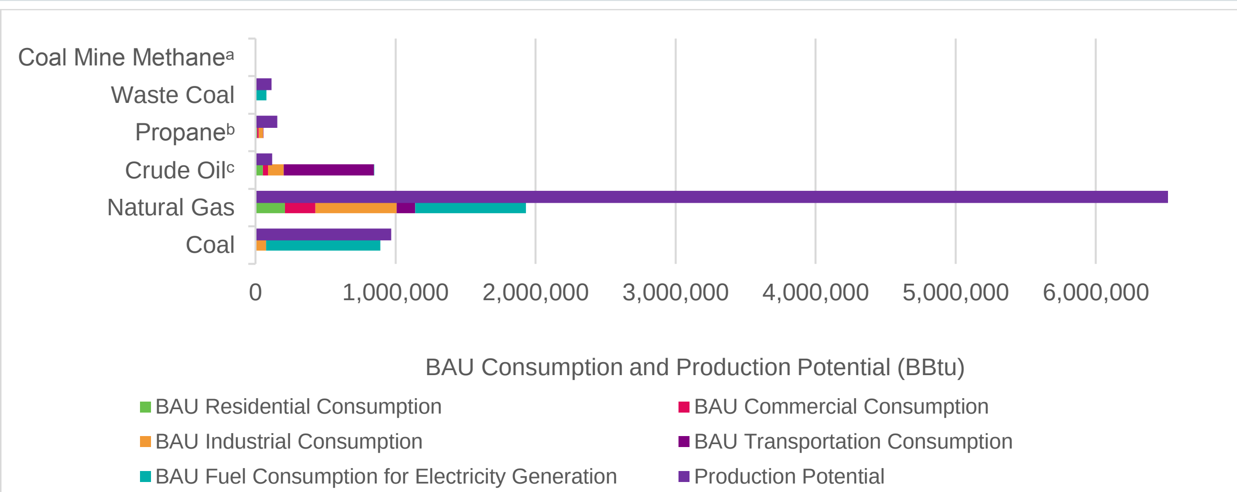
Notes: The purple columns show the economic potential production of each fuel type. The stacked bars show BAU consumption by sector of each fuel type.

[a] Coal mine methane potential is compared to BAU production of coal mine methane, which is allocated to sectors based on the sector allocation of natural gas.

[b] Propane potential is compared to BAU consumption of LPG.

[c] Crude oil potential is compared to BAU consumption of motor gasoline, LPG, distillate fuel oil, residual fuel oil, jet fuel, kerosene, and petroleum coke.

Figure 30: 2050 Energy Production Economic Potential and BAU Energy Consumption for Fossil Fuels by Fuel Type (and BAU by Sector)



Notes: The purple columns show the economic potential production of each fuel type. The stacked bars show BAU consumption by sector of each fuel type.

[a] Coal mine methane potential is compared to BAU production of coal mine methane, which is allocated to sectors based on the sector allocation of natural gas.

[b] Propane potential is compared to BAU consumption of LPG.

[c] Crude oil potential is compared to BAU consumption of motor gasoline, LPG, distillate fuel oil, residual fuel oil, jet fuel, kerosene, and petroleum coke.

Table 21: Energy Production Potential for Renewable and Alternative Fuels by Fuel Type

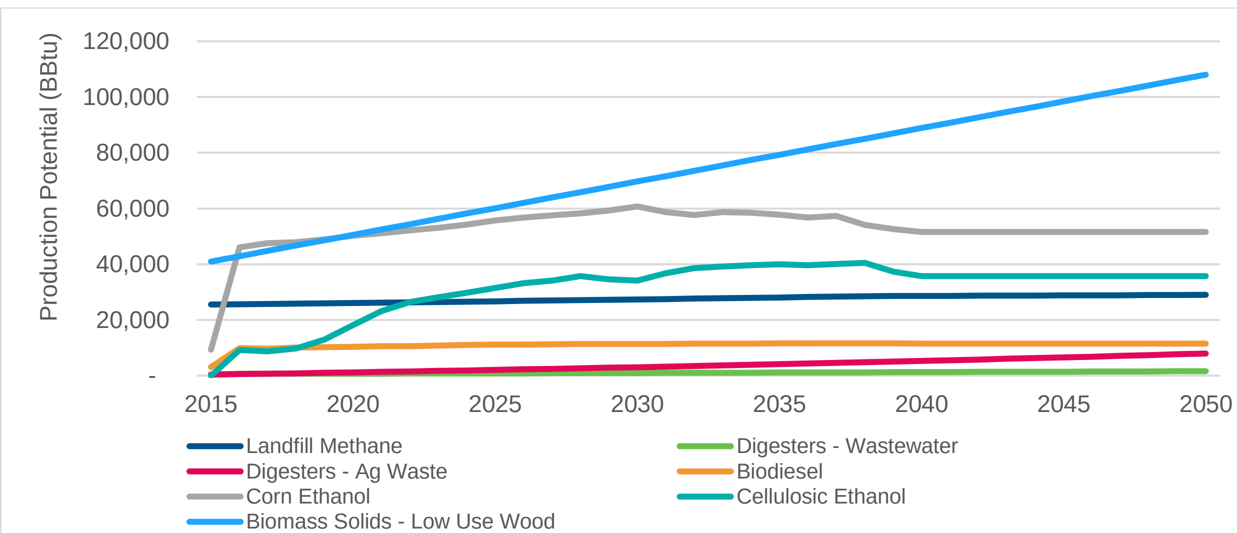
Fuel Type	Unit	Annualized Economic Potential					Economic Potential[b]	Technical Potential[b]
		2015[a]	2020	2025	2030	2050		
Production Potential								
Landfill Methane	BBtu	25,535	26,087	26,695	27,358	29,008	29,008	32,349
Digesters – Wastewater	BBtu	409	722	838	966	1,602	1,602	1,602
Digesters – Ag Waste	BBtu	358	1,171	2,059	3,043	7,930	7,930	7,930
Biodiesel	BBtu	3,070	10,307	11,086	11,320	11,508	11,591	NE
Corn Ethanol	BBtu	9,319	50,233	55,702	60,706	51,510	60,706	NE
Cellulosic Ethanol	BBtu	0	18,120	31,443	34,066	35,771	40,461	NE
Biomass Solids – Low-Use Wood	BBtu	40,950	50,529	60,107	69,686	108,000	2,640,150	10,312,200
Total	**BBtu**	**79,641**	**157,169**	**187,931**	**207,145**	**245,331**	**2,791,449**	**10,354,082**
BAU Fuel Consumption (excluding electricity consumption)	BBtu	3,842,140	3,966,838	3,967,135	3,945,116	4,241,188	NA	NA

Note: "NE" indicates that the value was not estimated.

[a] 2015 values are historical data provided for reference. Potential values begin after 2015.

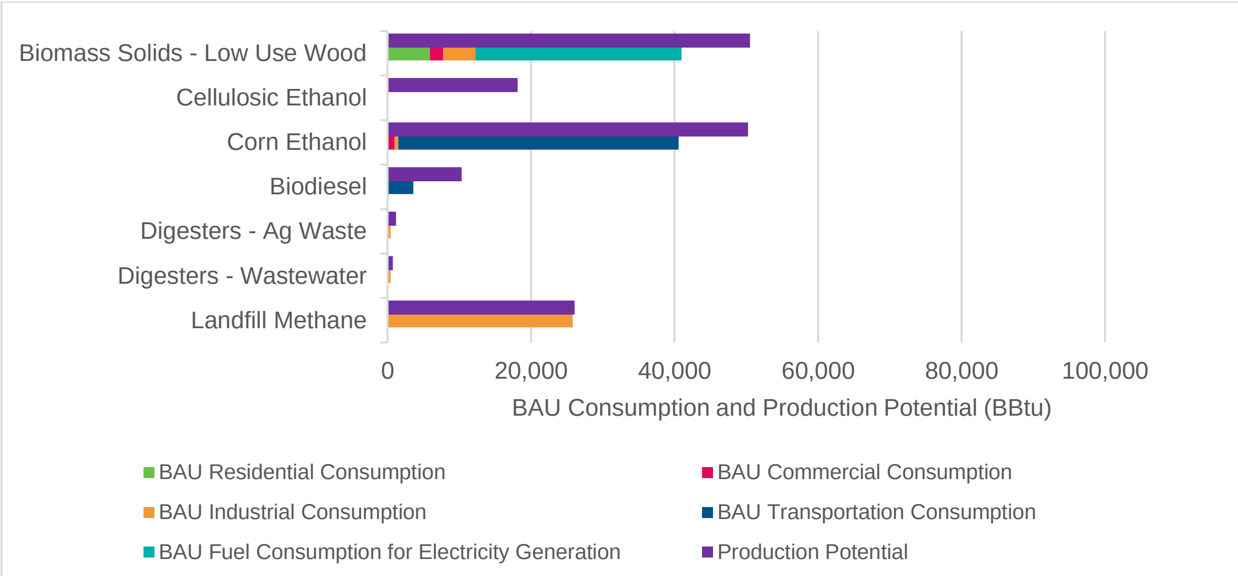
[b] Time-dimensionless economic and technical potentials for all renewable and alternative fuels apart from biomass solids – low-use wood are based on the highest annualized potential value in the 2015 to 2050 time-series since the feedstocks for these fuels regenerate on a short timeframe. The time-dimensionless economic and technical potential for biomass solids – low-use wood is based on the economic and technical potential for current standing wood values.

Figure 31: Energy Production Economic Potential for Renewable and Alternative Fuels by Fuel Type[a]



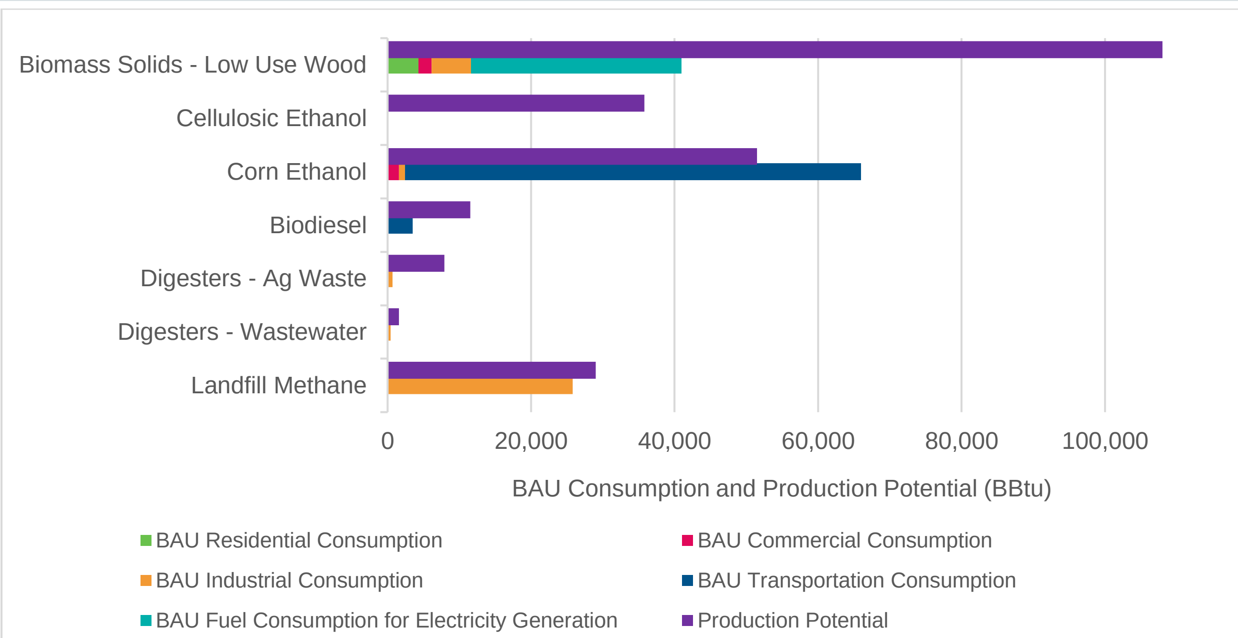
[a] 2015 values are historical data provided for reference. Potential values begin after 2015. Total BAU fuel consumption was not included in this chart due to scaling issues; for reference, 2015 historical fuel consumption were estimated to be 4,384,906 BBtu.

Figure 32: 2020 Energy Production Economic Potential and BAU Energy Consumption for Renewable and Alternative Fuels by Fuel Type (and BAU by Sector)



Notes: The purple columns show the economic potential production of each fuel type. The stacked bar shows BAU consumption by sector of each fuel type.

Figure 33: 2050 Energy Production Economic Potential and BAU Energy Consumption for Renewable and Alternative Fuels by Fuel Type (and BAU by Sector)



Notes: The purple columns show the economic potential production of each fuel type. The stacked bar shows BAU consumption by sector of each fuel type.

3.5. Electricity Generation

3.5.1 Sources and Methodology

The sections below present the Analysis Team's approach and sources for determining technical and economic potential for electricity generation in the Commonwealth of Pennsylvania.

Fossil Fuels

Electricity generation potential for coal and natural gas: For coal and natural gas, the Analysis Team followed a very similar process to that used for the annualized energy production values. The Analysis Team considered AEO quantities used to project BAU results in future years and reviewed each AEO side case (see Section 3.4.1 for descriptions) or each quantity to provide the scenario with the maximum electricity generation potential. This was determined by comparing the highest average generation from 2030 through 2039 as this timeframe would allow for assumptions reflected within each case to take effect. After determining the case that creates the highest generation, the Analysis Team projected historical data from the BAU Energy Assessment report for each fuel forward using both the AEO reference case and the identified case values with the highest generation potential and a "differential" was determined for each future year. By applying this differential to BAU results, the Analysis Team determined an annualized maximum generation potential. This case was also applied in a similar fashion to future year capacities, fuel consumption, and fuel prices. Total economic and technical electricity generation potential was impractical to estimate for these fuels since the Commonwealth can also draw on out-of-state coal and natural gas to supply electricity generators. The Analysis Team did not produce long-run electricity generation supply curves for fossil fuels because such curves would logically be extensions of the coal and natural gas supply curve already provided.

Electricity generation potential for waste coal: The Analysis Team used the same steps to assess the economic potential for electricity generation from waste coal as was used to estimate waste coal production potential. Electricity generation estimates assumed that there would be no additional waste coal capacity built through 2050 (Ellis 2018). Therefore, the Analysis Team applied an average historical capacity factor based on 2000–2015 data to existing 2015 capacity to determine the expected economic potential for electricity generation in each year (EIA 2017c). The total economic generation potential was characterized in annual generation or capacity terms, because electricity is not a long-term storable commodity, and is equated to the maximum year of generation. Technical potential was not estimated. See Section 1.4 for more detail on how economic and technical potential are characterized in this report.

Nuclear

Electricity generation potential for nuclear: Nuclear electricity generation estimates relied on projected AEO quantities, using similar methods as those used for fossil fuels. From a technical standpoint, nuclear power is an established generation technology in Pennsylvania, and the technical potential exists to expand the nuclear fleet using current or emerging technologies. However, nuclear power is not currently economically competitive in today's wholesale power markets, as witnessed by the planned 2019 closure of the Three Mile Island and Beaver Valley stations. For these reasons, this analysis does not project substantial new generation from nuclear power stations. Total technical and economic potential are not shown here because there are no technical limits on fuel supplies or other factors that affect nuclear power development, while at the same time no new nuclear units are expected to be economically viable. Because the market for uranium and nuclear fuels is international in scope and the demand from the Commonwealth is not large enough to affect price of nuclear fuel, the incremental use of nuclear power in the Commonwealth through the construction of new power plants is not fuel supply limited and could technically occur at a nearly flat busbar cost.

Renewable and Alternative Energy

Electricity generation potential for biogas: The Analysis Team applied the same assumptions and data sources that were used to determine the resource production potential for each biogas resource to determine the economic and technical capacity potential for electricity generation from biogas sources. An estimated 95 percent system capacity factor was applied to determine electricity generation from both agricultural and wastewater digesters (Jones and Lamar 2015). Because landfill methane gas can be sold, it is assumed that is not tied to specific site projects. For that reason, the Analysis Team assumed constant operations for this project, making potential energy consumption for generation equal to potential production.

Electricity generation potential for solar, wind, and hydropower: Multiple data sources were used to compile economic and technical resource potential estimates for solar (both utility and building-scale), wind, and hydropower.

NREL's economic potential study (2016) gives three scenarios for estimated economic potential. Each scenario has projections based on whether new capacity for each technology needs to be added or no new capacity is added past the reference year of 2013. Scenarios that allowed new capacity were selected. To determine economic potential, the study calculated three kinds of levelized avoided cost of energy (LACE), which is the potential revenue available to a renewable project at each of the locations included in the analysis, and subtracted the levelized cost of energy (LCOE), which includes plant construction costs, technology costs and performance, and estimated intra-regional transmission costs. The three scenarios vary on what is included in LACE.

- Primary Case 1: The basic potential revenue calculations; little consideration of market factors that could affect actual deployment
- Primary Case 2: Also includes the value of avoided external costs associated with generation, in particular CO_2 emissions
- Primary Case 3: In addition to avoided external costs, includes the declining value of variable generation

The annual economic potential generation for each resource type for each scenario in NREL's *Renewable Energy Economic Potential* study are shown in Table 22 below. Because the LACE methodology is most appropriate for economic valuation of utility-scale PV, the Analysis Team used the NREL source only to estimate potential for utility-scale resources, and used other methods for building-scale PV.

Table 22: Economic Potentials of Renewable Resources by NREL Economic Potential Case

		Economic Potential – Annual Generation (GWh)			
Scenario[a]	Cases	Utility-Scale PV	Building-Scale PV	Wind	Hydropower
2015 Generation		5,510	123	3,525	2,604
Technical Potential		1,367,000	48,100	35,000	13,000
Primary Case 1 – LACE Only	Full capacity value	0.0	0.0	0.0	3,100
Primary Case 2 – LACE Including Value of Avoided External Costs	Full capacity value	101,700	0.0	3,200	8,500
Primary Case 3 – LACE Including Value of Avoided External Costs and Declining Value of Variable Generation	Full capacity value	0.0	0.0	3,000	8,500

[a] Note that the economic potentials presented for each scenario above are incremental and do not include existing generation amounts. In addition, the Pennsylvania Clean Energy Market Report provides economic potential for building-scale PV, which is used for this report and explained in more detail below (Nature Conservancy 2017).

Solar: Because the NREL study used an avoided-cost method tied to wholesale power prices, it is more suited to assessment of utility-scale solar PV projects, which compete in such wholesale markets. Building-scale PV analysis, however, typically uses fully bundled retail electricity prices for economic valuation. To estimate building-scale potential, therefore, the Analysis Team based the economic and technical potential of solar resources on a 2017 Nature Conservancy report (Nature Conservancy 2017) which builds off NREL's *Renewable Energy Economic Potential* study (NREL 2016). Prices for utility-scale solar were obtained from NREL whereas prices for distributed solar were obtained from the Nature Conservancy (NREL 2016, Nature Conservancy 2017). Although this report is conservative by not incorporating falling prices over time into the results, the economic potential of solar in Pennsylvania could significantly increase as installed prices of solar decrease as many sources expect (HIS 2017, IRENA 2016).

- *Background on the NREL 2016 report.* The Analysis Team reviewed updated technical potential estimates (which take into account real-world geographic constraints and technical constraints) for utility- and building-scale solar generation from NREL 2016, which were based on initial technical potential estimates in an earlier NREL report, *U.S. Renewable Energy Technical Potentials* (NREL 2012). The technical potential in this study was calculated using GIS analysis for utility-scale PV and building-scale PV. The analysis further broke out utility-scale PV into urban and rural utility-scale PV. Areas were excluded depending on whether they were within or outside of urbanized area boundaries defined by the U.S. Census Bureau. Then, these areas were limited to slopes less than 5 percent as per standard industry practice. Parking lots, roads, federally protected lands, areas of critical environmental concern, and other areas deemed unlikely for development were excluded. Contiguous areas less than 18,000 square meters for urban scale and one square kilometer for rural scale were excluded. State-level capacity factors

(SAM-modeled) and an assumption of a 1-axis tracking collector with the axis of rotation aligned north-south at 0-degree tilt and power density of 39 MW/sq. km were used to calculate total technical potential.

Building-scale solar technical potential was calculated using the number of and typical installation sizes for residential buildings and different types of commercial buildings based on available roof space buildings (U.S. Census Bureau 2013 and EIA 2003). Usable roof area was calculated through light detection and ranging (LIDAR) analysis of rooftop suitability. Solar panel efficiency was estimated at 15 percent.

In the NREL study scenarios presented in Table 22, utility-scale PV in Primary Case 2 (LACE including cost of externalities) was the only scenario showing economic potential in this study, with 101,713 GWh generation by 2050, compared to 1,367,000 GWh technical potential. Once economic effects from increased costs from intermittent generation were assumed, solar became unviable, but since the publication of this study, there have been advances in declining costs of battery storage that may address intermittency concerns with solar deployment and may make significant amounts of solar viable in the future. For more on battery storage, see Section 3.6 of this report. Primary Case 2 was chosen instead of Case 3 as representative of economic resource potential for utility-scale solar in order to capture the potential significance of solar under favorable conditions. The study shows that no new building-scale solar is viable without policies to support them under any of the scenarios in the study, so building-scale growth from the BAU Energy Assessment is assumed. In comparison, the Finding Pennsylvania's Solar Future Plan (PA DEP 2018), which aims for generation equal to 10 percent of total electric consumption in Pennsylvania by 2030, shows 9,494 GWh of generation from utility-scale PV and 5,112 GWh of building-scale PV is possible.

Capital costs for utility-scale solar were obtained from NREL 2016. These costs were used to calculate LCOE that determined economic potential.

- *Background on the Pennsylvania Clean Energy Market Report*. The Pennsylvania Clean Energy Market Report (Nature Conservancy 2017) built off the 2017 NREL report and a Statewide Evaluator study to show the economic potential for distributed solar was greater than zero. The study based its LCOE for distributed solar on updated assumptions that assumed a useful life of 25 years, tested a range of solar installation costs and solar renewable energy certificate (SREC) prices, and then compared the resulting price per kWh against electricity prices being paid by customers (12 to 14 cents per kWh for residential and 8 to 9 cents per kWh for commercial). In most scenarios, as is seen in Figure 34 and Figure 35, residential and commercial distributed solar are economical.

  Although the Nature Conservancy's 2017 report focuses more on showing that the economic potential of distributed solar is greater than zero than on establishing a precise amount that is economical, the view portrayed in the report is that a conservative estimate of economic potential for distributed solar would be 25 percent of the technical potential established in the 2016 NREL report, or 9,700 MW. This is the time-dimensionless economic potential the Analysis Team shows in the results, which are annualized to increase from historical 2015 levels to

9,700 MW by 2050. The Analysis Team also uses the utility-scale economic potential provided by the Nature Conservancy's 2017 report of 62,610 MW, which is derived from the 2016 NREL report.

Figure 34: Residential Levelized Cost of Energy under Different Price Points[a]

		SREC Price ($/MWh)										
		$0	$10	$20	$30	$40	$50	$60	$70	$80	$90	$100
	$3.50	11.76	10.76	9.76	8.76	7.76	6.76	5.76	4.76	3.76	2.76	1.76
	$3.40	11.42	10.42	9.42	8.42	7.42	6.42	5.42	4.42	3.42	2.42	1.42
	$3.30	11.08	10.08	9.08	8.08	7.08	6.08	5.08	4.08	3.08	2.08	1.08
	$3.20	10.75	9.75	8.75	7.75	6.75	5.75	4.75	3.75	2.75	1.75	0.75
	$3.10	10.41	9.41	8.41	7.41	6.41	5.41	4.41	3.41	2.41	1.41	0.41
Cost ($/W)	$3.00	10.08	9.08	8.08	7.08	6.08	5.08	4.08	3.08	2.08	1.08	0.08
	$2.90	9.74	8.74	7.74	6.74	5.74	4.74	3.74	2.74	1.74	0.74	
	$2.80	9.41	8.41	7.41	6.41	5.41	4.41	3.41	2.41	1.41	0.41	
	$2.70	9.07	8.07	7.07	6.07	5.07	4.07	3.07	2.07	1.07	0.07	
	$2.60	8.73	7.73	6.73	5.73	4.73	3.73	2.73	1.73	0.73		
	$2.50	8.40	7.40	6.40	5.40	4.40	3.40	2.40	1.40	0.40		

[a] Represent cases where the LCOE is below the low range of average retail electricity prices for Pennsylvania. This figure is based on cash purchase of a system.
Source: Nature Conservancy 2017.

Figure 35: Commercial Levelized Cost of Energy under Different Price Points[a]

		SREC Price ($/MWh)										
		$0	$10	$20	$30	$40	$50	$60	$70	$80	$90	$100
	$3.00	10.08	9.08	8.08	7.08	6.08	5.08	4.08	3.08	2.08	1.08	0.08
	$2.90	9.74	8.74	7.74	6.74	5.74	4.74	3.74	2.74	1.74	0.74	
	$2.80	9.41	8.41	7.41	6.41	5.41	4.41	3.41	2.41	1.41	0.41	
	$2.70	9.07	8.07	7.07	6.07	5.07	4.07	3.07	2.07	1.07	0.07	
	$2.60	8.73	7.73	6.73	5.73	4.73	3.73	2.73	1.73	0.73		
Cost ($/W)	$2.50	8.40	7.40	6.40	5.40	4.40	3.40	2.40	1.40	0.40		
	$2.40	8.06	7.06	6.06	5.06	4.06	3.06	2.06	1.06	0.06		
	$2.30	7.73	6.73	5.73	4.73	3.73	2.73	1.73	0.73			
	$2.20	7.39	6.39	5.39	4.39	3.39	2.39	1.39	0.39			
	$2.10	7.05	6.05	5.05	4.05	3.05	2.05	1.05	0.05			
	$2.00	6.72	5.72	4.72	3.72	2.72	1.72	0.72				

[a] Dark green cells represent cases where the LCOE is below the low range of average retail electricity prices for Pennsylvania. Light green cells represent cases where the LCOE is below the high range of average retail electricity prices for Pennsylvania. Pink cells represent cases, which are not economical. This figure is based on cash purchase of a system.
Source: Nature Conservancy 2017.

Wind: The NREL *Renewable Energy Economic Potential* study (NREL 2016) described above was also used to determine economic and technical potential estimates for wind. For wind, Primary Case 3 (including cost of externalities and declining value of variable generation) was selected because it had the most ambitious generation and capacity potential estimates, given Pennsylvania's already realized progress. This scenario results in about twice as much electricity generation from wind in 2050 as in 2016. For technical potential, the NREL study used wind resource data developed for the 2015 WindVision analysis to show 12,000 MW of technical wind potential (DOE 2015). An installation density of 3 MW/sq. km was used. Alternatively, the American Wind Energy Association (AWEA) fact sheet cites NREL data showing that while technical potential for 80 meter hub heights is relatively small (878 MW), if hub heights are considered for 110 meters, the technical potential for wind capacity rises to 43,565 MW (AWEA, 2018).

Hydropower: The most ambitious AEO scenario showing the most growth over the study period—low oil and gas resource and technology—was used to adjust the BAU reference case using the annual growth rate. This resulted in 5,033 GWh of generation in 2050 compared to 3,255 GWh in 2016. In comparison, the NREL *Renewable Energy Economic Potential* report shows economic potential of 11,025 GWh in 2050 (8,500 GWh incremental to 2013 hydropower generation) (NREL 2016). Technical potential was obtained from the same report (updated from the 2012 NREL *U.S. Renewable Energy Technical Potentials* report) and is estimated at 13,000 GWh. The wholesale electricity prices in the AEO projections were used for hydropower generation prices.

Electricity generation potential for biomass solids – low-use wood: The Analysis Team reviewed the same resources and applied similar assumptions to those that were used to determine the resource production potential for biomass to determine the potential for electricity generation from biomass. The Pennsylvania Wood Energy Prospectus estimates that based on a sustainable yield of 5.4 million dry tons of low-use wood, 7,500 GWh of electricity could be generated (Pennsylvania State Wood Energy Team 2016). The Analysis Team then scaled this estimate up to 8,036 GWh to align with the sustainable yield of 6 million dry tons of low-use wood that is estimated in Section 3.3 for biomass energy production.

Because there are other economical uses for biomass besides electricity generation, the Analysis Team took the 2015 share of energy wood that is currently used for non-electricity generation purposes (60 percent based on the BAU assessment) and discounted the potential generation by that amount under the assumption that future uses of wood for energy would be apportioned across sectors at the same rate. Based on these assumptions, the Analysis Team estimated 3,201 GWh as the time-dimensionless economic potential for electricity generation from biomass. Biomass generation capacity was not estimated due to the multiple applications of wood for electricity use ranging from stand-alone CHP applications to co-firing a small percentage of biomass in a larger coal-generating unit. The Analysis Team did not estimate biomass prices given (1) the variability in uses for biomass fuel and (2) the PA DCNR study appeared to estimate the sustainable yield of 6 million dry tons per year based on implicitly *rather than explicitly* incorporating economic factors (e.g., discounting high value wood that will go to non-energy markets, factoring in operability constraints that would make harvesting less cost-effective) (PA DCNR n.d.).

Combined Heat and Power

Electricity generation potential for CHP: The Analysis Team used ICF's proprietary CHP technical database to evaluate the potential for new CHP installations in Pennsylvania. Several commercial, institutional, and industrial building types can support CHP, and the ICF database estimates the thermal and electric loads for these facilities throughout the country, including Pennsylvania. This analysis evaluated potential for CHP installations, which can be served by a variety of fuels, but the most common fuel is natural gas. The number of facilities and technical potential are estimated for different CHP size categories in Table 23. Facilities were characterized as high load factor applications with 24/7 operation or low load factor applications that shut down at night. Wastewater treatment plants were not included in this analysis, as they are evaluated separately for biogas resource potential.

Table 23: 2016 Technical Potential for CHP in Pennsylvania with Non-Renewable Fuels

	Low Load Factor		High Load Factor		Total	
Size	**Sites**	**MW**	**Sites**	**MW**	**Sites**	**MW**
<500 kW	5,824	580	3,464	546	9,288	1,125
500–999 kW	1,263	534	627	410	1,890	944
1–4.9 MW	510	367	677	1,422	1,187	1,789
5–19.9 MW	5	60	149	1,270	154	1,330
≥20 MW	1	21	33	1,399	34	1,420
Total	**7,603**	**1,561**	**4,949**	**5,047**	**12,552**	**6,608**

More details on Pennsylvania sites with technical potential for CHP can be found in the DOE report, *Combined Heat and Power (CHP) Technical Potential in the United States* (DOE 2016b).

The technical potential is expected to grow over time as existing facilities expand their operations and new facilities are constructed. The Analysis Team applied growth rates for energy consumption in the commercial and industrial sectors in the Middle Atlantic Census Division from EIA's 2017 AEO to estimate the potential capacity for new CHP systems in 2050.[34] The results are shown in Table 24.

Table 24: Technical Potential (MW) for CHP in 2016 and 2050, with AEO Growth Rates

	Low Load Factor		High Load Factor		Total	
Size	**2016**	**2050**	**2016**	**2050**	**2016**	**2050**
<500 kW	580	600	546	565	1,125	1,164
500–999 kW	534	552	410	424	944	976
1–4.9 MW	367	407	1,422	1,578	1,789	1,985
5–19.9 MW	60	71	1,270	1,505	1,330	1,576
≥20 MW	21	25	1,399	1,658	1,420	1,683
Total	**1,561**	**1,655**	**5,047**	**5,729**	**6,608**	**7,384**

In addition to evaluating the technical potential through 2050, the Analysis Team evaluated the economics for CHP installations in Pennsylvania, based on state average electricity and natural gas prices for the size categories shown in Table 25. For potential CHP installations under 1 MW, state average

[34] For sites with CHP potential below 1 MW, the AEO commercial growth rate for energy consumption was used. For sites with CHP potential 5 MW or larger, the AEO industrial growth rate was used. For sites in the 1–5 MW size range, the average of the two energy consumption growth rates was applied.

electricity and natural gas prices for the commercial sector were applied to the economic analysis, using 2016 EIA data. Electricity and gas escalation rates for the commercial sector in the AEO Middle Atlantic reference case were used to estimate energy costs through 2050. For CHP installations 1–20 MW in size, 2016 state average industrial sector electricity prices were used, and for potential installations over 20 MW, gas prices were reduced to the state average city-gate price, plus $2 per MMBtu for pipeline transportation. For all potential installations over 1 MW in size, electricity and gas escalation rates for the industrial sector in the AEO Middle Atlantic reference case were used to estimate energy costs through 2050. Energy costs and escalation rates used in the analysis are shown in Table 25.

Table 25: Energy Costs and Escalation Rates for Pennsylvania CHP Analysis

CHP Size	Electricity Price (cents/kWh)	Electricity Escalation (%)	Natural Gas Price ($/MMBtu)	Natural Gas Escalation (%)
<500 kW	9.22	0.7%	$7.93	1.4%
500–999 kW	9.22	0.7%	$7.93	1.4%
1–4.9 MW	6.92	0.8%	$7.20	1.4%
5–19.9 MW	6.92	0.8%	$7.20	1.4%
≥20 MW	6.92	0.8%	$5.62	1.4%

CHP cost and performance data, collected by the Analysis Team for recent efforts for the DOE CHP Deployment Program and EPA CHP Partnership, were applied to potential CHP installations for the appropriate size ranges. Table 26 shows the assumptions that were used for energy prices and CHP cost and performance in the economic analysis.

Table 26: CHP Cost and Performance Assumptions

CHP Size Range	50–500 kW	500–999 kW	1–4.9 MW	5–19.9 MW	≥ 20 MW
Prime Mover	Engine	Engine	Engine	Turbine[a]	Turbine
Installed Cost ($/kW)	$2,900	$2,200	$1,800	$1,800	$1,270
O&M ($/kWh)	$0.021	$0.017	$0.016	$0.012	$0.009
Electric Efficiency (HHV)	29.6%	34.3%	40.9%	28.0%	35.5%
Heat Rate (Btu/kWh)	11,530	9,950	8,340	12,190	9,610
Thermal Output (Btu/kWh)	6,100	5,164	3,215	4,893	3,305
Availability	95%	95%	95%	95%	95%
Thermal Utilization	90%	90%	90%	100%	100%
Displaced Boiler Efficiency	80%	80%	80%	80%	80%

[a] For the 5–19.9 MW category, the 1–4.9 MW engine with higher electric efficiency was also analyzed.

The economic analysis showed that some small (500–999 kW) facilities with high load factors and commercial electricity rates could potentially support economic CHP installations with payback periods under 10 years throughout the 2016–2050 timeframe. Average industrial electricity prices are relatively low for Pennsylvania, so sites in the 1–20 MW size range that were modeled with these prices were not considered to have economic potential. Larger (>20 MW) sites with lower gas rates that are capable of supporting high-efficiency, low-cost combustion turbine installations were able to achieve payback periods lower than 10 years in both 2016 and 2050. The results of the economic analysis are shown in Table 27.

Table 27: Results of Economic Analysis for Pennsylvania CHP Applications

	Simple Payback (Years, Low Load Factor)		Simple Payback (Years, High Load Factor)		Economic Potential (MW)
Size	2016	2050	2016	2050	
<500 kW	26	26	16	16	0
500-999 kW	15	14	9	8	424
1-4.9 MW	33	36	20	22	0
5-19.9 MW	33	36	20	22	0
≥20 MW	11	11	7	7	1,658
				Total	2,082

Overall, 2,082 MW of CHP capacity is estimated to be economical, with payback periods under 10 years, all for high load factor applications modeled with 7,500 full-load equivalent hours (15,615 GWh). Systems at the 500–999 kW size show the lowest payback period. This is because for the <500 kW category, equipment/installation costs are higher on a per-kW basis, and for installations 1 MW or larger, the modeled electricity price goes down, making economics less favorable. At >20 MW, the improved cost and performance for larger systems makes them more economical.

Based on the economic indicators, the Analysis Team annualized 25 percent of the potential in the 500-999 kW size range and 40 percent of the potential in the >20 MW size range through 2050, with annual values increasing slightly over time due to marginally improved economics.

3.5.2 Summary of Results

This section summarizes key trends that emerge from the assessment of electricity generation technical and economic potential, places these trends in context, and also discusses the climate effects and economic factors associated with electricity generation potential where available. For both the annual and time-dimensionless resource potentials for electricity generation, the following potentials include both the existing stock of generating units and any incremental generation beyond the BAU Energy Assessment. The summary figures and tables below reveal electricity generation potential estimates and trends that have implications for Pennsylvania's energy future.

- **Fossil fuels show continuing potential.** As Table 28 and Table 29 and indicate, fossil fuels could continue to provide more than half of Pennsylvania's electricity through 2050 (see also Figure 36). If, as projected, natural gas takes a larger share of the power generation fuel mix, however, this would likely result in only a moderate reduction in the emissions intensity of the generation fleet. The impact on the grid emissions intensity depends on the generation mix that natural gas is displacing, since Pennsylvania's average GHG emissions intensity for electricity generation is about the same as a natural gas combined-cycle plant (DOE 2016d, EPA 2018c).[35] Table 29 shows that by 2030 (and likely much sooner), gas has the potential to become the leading fossil fuel for power generation. In the near term, the PJM market has substantial underused coal capacity that can become economic under some market conditions, increasing the near-term economic potential for coal generation in the AEO's most favorable coal scenario. Over the longer term, however, AEO's most bullish gas scenario shows gas eclipsing coal as new capacity additions are predominantly gas-fired.

- **Renewable power generation shows major growth potential.** Table 28 indicates that renewable power generation has the economic potential to increase almost 12-fold by 2050 from 2015 levels if all renewable resources are developed to their potential (see also Figure 37). The economic potential of renewable power generation in 2050 would be equal to 77 percent of BAU electricity consumption and 42 percent of BAU electricity generation in 2050. This is assuming the development of one resource does not crowd out the potential development of another renewable resource. Of the renewable resource types, solar PV shows the largest resource potential, primarily in larger utility-scale systems. Residential and commercial building-scale solar arrays see moderate growth, and if installed, solar prices continue to drop; the economic potential for solar resources would increase further than what is presented in this report. Table 30 breaks out renewable generation by resource type.
- **Pennsylvania-specific resources can offer important contributions.** The Commonwealth contains site-specific, indigenous resources such as waste coal-fired power plants as well as landfill methane and wastewater and agricultural waste digesters, which while smaller in absolute scale than the potential estimates associated with other resource types, nonetheless add diversity and competition to the resource mix (see Table 30).

Key Results: Electricity Generation

- The economic outlook for nuclear electricity generation is low, with the annualized economic potential for generation in 2050 dropping to less than half of historical 2015 generation. The retirement of nuclear units creates opportunities for new fossil and renewable generators to come online.
- Renewable and alternative fuel electricity generating resources have the potential for significant growth, with annualized economic potential reaching 112,609 GWh in 2050 compared to historical generation of 9,588 GWh in 2015. This potential is led by utility-scale solar PV generation, accounting for 73 percent of economic potential in 2050.
- Fossil fuel generating resources also have significant potential to grow. When adding up coal, waste coal, and natural gas generation potentials, the annualized economic potential for 2050 is 59 percent higher than historical 2015 generation values for those fuel types.
- The technical potential for renewable generation in Pennsylvania is very large, equivalent to over eight times the historical 2015 electricity consumption.

[35] Comparing the lifecycle emissions of coal and gas, baseload gas generation is about half as GHG emissions intensive as coal generation (DOE 2016).

- **Nuclear electricity generation shows expected declines.** Table 28 and Table 31 indicate that the electricity generation potential from nuclear power will decline in future years. This decline in potential is based on both the announced retirement of the Three Mile Island power plant as well as an expected decrease in reliance on nuclear power going forward. See also Figure 38.
- **CHP is both a resource and an enabling technology.** Because CHP can be analyzed and developed as a type of power generation project, it can be modeled as a resource, and we have developed resource estimates accordingly. Annualized CHP economic potential doubles over the study period, as shown in Figure 39 and Table 32. However, CHP is typically developed as a customer-owned, distributed resource and so is not fully comparable to typical utility-scale power generation. There are also accounting issues related to the fact that CHP projects can increase customer-site fuel consumption but reduce customer electricity purchases, while offsetting utility-scale generation. It is therefore important to treat CHP carefully as a unique category.

Table 28: Electricity Generation Potential by Fuel Type

Fuel Type	Unit	Annualized Economic Potential					Economic Potential	Technical Potential
		2015[a]	*2020*	*2025*	*2030*	*2050*		
Electricity Generation Potential by Fuel Type Compared to BAU Consumption								
BAU Electricity Consumption	GWh	146,344	143,702	146,532	144,742	145,634	NA	NA
Fossil Fuels	GWh	131,480	158,079	161,282	177,581	209,087	NA[b]	NA
Renewable and Alternative Fuels	GWh	9,588	25,743	40,134	54,759	112,609	112,609	1,208,115
Nuclear	GWh	80,517	59,546	60,058	60,044	39,073	NA	NA
CHP[c]	GWh	14,924	17,129	19,356	21,641	31,357	31,357	66,160

Note: “NA” indicates that the value is not applicable.

[a] 2015 is historical data and provided for reference. Potential projections begin after 2015.

[b] Economic potential for coal mine methane is estimated to be 9,585 BBtu, which represents the maximum economic potential for a given year. Technical potential was not estimated for coal, natural gas, or waste coal.

[c] CHP potential includes installations fueled by fossil fuels and renewable and alternative fuels and therefore should not be combined with potential estimates from specific fuel types.

Table 29: Electricity Generation Potential for Fossil Fuels by Fuel Type

Fuel Type	Unit	Annualized Economic Potential					Economic Potential[b]	Technical Potential
		2015[a]	*2020*	*2025*	*2030*	*2050*		
Electricity Generation Potential by Fuel Type Compared to BAU Consumption								
BAU Electricity Consumption	GWh	146,344	143,702	146,532	144,742	145,634	NA	NA
Coal	GWh	64,828	78,547	81,837	83,669	83,380	NA	NA
Natural Gas	GWh	60,102	69,948	69,861	84,327	116,123	NA	NA
Waste Coal	GWh	6,551	9,585	9,585	9,585	9,585	9,585	NE
Total	**GWh**	**131,480**	**158,079**	**161,282**	**177,581**	**209,087**	**NA**	**NA**

Note: "NE" indicates that the value was not estimated. "NA" indicates that the value is not applicable.

[a] 2015 is historical data and provided for reference. Potential projections begin after 2015.

[b] Economic potential is estimated for waste coal as opposed to other fuel types because no new waste coal plants are expected to be economical to build.

Figure 36: Electricity Generation Economic Potential for Fossil Fuels by Fuel Type

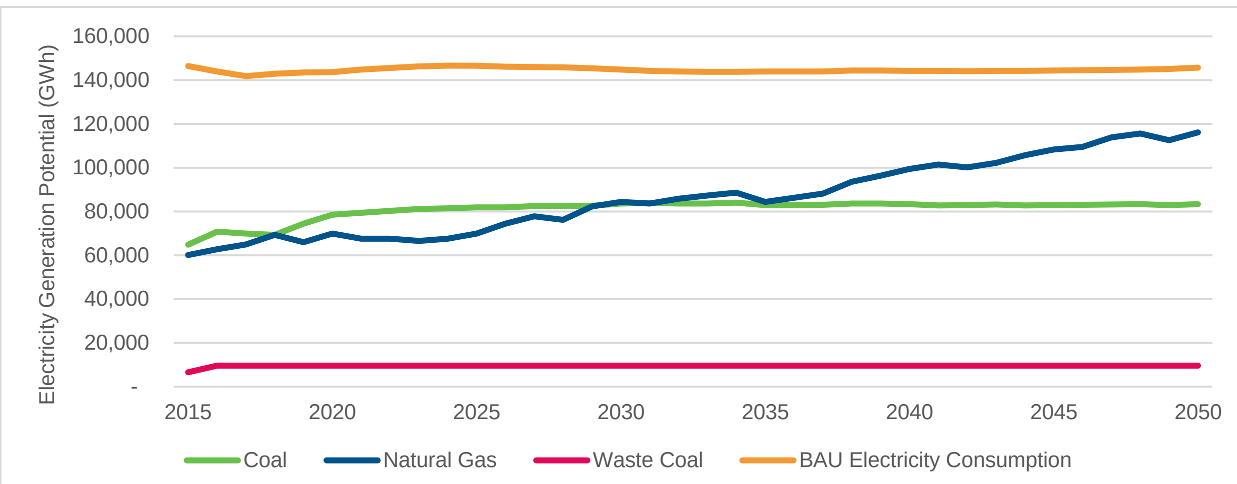
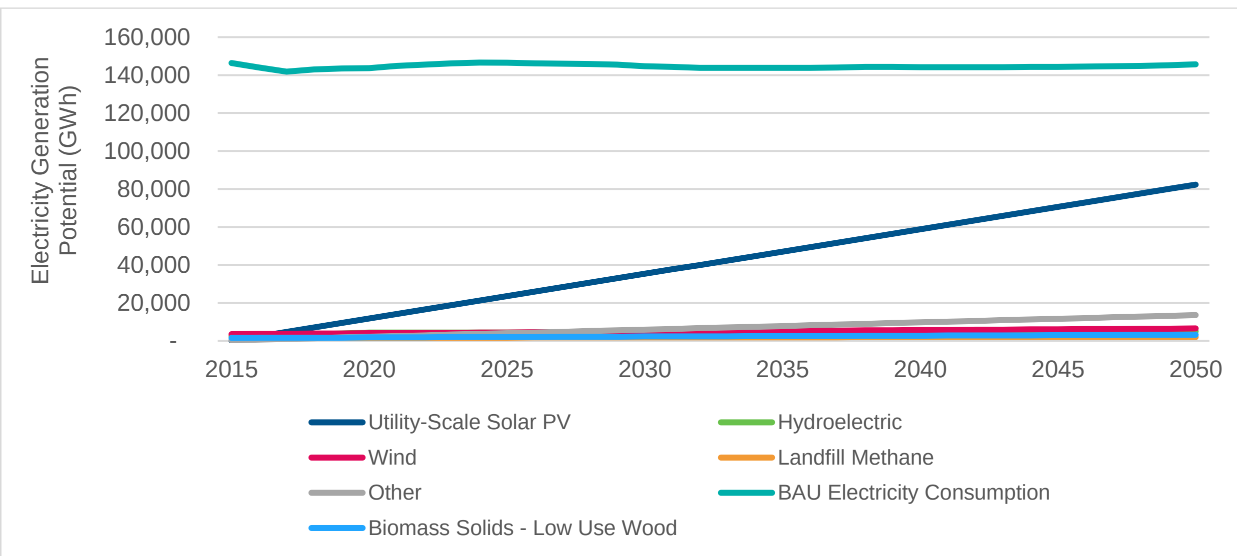


Table 30: Electricity Generation Potential for Renewable and Alternative Fuels by Fuel Type[a]

Fuel Type	Unit	Annualized Economic Potential					Economic Potential	Technical Potential
		2015[a]	*2020*	*2025*	*2030*	*2050*		
Electricity Generation Potential by Fuel Type Compared to BAU Consumption								
BAU Electricity Consumption	GWh	146,344	143,702	146,532	144,742	145,634	NA	NA
Utility-Scale Solar PV	GWh	33	11,783	23,533	35,282	82,281	82,281	1,105,862
Building-Scale Solar PV – Residential	GWh	92	1,025	1,959	2,892	6,625	6,625	26,567
Building-Scale Solar PV – Commercial	GWh	85	948	1,810	2,672	6,121	6,121	24,548
Hydroelectric	GWh	2,604	4,393	4,423	4,673	5,033	5,033	13,000
Wind	GWh	3,525	3,957	4,390	4,822	6,552	6,552	35,000
Landfill Methane	GWh	1,621	1,678	1,740	1,808	1,977	1,977	2,320
Digesters – Wastewater	GWh	40	70	81	94	156	156	156
Digesters – Ag Waste	GWh	32	98	172	254	662	662	662
Biomass Solids – Low-Use Wood	GWh	1,556	1,791	2,026	2,261	3,201	3,201	NA
Total	**GWh**	**9,588**	**25,743**	**40,134**	**54,759**	**112,609**	**112,609**	**1,208,115**

[a] 2015 values are historical data provided for reference. Potential projections begin after 2015.

Figure 37: Electricity Generation Economic Potential for Renewable and Alternative Fuels by Fuel Type[a]



a "Other" includes residential and commercial building-scale solar PV, digesters – wastewater, and digesters – ag waste. 2015 values are historical data provided for reference. Potential projections begin after 2015.

Table 31: Electricity Generation Potential for Nuclear Compared to BAU Electricity Consumption

	Unit	Annualized Economic Potential					Economic Potential[b]	Technical Potential[b]
		2015[a]	*2020*	*2025*	*2030*	*2050*		
BAU Electricity Consumption	GWh	146,344	143,702	146,532	144,742	145,634	NA	NA
Electricity Generation Potential	GWh	80,517	59,546	60,058	60,044	39,073	NA	NA

Note: "NA" indicates that the value is not applicable.

[a] 2015 is historical data and provided for reference. Potential projections begin after 2015.

[b] Technical and economic potential are not shown here because there are no technical limits on fuel supplies or other factors that affect nuclear power development, while at the same time no new nuclear units are expected to be economically viable.

Figure 38: Electricity Generation Economic Potential for Nuclear

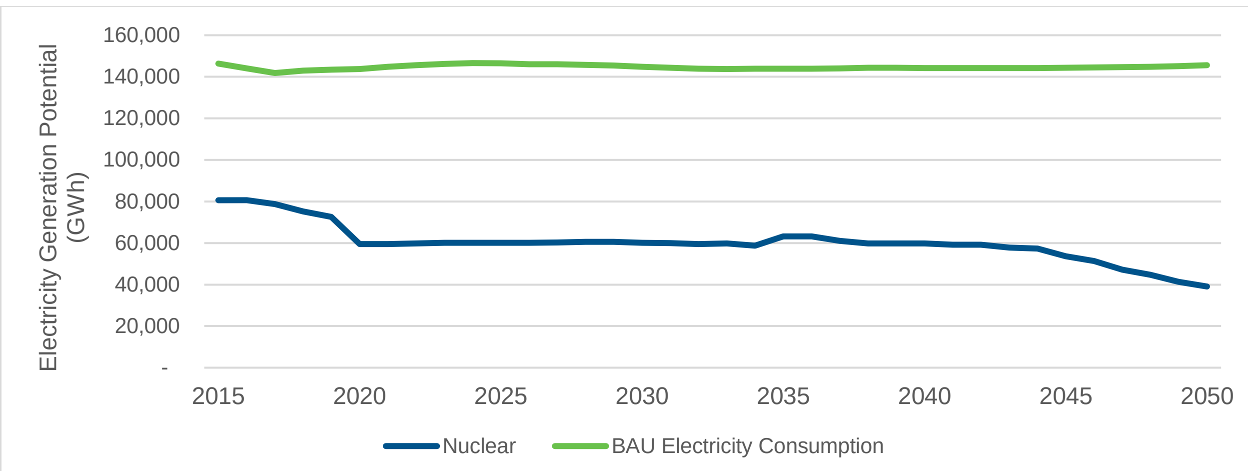
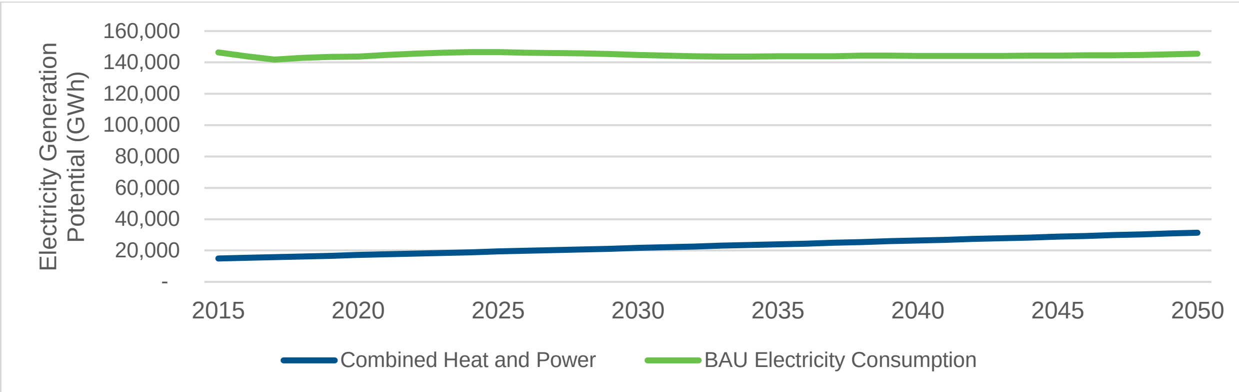


Table 32: Electricity Generation Potential for Combined Heat and Power

	Unit	Annualized Economic Potential					Economic Potential	Technical Potential
		2015[a]	*2020*	*2025*	*2030*	*2050*		
BAU Electricity Consumption	GWh	146,344	143,702	146,532	144,742	145,634	NA	NA
Electricity Generation Potential	GWh	14,924	17,129	19,356	21,641	31,357	31,357	66,160

[a] 2015 is historical data and provided for reference. Potential projections begin after 2015.

Figure 39: Electricity Generation Economic Potential for Combined Heat and Power



3.6. Enabling Technologies

A number of technologies exist that the Analysis Team classifies as "enabling," meaning that they do not constitute energy resources in themselves, but rather enable higher-efficiency and/or lower-emission use of other energy resources. Some enabling technologies are commercially viable today, while others are still in developmental phases. For these reasons, they are not quantified in this energy resource analysis; however, they could factor into one or more policy and market scenarios in the future in Pennsylvania.

Battery Energy Storage

Trends in the cost and performance of electric storage batteries suggest that they could play a transformative role in renewable electricity and grid operations. Batteries can enable electricity grids to integrate more renewables and other distributed energy resources, making the power sector potentially more efficient, cleaner, and more resilient. However, battery technology does not create new energy resources but rather enables the storage of electricity, which otherwise needs to be consumed at the time it is generated. The resulting shift in usage periods enables greater deployment of variable renewable generation resources. Yet future battery performance and costs—and the regulatory and market barriers to deployment—are highly uncertain, making quantitative estimates of the potential impacts on energy generation, usage, and associated emissions very speculative.

CHP/Microgrids

While CHP potential has been quantified in the sections above alongside that of other energy resource choices, it is primarily an enabling technology in that it relies on primary fuels such as natural gas or biomass. CHP is fundamentally a more efficient process for converting raw fuel to thermal and electrical energy and therefore represents an important technology choice and policy priority, even though CHP does not by itself create new primary energy resources.

Microgrids are smaller-scale electricity distribution systems that can be operated within a larger electric grid, or operated independently in an "islanded" fashion. They often are coupled with CHP technology to provide the thermal and electric energy they distribute, but can also be powered by other energy sources, including renewables. Microgrids can be designed and operated in an integrated fashion, using CHP, renewable energy, storage technology, and advanced energy management to provide efficient, low-emission, and resilient energy services. They are currently best applied in larger campus-style facilities, such as hospitals, universities campuses, or government complexes. As with CHP, microgrids are not a primary energy resource, but rather an enabling technology approach that uses energy resources to support other goals.

Hydrogen Fuel Cells

Hydrogen fuel cells can be used for a variety of applications, which may include powering buildings, vehicles, portable electronic devices, data centers, telecommunications towers, hospitals, emergency response systems, or military applications (DOE 2017b). For the latter applications, fuels cells are made more attractive by the fact that they offer off-grid power sources that can be used to meet critical functions that cannot be disrupted by power failures from the grid. While there are perceived and real barriers (such as cost, safety, and infrastructure) to the commercialization of hydrogen fuels cells, new systems may start to become commercially viable in the next few years (Roberts 2018). With national laboratories such as NREL and other organizations focused on hydrogen fuel cell research and development,[36] fuel cell technologies could create new energy resource choices for Pennsylvania.

At present, however, fuel cell technology remains specialized and not commercially competitive at large scale. Moreover, much fuel cell technology has relied on separation of hydrogen from natural gas, which makes fuel cells more a carrier technology than a primary energy resource. Separation of hydrogen from water via hydrolysis holds significant promise, but also requires electricity to power the process. If renewable power could drive hydrolysis processes cost-effectively, then fuel cells could become more competitive, although hydrogen would still be a carrier fuel more than a primary resource. For the purposes of this project, direct use of renewables, natural gas, and electric-drive technologies are expected to remain the principal market choices.

Electrification

Electrification, or the conversion of fossil fuel-fired end-use technologies to electricity, offers potential benefits such as increased energy efficiency and reduced climate impacts. Converting internal combustion vehicles, fuel-fired heating systems, and other end-uses to electric technologies can increase efficiency and reduce emissions at the point of use, and if other forces reduce the emissions intensity of the power sector, such end-use conversions can also reduce total emissions across the energy system. Some of these types of electrification are covered above, such as the use of PEVs for transportation. A recent study by NREL on electrification in the United States, *Electrification Futures Study: End-Use Electric Technology Cost and Performance Projections through 2050*, shows significant potential for electrification in all sectors and non-prohibitive costs for market penetration in multiple scenarios (Jadun et al. 2017). The study also highlights a wealth of data to support analysis of future electrification in some sectors for specific technologies (e.g., light-duty vehicles), and a lack of available

[36] For example, in December 2017, NREL issued a Request for Information for hydrogen compressor manufacturing capabilities that may meet the need of hydrogen stations available in the future (see https://www.nrel.gov/news/program/2017/nrel-issues-request-for-information-on-hydrogen-compressor-manufacturing-capabilities.html).

robust data in others (e.g., heavy-duty vehicles). These findings are in line with the Analysis Team's findings presented above as well.

As with CHP and battery storage, however, electrification is not in itself a primary energy resource, but rather a technology policy approach that can increase efficiency and reduce emissions across energy markets and over the longer term.

Internet of Things

The internet of things (IoT) is a catchphrase that refers to the scenario that is resulting from increasingly more common household and workplace devices and energy systems being designed with internet-connect capabilities. This connectivity can enable a variety of "smart" usage features, such as remotely adjusting HVAC thermostats, powering down devices when not in use, or optimizing operational schedules, among others. Using IoT for smart homes, buildings, or roads gives building operators more control than ever to implement energy-saving measures and reduce the use of standby power within system boundaries. An April 2016 report shows the largest energy efficiency potential for IoT is for home automation. This application is expected to address an estimated 36 TWh of worldwide standby energy consumption by 2025, followed by smart appliances with an estimated 7 TWh of impact, and smart lighting at 3 TWh (IEA 2016). Smart roads and smart street lighting have relatively smaller impact compared to these three applications (Kyburz 2016).

Although IoT technologies show significant promise, like other enabling technologies they are hard to characterize in specific terms, and their cost and performance characteristics are in flux and thus difficult to predict over an extended study period. They could, however, be included in policy and market strategies in Pennsylvania's Climate Action Plan updates, like other enabling technologies.

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Appendix A. Detailed Historical and Projected Business-as-Usual Energy Data

Historical Energy Consumption

Table 33: Historical Energy Consumption by Sector and Related Environmental and Economic Factors

	Unit	2000	2005	2010	2015	Change from 2005 to 2015
Total Energy Consumption (Excl. Electricity Consumption)	**BBtu**	**4,070,435**	**4,142,247**	**3,918,687**	**3,842,982**	**-7%**
Residential	BBtu	439,904	412,901	363,386	373,862	-9%
Commercial	BBtu	218,499	218,020	189,385	208,089	-5%
Industrial	BBtu	964,964	931,784	816,329	1,082,248	16%
Transportation	BBtu	995,665	1,024,102	953,230	881,874	-14%
Electricity Generation[a]	BBtu	1,451,403	1,555,441	1,596,357	1,296,909	-17%
Total Electricity Consumption	**GWh**	**133,846**	**148,273**	**148,964**	**146,344**	**-1%**
Residential	GWh	45,008	53,661	55,253	54,419	1%
Commercial	GWh	42,988	45,782	47,366	43,745	-4%
Industrial	GWh	45,449	47,950	45,458	47,404	-1%
Transportation	GWh	401	880	887	776	-12%
Energy Expenditures (Excl. Electricity Consumption)	**$ Million**	**$27,284.91**	**$40,270.34**	**$40,881.63**	**$32,507.23**	**-19%**
Residential	$ Million	$5,095.75	$6,890.28	$6,024.08	$4,864.30	-29%
Commercial	$ Million	$2,015.19	$3,095.82	$2,353.90	$2,205.58	-29%
Industrial	$ Million	$2,679.92	$4,436.61	$4,491.40	$4,291.02	-3%
Transportation	$ Million	$14,209.68	$20,385.85	$21,878.86	$17,049.73	-16%
Energy Expenditures from Electricity Consumption	**$ Million**	**$13,647.95**	**$14,492.86**	**$16,544.35**	**$14,979.80**	**3%**
Residential	$ Million	$5,764.66	$6,325.80	$7,626.64	$7,423.20	17%
Commercial	$ Million	$4,492.13	$4,652.32	$5,199.27	$4,199.20	-10%
Industrial	$ Million	$3,355.56	$3,438.80	$3,642.25	$3,296.70	-4%
Transportation	$ Million	$35.60	$75.94	$76.19	$60.70	-20%
GHG Emissions (Excl. Electricity Consumption)[b]	**$MtCO_2e$**	**153,455,817**	**149,614,366**	**130,333,198**	**139,976,747**	**-6%**
Residential	$MtCO_2e$	25,836,249	24,014,169	20,296,090	20,793,266	-13%
Commercial	$MtCO_2e$	13,012,460	12,992,767	10,606,803	11,501,978	-11%
Industrial	$MtCO_2e$	43,449,222	39,839,989	35,098,532	48,458,778	22%

	Unit	2000	2005	2010	2015	Change from 2005 to 2015
Transportation	$MtCO_2e$	71,157,886	72,767,442	64,331,774	59,222,725	-19%
GHG Emissions from Electricity Consumption[c]	**$MtCO_2e$**	**80,751,624**	**89,455,684**	**84,576,070**	**69,540,787**	**-22%**
Residential	$MtCO_2e$	27,154,111	32,374,616	31,370,543	25,859,209	-20%
Commercial	$MtCO_2e$	25,935,409	27,621,078	26,892,606	20,787,061	-25%
Industrial	$MtCO_2e$	27,420,174	28,929,070	25,809,316	22,525,771	-22%
Transportation	$MtCO_2e$	241,930	530,919	503,605	368,745	-31%
SO_2 Emissions (Excl. Electricity Consumption)	**MT**	**224,807**	**437,105**	**314,515**	**343,876**	**-21%**
SO_2 Emissions from Electricity Consumption	**MT**	**577,610**	**615,268**	**247,451**	**165,553**	**-73%**
NO_x Emissions (Excl. Electricity Consumption)	**MT**	**321,281**	**383,888**	**340,199**	**349,893**	**-9%**
NO_x Emissions from Electricity Consumption	**MT**	**164,528**	**113,722**	**80,711**	**78,993**	**-31%**
Hg Emissions (Excl. Electricity Consumption)	**MT**	**1**	**1**	**1**	**1**	**-12%**
Hg Emissions Electricity Consumption	**MT**	**3**	**3**	**3**	**3**	**-1%**
Pennsylvania State Gross Domestic Product (GDP)	**Million Chained $ of State GDP**	**395,602**	**482,200**	**584,412**	**708,402**	**47%**
Btu per dollar of state GDP [d]	**Btu per Million Chained $ of State GDP**	**9.35**	**7.81**	**6.10**	**4.93**	**-37%**

[a] There may be some overlap of energy consumption between electricity generation and other sectors due to the addition of energy consumption from small CHP units to the electricity generation sector. Any overlap would represent a small percentage of total consumption.

[b] GHG emissions estimates for residential and commercial energy consumption are within 1% of Pennsylvania's estimates calculated using EPA's State Inventory Tool. Transportation sector GHG estimates are within 5%. Industrial sector GHG emissions estimates shown here are generally 27–36% lower than Pennsylvania's estimates calculated using EPA's State Inventory Tool. The discrepancy in industrial sector emissions are due to the inclusion of several fuels in an "Other" category for this analysis. Roughly 35% of overall fuels consumed on a Btu basis were allocated to "Other" and emissions were not estimated for these fuels.

[c] GHG emissions estimates for electricity consumption are within 0.1% of Pennsylvania's estimates calculated using EPA's State Inventory Tool.

[d] Energy consumption used to calculate Btu per dollar of state GDP does not include electricity consumption but does include energy consumed by electricity generation.

Table 34: Historical Energy Consumption Prices by Sector and Fuel Type

	Unit	2000	2005	2010	2015
Electricity					
Residential	$/MWh	$128.07	$117.89	$138.02	$136.41
Commercial	$/MWh	$104.51	$101.61	$109.77	$95.98
Industrial	$/MWh	$75.63	$75.29	$83.21	$71.96
Transportation	$/MWh	$88.97	$86.43	$85.92	$78.20
Natural Gas					
Residential	$/MMBtu	$11.02	$16.34	$13.52	$10.52
Commercial	$/MMBtu	$10.02	$14.99	$10.98	$8.88
Industrial	$/MMBtu	$6.65	$12.93	$8.63	$8.18
Transportation	$/MMBtu	$6.35	$11.43	$3.95	$7.32
Coal					
Residential	$/MMBtu	$3.37	$3.98	NA	NA
Commercial	$/MMBtu	$1.80	$2.64	$4.86	$4.46
Industrial	$/MMBtu	$2.10	$3.35	$5.25	$3.82
Transportation	$/MMBtu	NA	NA	NA	NA
Motor Gasoline					
Commercial	$/MMBtu	$16.24	$21.77	$25.17	$20.80
Industrial	$/MMBtu	$16.24	$21.77	$25.17	$20.80
Transportation	$/MMBtu	$16.24	$21.77	$25.17	$20.80
LPG					
Residential	$/MMBtu	$22.01	$25.69	$32.76	$26.07
Commercial	$/MMBtu	$17.01	$21.35	$26.17	$22.76
Industrial	$/MMBtu	$17.34	$22.73	$30.21	$25.32
Transportation	$/MMBtu	$21.20	$23.28	$28.21	$26.42
Distillate Fuel Oil					
Residential	$/MMBtu	$12.57	$18.07	$23.28	$19.63
Commercial	$/MMBtu	$9.42	$15.93	$19.90	$14.12
Industrial	$/MMBtu	$10.40	$16.60	$19.66	$14.58
Transportation	$/MMBtu	$15.91	$21.54	$24.54	$21.27
Residual Fuel Oil					
Commercial	$/MMBtu	$5.64	$9.04	$14.03	$8.98
Industrial	$/MMBtu	$5.64	$9.04	$14.03	$8.98
Transportation	$/MMBtu	$4.63	$8.05	$12.04	$8.41
Jet Fuel					
Transportation	$/MMBtu	$9.15	$15.12	$17.50	$11.99
Kerosene					
Residential	$/MMBtu	$12.55	$17.39	$26.41	$16.97
Commercial	$/MMBtu	$12.55	$17.39	$26.41	$16.97
Industrial	$/MMBtu	$10.88	$16.64	$20.16	$18.69
Biodiesel					
Transportation	$/MMBtu	$2.22	$3.78	$4.01	$5.53

	Unit	2000	2005	2010	2015
Ethanol (Corn)					
Commercial	$/MMBtu	$1.59	$2.83	$2.43	$2.52
Industrial	$/MMBtu	$1.59	$2.83	$2.43	$2.52
Transportation	$/MMBtu	$1.59	$2.83	$2.43	$2.52
Ethanol (Cellulosic)					
Commercial	$/MMBtu	$1.59	$2.83	$2.43	$2.52
Industrial	$/MMBtu	$1.59	$2.83	$2.43	$2.52
Transportation	$/MMBtu	$1.59	$2.83	$2.43	$2.52
Wood and Biogenic Waste					
Residential	$/MMBtu	$4.70	$6.55	$8.27	$6.70
Commercial	$/MMBtu	$2.83	$4.51	$5.15	$4.02
Industrial	$/MMBtu	$1.88	$3.11	$2.81	$2.59
Biogas					
Residential	$/MMBtu	NE	NE	NE	NE
Commercial	$/MMBtu	NE	NE	NE	NE
Industrial	$/MMBtu	NE	NE	NE	NE
Transportation	$/MMBtu	NE	NE	NE	NE

"NA" indicates that the value is not applicable. In this case, it indicates that there was no consumption of that fuel type for a given year.

"NE" indicates that the value was not estimated.

Future Consumption Trends (Projections)

Table 35: Future Energy Consumption by Sector and Related Environmental and Economic Factors

	Unit	2015	2020	2025	2030	2050	Change from 2015 to 2050
Total Energy Consumption (Excl. Electricity Consumption)	**BBtu**	**3,842,982**	**3,967,461**	**3,967,763**	**3,945,744**	**4,241,700**	**10%**
Residential	BBtu	373,862	344,069	330,319	318,870	278,081	-26%
Commercial	BBtu	208,089	211,751	213,373	220,644	264,121	27%
Industrial	BBtu	1,082,248	1,063,722	1,099,823	1,091,240	1,148,797	6%
Transportation	BBtu	881,874	892,444	843,973	800,351	852,673	-3%
Electricity Generation[a]	BBtu	1,296,909	1,455,475	1,480,274	1,514,639	1,698,028	31%
Total Electricity Consumption	**GWh**	**146,344**	**143,702**	**146,532**	**144,742**	**145,634**	**0%**
Residential	GWh	54,419	50,348	49,216	48,949	45,981	-16%
Commercial	GWh	43,745	44,498	44,278	43,329	44,155	1%
Industrial	GWh	47,404	47,814	51,417	50,298	52,096	10%
Transportation	GWh	776	1,042	1,621	2,166	3,402	338%

	Unit	2015	2020	2025	2030	2050	Change from 2015 to 2050
Energy Expenditures (Excl. Electricity Consumption)	**$ Million**	**$32,507.23**	**$35,688.72**	**$37,491.23**	**$37,204.98**	**$43,915.34**	**35%**
Residential	$ Million	$4,864.30	$4,853.16	$4,876.85	$4,813.75	$4,760.89	-2%
Commercial	$ Million	$2,205.58	$2,450.66	$2,579.36	$2,720.75	$3,659.91	66%
Industrial	$ Million	$4,291.02	$6,008.96	$6,500.71	$6,638.41	$8,707.79	103%
Transportation	$ Million	$17,049.73	$17,960.07	$18,822.00	$18,121.33	$20,406.41	20%
Energy Expenditures from Electricity Consumption	**$ Million**	**$14,979.80**	**$16,044.85**	**$17,000.68**	**$17,266.98**	**$18,408.49**	**23%**
Residential	$ Million	$7,423.20	$7,869.92	$8,096.16	$8,217.15	$8,553.57	15%
Commercial	$ Million	$4,199.20	$3,974.53	$4,178.12	$4,218.93	$4,501.69	7%
Industrial	$ Million	$3,296.70	$4,130.83	$4,602.82	$4,654.05	$5,060.25	53%
Transportation	$ Million	$60.70	$69.58	$123.59	$176.84	$292.99	383%
GHG Emissions (Excl. Electricity Consumption)	**$MtCO_2e$**	**139,976,747**	**139,596,948**	**134,668,171**	**129,151,932**	**128,516,436**	**-8%**
Residential	$MtCO_2e$	20,793,266	19,028,125	18,147,894	17,442,863	14,996,487	-28%
Commercial	$MtCO_2e$	11,501,978	11,753,145	11,816,629	12,184,049	14,404,497	25%
Industrial	$MtCO_2e$	48,458,778	49,331,910	48,945,744	47,128,432	45,445,722	-6%
Transportation	$MtCO_2e$	59,222,725	59,483,769	55,757,903	52,396,588	53,669,730	-9%
GHG Emissions from Electricity Consumption	**$MtCO_2e$**	**69,540,787**	**68,285,291**	**69,630,249**	**68,779,371**	**69,203,238**	**0%**
Residential	$MtCO_2e$	25,859,209	23,924,495	23,387,037	23,259,860	21,849,808	-16%
Commercial	$MtCO_2e$	20,787,061	21,145,092	21,040,449	20,589,539	20,981,863	1%
Industrial	$MtCO_2e$	22,525,771	22,720,721	24,432,656	23,900,815	24,755,159	10%
Transportation	$MtCO_2e$	368,745	494,984	770,106	1,029,156	1,616,409	338%
SO_2 Emissions (Excl. Electricity Consumption)	**MT** [b]	**343,876**	**296,417**	**276,306**	**245,989**	**125,178**	**-64%**
SO_2 Emissions from Electricity Consumption	**MT**	**165,553**	**162,564**	**165,766**	**163,741**	**164,750**	**0%**
NO_x Emissions (Excl. Electricity Consumption)	**MT**	**349,893**	**292,853**	**236,953**	**182,275**	**154,105**	**-56%**
NO_x Emissions from Electricity Consumption	**MT**	**78,993**	**77,567**	**79,095**	**78,128**	**78,609**	**0%**
Hg Emissions (Excl. Electricity Consumption)	**MT**	**1**	**1**	**1**	**1**	**1**	**-23%**

	Unit	2015	2020	2025	2030	2050	Change from 2015 to 2050
Hg Emissions Electricity Consumption	**MT**	**3**	**3**	**3**	**3**	**3**	**0%**
Pennsylvania State GDP	**Million Chained $ of State GDP**	**708,402**	**744,233**	**829,762**	**915,291**	**1,268,552**	**79%**
Btu per dollar of state GDP [c]	**Btu per Million Chained $ of State GDP**	**4.93**	**4.85**	**4.35**	**3.92**	**3.04**	**-38%**

[a] There may be some overlap of energy consumption between electricity generation and other sectors due to the addition of energy consumption from small CHP units to the electricity generation sector. Any overlap would represent a small percentage of total consumption.

[b] MT is million metric tons.

[c] Energy consumption used to calculate Btu per dollar of state GDP does not include electricity consumption but does include energy consumed by electricity generation.

Table 36: Future Energy Consumption Prices by Sector and Fuel Type

	Unit	2015	2020	2025	2030	2050
Electricity						
Residential	$/MWh	$136.41	$156.31	$164.50	$167.87	$186.02
Commercial	$/MWh	$95.98	$89.32	$94.36	$97.37	$101.95
Industrial	$/MWh	$71.96	$86.39	$89.52	$92.53	$97.13
Transportation	$/MWh	$78.20	$66.80	$76.26	$81.65	$86.13
Natural Gas						
Residential	$/MMBtu	$10.52	$11.05	$11.58	$11.92	$14.34
Commercial	$/MMBtu	$8.88	$10.29	$10.70	$10.85	$12.45
Industrial	$/MMBtu	$8.18	$6.90	$7.30	$7.45	$9.27
Transportation	$/MMBtu	$7.32	$7.38	$7.25	$7.00	$7.26
Coal						
Residential	$/MMBtu	NA	NA	NA	NA	NA
Commercial	$/MMBtu	$4.46	$4.96	$5.24	$5.56	$5.48
Industrial	$/MMBtu	$3.82	$4.25	$4.49	$4.76	$4.70
Transportation	$/MMBtu	NA	NA	NA	NA	NA
Motor Gasoline						
Commercial	$/MMBtu	$20.80	$21.53	$24.43	$25.21	$28.53
Industrial	$/MMBtu	$20.80	$21.53	$24.43	$25.21	$28.53
Transportation	$/MMBtu	$20.80	$21.53	$24.43	$25.21	$28.53

	Unit	2015	2020	2025	2030	2050
LPG						
Residential	$/MMBtu	$26.07	$26.52	$27.63	$28.57	$34.12
Commercial	$/MMBtu	$22.76	$23.07	$24.03	$24.85	$29.67
Industrial	$/MMBtu	$25.32	$25.90	$27.50	$28.86	$36.83
Transportation	$/MMBtu	$26.42	$26.82	$27.93	$28.88	$34.41
Distillate Fuel Oil						
Residential	$/MMBtu	$19.63	$22.33	$24.42	$25.68	$29.60
Commercial	$/MMBtu	$14.12	$15.27	$16.36	$17.46	$20.43
Industrial	$/MMBtu	$14.58	$15.94	$17.21	$18.37	$21.42
Transportation	$/MMBtu	$21.27	$24.88	$27.73	$29.21	$32.90
Residual Fuel Oil						
Commercial	$/MMBtu	$8.98	$11.38	$12.83	$14.16	$18.05
Industrial	$/MMBtu	$8.98	$11.62	$13.19	$14.56	$18.57
Transportation	$/MMBtu	$8.41	$13.81	$16.22	$17.64	$21.97
Jet Fuel						
Transportation	$/MMBtu	$11.99	$15.61	$17.79	$19.24	$23.75
Kerosene						
Residential	$/MMBtu	$16.97	$19.30	$21.11	$22.20	$25.59
Commercial	$/MMBtu	$16.97	$18.36	$19.66	$20.99	$24.55
Industrial	$/MMBtu	$18.69	$20.44	$22.06	$23.55	$27.46
Biodiesel						
Transportation	$/MMBtu	$5.53	$6.47	$7.21	$7.60	$8.56
Ethanol (Corn)						
Commercial	$/MMBtu	$2.52	$3.25	$3.15	$2.91	$2.57
Industrial	$/MMBtu	$2.52	$3.25	$3.15	$2.91	$2.57
Transportation	$/MMBtu	$2.52	$3.25	$3.15	$2.91	$2.57
Ethanol (Cellulosic)						
Commercial	$/MMBtu	$2.52	$3.25	$3.15	$2.91	$2.57
Industrial	$/MMBtu	$2.52	$3.25	$3.15	$2.91	$2.57
Transportation	$/MMBtu	$2.52	$3.25	$3.15	$2.91	$2.57
Wood and Biogenic Waste						
Residential	$/MMBtu	$6.70	$8.39	$8.62	$8.85	$9.04
Commercial	$/MMBtu	$4.02	$5.03	$5.17	$5.31	$5.43
Industrial	$/MMBtu	$2.59	$3.24	$3.33	$3.42	$3.50
Biogas						
Residential	$/MMBtu	NE	NE	NE	NE	NE
Commercial	$/MMBtu	NE	NE	NE	NE	NE
Industrial	$/MMBtu	NE	NE	NE	NE	NE
Transportation	$/MMBtu	NE	NE	NE	NE	NE

“NA” indicates that the value is not applicable. In this case, it indicates that there was no consumption of that fuel type for a given year.
“NE” indicates that the value was not estimated.

Historical Energy Production

Table 37: Historical Energy Production by Fuel Type (BBtu)

	2000	2005	2010	2015	Change from 2005 to 2015
Fossil Fuels					
Bituminous Coal	1,682,348	1,538,997	1,264,992	1,015,484	-34%
Anthracite Coal	59,142	50,357	71,172	98,374	95%
Natural Gas	156,171	176,540	600,849	5,128,439	2805%
Crude Oil	8,700	14,268	18,769	39,979	180%
Coal Mine Methane	79	952	1,427	1,427	50%
Waste Coal	86,397	114,022	127,291	77,962	-32%
Total – Fossil Fuels	**1,992,837**	**1,895,135**	**2,084,500**	**6,361,665**	**236%**
Renewable and Alternative Fuels					
Landfill Gas Methane	3,303	5,928	17,744	25,535	331%
Digesters – Wastewater	-	21	33	409	1812%
Digesters – Ag Waste	80	81	222	358	345%
Biodiesel	-	1,287	2,574	3,070	139%
Wood and Biogenic Waste	86,747	72,538	70,040	70,874	-2%
Corn Ethanol	-	-	-	9,319	N/A
Cellulosic Ethanol	-	-	-	-	N/A
Total – Renewable and Alternative Fuels	**90,130**	**79,854**	**90,614**	**109,565**	**37%**
Total	**2,082,968**	**1,974,990**	**2,175,114**	**6,471,230**	**228%**

Table 38: Greenhouse Gas Emissions from Fossil Fuel Production by Fuel Type ($MTCO_2e$)

	2000	2005	2010	2015
Anthracite Coal	NE	NE	NE	NE
Bituminous Coal	NE	NE	NE	NE
Crude Oil	30,870	62,483	86,393	148,006
Natural Gas	3,672,000	4,782,035	4,561,250	7,180,228

Future Production Trends (Projections)

Table 39: Future Energy Production by Fuel Type (BBtu)

	2015	2020	2025	2030	2050	Change from 2015 to 2050
Fossil Fuels						
Bituminous Coal	1,015,484	895,801	895,041	802,473	715,199	-30%
Anthracite Coal	98,374	83,121	94,355	108,330	143,156	46%
Natural Gas	5,128,439	6,594,754	7,219,480	7,744,559	10,194,872	99%
Crude Oil	39,979	47,687	45,074	42,921	79,254	98%
Coal Mine Methane	1,427	1,427	1,427	1,427	1,427	0%
Waste Coal	77,962	77,962	77,962	77,962	77,962	0%
Total – Fossil Fuels	**6,361,665**	**7,700,751**	**8,333,338**	**8,777,670**	**11,211,869**	**76%**
Renewable and Alternative Fuels						
Landfill Gas Methane	25,535	25,795	25,795	25,795	25,795	1%
Digesters – Wastewater	409	409	409	409	409	0%
Digesters – Ag Waste	358	405	451	498	684	91%
Biodiesel	3,070	3,349	3,349	3,349	3,349	9%
Wood and Biogenic Waste	70,874	76,869	76,427	76,978	83,466	18%
Corn Ethanol	9,319	9,319	9,319	9,319	9,319	0%
Cellulosic Ethanol	-	-	-	-	-	N/A
Total – Renewable and Alternative Fuels	**109,565**	**116,145**	**115,750**	**116,347**	**123,020**	**12%**
Total	**6,471,230**	**7,816,896**	**8,449,087**	**8,894,018**	**11,334,889**	**75%**

Table 40: Future Energy Production Prices by Fuel Type

	Unit	2015	2020	2025	2030	2050
Crude Oil	$/barrel	40.56	68.40	79.52	87.66	110.25
Natural Gas	$/Mcf [a]	3.34	3.55	4.05	4.18	5.04
Coal	$/short ton	63.95	61.32	62.85	65.64	76.62

[a] Mcf is million cubic feet.

Table 41: Greenhouse Gas Emissions from Fossil Fuel Production by Fuel Type ($MTCO_2e$)

	2015	2020	2025	2030	2050
Anthracite Coal	NE	NE	NE	NE	NE
Bituminous Coal	NE	NE	NE	NE	NE
Crude Oil	148,006	176,542	166,866	158,895	293,407
Natural Gas	7,180,228	6,972,036	7,429,144	7,839,686	10,019,725

Historical Electricity Generation

Table 42: Historical Electricity Generation from Fossil Fuels by Fuel Type and Related Environmental and Economic Factors

	Unit	2000	2005	2010	2015	Change from 2005 to 2015
Total Electricity Generation	**GWh**	**132,985**	**148,678**	**157,764**	**134,205**	**-10%**
Natural Gas	GWh	2,971	11,088	34,177	60,102	442%
Coal	GWh	116,403	121,124	110,560	64,828	-46%
Waste Coal	GWh	7,999	9,972	10,659	6,551	-34%
Residual Fuel Oil	GWh	2,514	4,031	249	34	-99%
Distillate Fuel Oil	GWh	1,255	667	356	729	9%
Petroleum Coke	GWh	22	275	-	-	-100%
Coal Mine Methane	GWh	-	-	-	-	N/A
Other Fuel (CHP)	GWh	2,231	2,231	2,471	2,471	11%
Pumped Storage	GWh	(411)	(711)	(708)	(509)	-28%
Total Capacity	**MW**	**30,638**	**40,175**	**39,769**	**35,161**	**-12%**
Natural Gas	MW	1,786	11,056	10,964	14,147	28%
Coal	MW	20,554	20,544	20,194	15,184	-26%
Waste Coal	MW	988	1,732	1,711	1,615	-7%
Residual Fuel Oil	MW	3,715	4,203	1,939	4	-100%
Distillate Fuel Oil	MW	1,877	701	3,199	2,176	211%
Petroleum Coke	MW	67	289	67	67	-77%
Coal Mine Methane	MW	-	-	-	-	N/A
Other Fuel (CHP)	MW	382	382	427	427	12%
Pumped Storage	MW	1,269	1,269	1,269	1,541	21%
Total Energy Consumption[a]	**BBtu**	**1,418,255**	**1,528,807**	**1,564,406**	**1,267,831**	**-17%**
Natural Gas	BBtu	25,490	84,377	254,572	458,638	444%
Coal	BBtu	1,211,908	1,226,181	1,121,028	670,514	-45%
Waste Coal	BBtu	86,397	114,022	127,291	77,962	-32%
Residual Fuel Oil	BBtu	29,922	44,473	2,663	96	-100%
Distillate Fuel Oil	BBtu	15,088	7,406	4,245	6,014	-19%
Petroleum Coke	BBtu	154	3,053	-	-	-100%
Coal Mine Methane	BBtu	-	-	-	-	N/A
Other Fuel (CHP)	BBtu	49,295	49,295	54,607	54,607	11%
Pumped Storage	BBtu	NA	NA	NA	NA	N/A
Expenditures	**$ Million**	**$2,757.73**	**$5,036.64**	**$5,480.29**	**$3,422.40**	**-32%**
Natural Gas	$ Million	$320.61	$1,862.03	$2,015.83	$1,534.16	-18%
Coal	$ Million	$1,886.76	$2,341.43	$2,951.75	$1,551.78	-34%
Waste Coal	$ Million	$272.99	$360.28	$402.21	$246.34	-32%
Residual Fuel Oil	$ Million	$143.94	$356.92	$35.51	$1.72	-100%

	Unit	2000	2005	2010	2015	Change from 2005 to 2015
Distillate Fuel Oil	$ Million	$133.14	$109.07	$74.99	$88.40	-19%
Petroleum Coke	$ Million	$0.29	$6.91	$0.00	$0.00	-100%
Coal Mine Methane	$ Million	$0.00	$0.00	$0.00	$0.00	N/A
Other Fuel (CHP)	$ Million	NE	NE	NE	NE	N/A
Pumped Storage	$ Million	NA	NA	NA	NA	N/A
GHG Emissions[b]	**$MtCO_2e$**	**124,433,724**	**132,246,404**	**129,116,757**	**93,811,447**	**-29%**
Natural Gas	$MtCO_2e$	1,353,682	4,480,893	13,519,235	24,356,356	444%
Coal	$MtCO_2e$	111,725,089	113,040,908	103,346,917	61,814,304	-45%
Waste Coal	$MtCO_2e$	7,964,921	10,511,598	11,734,920	7,187,229	-32%
Residual Fuel Oil	$MtCO_2e$	2,254,507	3,350,872	200,641	7,227	-100%
Distillate Fuel Oil	$MtCO_2e$	1,119,762	549,639	315,044	446,331	-19%
Petroleum Coke	$MtCO_2e$	15,763	312,494	-	-	-100%
Coal Mine Methane	$MtCO_2e$	-	-	-	-	N/A
Other Fuel (CHP)	$MtCO_2e$	NE	NE	NE	NE	N/A
Pumped Storage	$MtCO_2e$	NE	NE	NE	NE	N/A
SO_2 Emissions	**MT**	**957,489**	**2,177,007**	**2,025,848**	**1,218,258**	**-44%**
Natural Gas	MT	373	1,090	2,213	3,588	229%
Coal	MT	890,339	1,985,976	1,815,665	1,085,994	-45%
Waste Coal	MT	63,473	184,675	206,167	126,270	-32%
Residual Fuel Oil	MT	543	1,779	107	4	-100%
Distillate Fuel Oil	MT	2,735	2,960	1,696	2,403	-19%
Petroleum Coke	MT	27	528	-	-	-100%
Coal Mine Methane	MT	-	-	-	-	N/A
Other Fuel (CHP)	MT	NE	NE	NE	NE	N/A
Pumped Storage	MT	NE	NE	NE	NE	N/A
NO_x Emissions	**MT**	**211,648**	**490,063**	**548,609**	**500,038**	**2%**
Natural Gas	MT	3,785	21,476	122,290	241,648	1025%
Coal	MT	185,845	414,544	378,994	226,685	-45%
Waste Coal	MT	13,249	38,548	43,034	26,357	-32%
Residual Fuel Oil	MT	2,701	8,850	530	19	-100%
Distillate Fuel Oil	MT	6,064	6,562	3,761	5,328	-19%
Petroleum Coke	MT	4	83	-	-	-100%
Coal Mine Methane	MT	-	-	-	-	N/A
Other Fuel (CHP)	MT	NE	NE	NE	NE	
Pumped Storage	MT	NE	NE	NE	NE	N/A
Hg Emissions	**MT**	**3.4**	**4.2**	**2.0**	**1.1**	**-73%**
Natural Gas	MT	0.0	0.0	0.0	0.1	444%
Coal	MT	1.7	1.8	1.6	1.0	-45%
Waste Coal	MT	0.1	0.2	0.2	0.1	-32%
Residual Fuel Oil	MT	1.5	2.3	0.1	0.0	-100%
Distillate Fuel Oil	MT	0.0	0.0	0.0	0.0	-19%

	Unit	2000	2005	2010	2015	Change from 2005 to 2015
Petroleum Coke	MT	0.0	0.0	-	-	-100%
Coal Mine Methane	MT	-	-	-	-	N/A
Other Fuel (CHP)	MT	NE	NE	NE	NE	
Pumped Storage	MT	NE	NE	NE	NE	N/A

[a] There may be some overlap of energy consumption between electricity generation and other sectors due to the addition of energy consumption from small CHP units to the electricity generation sector. Any overlap would represent a small percentage of total consumption.

[b] GHG emissions estimates for electricity generation are generally 6–10% greater than Pennsylvania's estimates calculated using EPA's State Inventory Tool.

"NA" indicates that the value is not applicable.

"NE" indicates that the value was not estimated.

Table 43: Historical Electricity Generation from Renewable and Alternative Fuels by Fuel Type and Related Environmental and Economic Factors

	Unit	2000	2005	2010	2015	Change from 2005 to 2015
Total Electricity Generation	**GWh**	**5,462**	**5,097**	**7,855**	**10,442**	**105%**
Utility-Scale Solar PV	GWh	-	-	2	33	N/A
Building-Scale Solar PV	GWh	-	-	16	178	N/A
Hydroelectric	GWh	2,290	2,232	2,332	2,604	17%
Wind	GWh	10	284	1,854	3,353	1081%
Wood and Biogenic Waste	GWh	2,852	2,176	2,559	2,582	19%
Landfill Gas Methane	GWh	304	396	1,069	1,621	309%
Digesters – Wastewater	GWh	-	2	3	40	2154%
Digesters – Ag Waste	GWh	7	7	20	32	345%
Total Capacity	**MW**	**1,182**	**1,554**	**2,283**	**3,313**	**113%**
Utility-Scale Solar PV	MW	-	-	6	37	N/A
Building-Scale Solar PV	MW	-	-	61	197	N/A
Hydroelectric	MW	723	775	775	920	19%
Wind	MW	10	223	748	1,334	498%
Wood and Biogenic Waste	MW	412	507	561	619	22%
Landfill Gas Methane	MW	37	48	129	195	309%
Digesters – Wastewater	MW	-	0	1	9	2154%

	Unit	2000	2005	2010	2015	Change from 2005 to 2015
Digesters – Ag Waste	MW	1	1	2	4	345%
Total Energy Consumption[a]	**BBtu**	**35,761**	**31,867**	**49,137**	**54,538**	**71%**
Utility-Scale Solar PV	BBtu	NA	NA	NA	NA	N/A
Building-Scale Solar PV	BBtu	NA	NA	NA	NA	N/A
Hydroelectric	BBtu	NA	NA	NA	NA	N/A
Wind	BBtu	NA	NA	NA	NA	N/A
Wood and Biogenic Waste	BBtu	32,378	25,837	31,137	28,236	9%
Biogas	BBtu	3,383	6,030	18,000	26,302	336%
Expenditures	**$ Million**	**$28.21**	**$68.17**	**$79.12**	**$72.50**	**6%**
Utility-Scale Solar PV	$ Million	NA	NA	NA	NA	N/A
Building-Scale Solar PV	$ Million	NA	NA	NA	NA	N/A
Hydroelectric	$ Million	NA	NA	NA	NA	N/A
Wind	$ Million	NA	NA	NA	NA	N/A
Wood and Biogenic Waste	$ Million	$28.21	$68.17	$79.12	$72.50	6%
Biogas	$ Million	NE	NE	NE	NE	N/A
GHG Emissions	**$MtCO_2e$**	**3,279**	**5,845**	**17,448**	**25,496**	**336%**
Utility-Scale Solar PV	$MtCO_2e$	NA	NA	NA	NA	N/A
Building-Scale Solar PV	$MtCO_2e$	NA	NA	NA	NA	N/A
Hydroelectric	$MtCO_2e$	NA	NA	NA	NA	N/A
Wind	$MtCO_2e$	NA	NA	NA	NA	N/A
Wood and Biogenic Waste	$MtCO_2e$	-	-	-	-	N/A
Biogas	$MtCO_2e$	3,279	5,845	17,448	25,496	336%
SO_2 Emissions	**MT**	**396**	**699**	**936**	**947**	**35%**
Utility-Scale Solar PV	MT	NA	NA	NA	NA	N/A
Building-Scale Solar PV	MT	NA	NA	NA	NA	N/A
Hydroelectric	MT	NA	NA	NA	NA	N/A
Wind	MT	NA	NA	NA	NA	N/A
Wood and Biogenic Waste	MT	367	646	778	706	9%
Biogas	MT	29	53	158	241	353%
NO_x Emissions	**MT**	**2,044**	**3,644**	**4,749**	**5,125**	**41%**
Utility-Scale Solar PV	MT	NA	NA	NA	NA	N/A

	Unit	2000	2005	2010	2015	Change from 2005 to 2015
Building-Scale Solar PV	MT	NA	NA	NA	NA	N/A
Hydroelectric	MT	NA	NA	NA	NA	N/A
Wind	MT	NA	NA	NA	NA	N/A
Wood and Biogenic Waste	MT	1,939	3,411	4,110	3,727	9%
Biogas	MT	105	233	639	1,398	499%
Hg Emissions	**MT**	**-**	**-**	**-**	**-**	**N/A**
Utility-Scale Solar PV	MT	NA	NA	NA	NA	N/A
Building-Scale Solar PV	MT	NA	NA	NA	NA	N/A
Hydroelectric	MT	NA	NA	NA	NA	N/A
Wind	MT	NA	NA	NA	NA	N/A
Wood and Biogenic Waste	MT	NE	NE	NE	NE	N/A
Biogas	MT	NE	NE	NE	NE	N/A

[a] There may be some overlap of energy consumption between electricity generation and other sectors due to the addition of energy consumption from small CHP units to the electricity generation sector. Any overlap would represent a small percentage of total consumption.

"NA" indicates that the value is not applicable.

"NE" indicates that the value was not estimated.

Table 44: Historical Electricity Generation from Traditional Nuclear and Related Environmental and Economic Factors

	Unit	2000	2005	2010	2015	Change from 2005 to 2015
Total Electricity Generation	GWh	73,771	76,289	77,828	80,517	6%
Total Capacity	MW	9,589	9,860	10,015	10,322	5%
Total Energy Consumption	BBtu	769	796	813	842	6%
Expenditures	$ Million	498	357	574	602	69%
GHG Emissions	$MtCO_2e$	NA	NA	NA	NA	N/A
SO_2 Emissions	MT	NA	NA	NA	NA	N/A
NO_x Emissions	MT	NA	NA	NA	NA	N/A
Hg Emissions	MT	NA	NA	NA	NA	N/A

"NA" indicates that the value is not applicable.

Future Generation Trends (Projections)

Table 45: Projected Electricity Generation by Fuel Type and Related Environmental and Economic Factors

	Unit	2015	2020	2025	2030	2050	Change from 2005 to 2015
Total Electricity Generation	**GWh**	**134,205**	**156,349**	**158,848**	**163,302**	**200,934**	**50%**
Natural Gas	GWh	60,102	69,800	69,830	73,491	113,649	89%
Coal	GWh	64,828	77,608	80,076	80,874	78,352	21%
Waste Coal	GWh	6,551	6,551	6,551	6,551	6,551	0%
Residual Fuel Oil	GWh	34	34	34	34	34	0%
Distillate Fuel Oil	GWh	729	305	306	304	304	-58%
Petroleum Coke	GWh	-	-	-	-	-	N/A
Coal Mine Methane	GWh	-	-	-	-	-	N/A
Other Fuel (CHP)	GWh	2,471	2,471	2,471	2,471	2,471	0%
Pumped Storage	GWh	(509)	(419)	(419)	(423)	(426)	-16%
Total Capacity	**MW**	**35,161**	**36,151**	**35,882**	**35,793**	**41,384**	**18%**
Natural Gas	MW	14,147	16,430	16,242	16,194	21,215	50%
Coal	MW	15,184	13,610	13,561	13,527	13,138	-13%
Waste Coal	MW	1,615	1,615	1,615	1,615	1,615	0%
Residual Fuel Oil	MW	4	4	4	4	4	0%
Distillate Fuel Oil	MW	2,176	2,457	2,426	2,417	3,378	55%
Petroleum Coke	MW	67	67	67	67	67	0%
Coal Mine Methane	MW	-	-	-	-	-	N/A
Other Fuel (CHP)	MW	427	427	427	427	427	0%
Pumped Storage	MW	1,541	1,541	1,541	1,541	1,541	0%
Total Energy Consumption[a]	**BBtu**	**1,267,831**	**1,419,139**	**1,444,606**	**1,477,263**	**1,653,038**	**30%**
Natural Gas	BBtu	458,638	506,943	506,720	530,911	731,936	60%
Coal	BBtu	670,514	777,527	803,378	812,052	786,757	17%
Waste Coal	BBtu	77,962	77,962	77,962	77,962	77,962	0%
Residual Fuel Oil	BBtu	96	96	96	96	96	0%
Distillate Fuel Oil	BBtu	6,014	2,004	1,843	1,635	1,680	-72%
Petroleum Coke	BBtu	-	-	-	-	-	N/A
Coal Mine Methane	BBtu	-	-	-	-	-	N/A
Other Fuel (CHP)	BBtu	54,607	54,607	54,607	54,607	54,607	0%

	Unit	2015	2020	2025	2030	2050	Change from 2005 to 2015
Pumped Storage	BBtu	NA	NA	NA	NA	NA	N/A
Expenditures	**$ Million**	**$3,422.40**	**$3,973.44**	**$4,263.43**	**$4,453.11**	**$6,009.56**	**76%**
Natural Gas	$ Million	$1,534.16	$1,960.95	$2,136.01	$2,275.67	$3,706.99	142%
Coal	$ Million	$1,551.78	$1,727.45	$1,840.52	$1,892.92	$2,010.61	30%
Waste Coal	$ Million	$246.34	$246.34	$246.34	$246.34	$246.34	0%
Residual Fuel Oil	$ Million	$1.72	$1.72	$1.72	$1.72	$1.72	0%
Distillate Fuel Oil	$ Million	$88.40	$36.98	$38.83	$36.45	$43.89	-50%
Petroleum Coke	$ Million	$0.00	$0.00	$0.00	$0.00	$0.00	N/A
Coal Mine Methane	$ Million	$0.00	$0.00	$0.00	$0.00	$0.00	N/A
Other Fuel (CHP)	$ Million	NE	NE	NE	NE	NE	N/A
Pumped Storage	$ Million	NA	NA	NA	NA	NA	N/A
GHG Emissions	**$MtCO_2e$**	**93,811,447**	**105,944,609**	**108,303,945**	**110,372,845**	**118,719,884**	**27%**
Natural Gas	$MtCO_2e$	24,356,356	26,921,637	26,909,787	28,194,480	38,870,051	60%
Coal	$MtCO_2e$	61,814,304	71,679,762	74,062,914	74,862,562	72,530,694	17%
Waste Coal	$MtCO_2e$	7,187,229	7,187,229	7,187,229	7,187,229	7,187,229	0%
Residual Fuel Oil	$MtCO_2e$	7,227	7,227	7,227	7,227	7,227	0%
Distillate Fuel Oil	$MtCO_2e$	446,331	148,754	136,788	121,348	124,684	-72%
Petroleum Coke	$MtCO_2e$	-	-	-	-	-	N/A
Coal Mine Methane	$MtCO_2e$	-	-	-	-	-	N/A
Other Fuel (CHP)	$MtCO_2e$	NE	NE	NE	NE	NE	N/A
Pumped Storage	$MtCO_2e$	NE	NE	NE	NE	NE	N/A
SO_2 Emissions	**MT**	**1,218,258**	**1,390,296**	**1,432,099**	**1,446,223**	**1,328,135**	**9%**
Natural Gas	MT	3,588	3,905	3,903	4,062	4,352	21%
Coal	MT	1,085,994	1,259,316	1,301,185	1,315,234	1,255,385	16%
Waste Coal	MT	126,270	126,270	126,270	126,270	67,726	-46%
Residual Fuel Oil	MT	4	4	4	4	-	-100%
Distillate Fuel Oil	MT	2,403	801	737	653	671	-72%
Petroleum Coke	MT	-	-	-	-	-	N/A
Coal Mine Methane	MT	-	-	-	-	-	N/A
Other Fuel (CHP)	MT	NE	NE	NE	NE	NE	N/A
Pumped Storage	MT	NE	NE	NE	NE	NE	N/A

	Unit	2015	2020	2025	2030	2050	Change from 2005 to 2015
NO_x Emissions	**MT**	**500,038**	**561,367**	**569,831**	**586,953**	**671,730**	**34%**
Natural Gas	MT	241,648	270,351	270,218	284,592	394,061	63%
Coal	MT	226,685	262,864	271,604	274,536	262,043	16%
Waste Coal	MT	26,357	26,357	26,357	26,357	14,137	-46%
Residual Fuel Oil	MT	19	19	19	19	-	-100%
Distillate Fuel Oil	MT	5,328	1,776	1,633	1,449	1,489	-72%
Petroleum Coke	MT	-	-	-	-	-	N/A
Coal Mine Methane	MT	-	-	-	-	-	N/A
Other Fuel (CHP)	MT	NE	NE	NE	NE	NE	N/A
Pumped Storage	MT	NE	NE	NE	NE	NE	N/A
Hg Emissions	**MT**	**1.1**	**1.3**	**1.3**	**1.3**	**1.3**	**17%**
Natural Gas	MT	0	0.1	0.1	0.1	0.1	60%
Coal	MT	1	1.1	1.1	1.2	1.1	17%
Waste Coal	MT	0	0.1	0.1	0.1	0.1	0%
Residual Fuel Oil	MT	0	0.0	0.0	0.0	0.0	0%
Distillate Fuel Oil	MT	0	0.0	0.0	0.0	0.0	-72%
Petroleum Coke	MT	-	-	-	-	-	N/A
Coal Mine Methane	MT	-	-	-	-	-	N/A
Other Fuel (CHP)	MT	NE	NE	NE	NE	NE	N/A
Pumped Storage	MT	NE	NE	NE	NE	NE	N/A

[a] There may be some overlap of energy consumption between electricity generation and other sectors due to the addition of energy consumption from small CHP units to the electricity generation sector. Any overlap would represent a small percentage of total consumption.

"NA" indicates that the value is not applicable.

"NE" indicates that the value was not estimated.

Table 46: Projected Electricity Generation from Renewable and Alternative Fuels by Fuel Type and Related Environmental and Economic Factors

	Unit	2015	2020	2025	2030	2050	Change from 2015 to 2050
Total Electricity Generation	**GWh**	**10,442**	**13,968**	**14,110**	**14,498**	**16,796**	**61%**
Utility-Scale Solar PV	GWh	33	186	364	542	1,255	3687%
Building-Scale Solar PV	GWh	178	498	520	542	631	255%
Hydroelectric	GWh	2,604	4,128	4,128	4,128	4,410	69%
Wind	GWh	3,353	4,139	4,140	4,161	4,621	38%
Wood and Biogenic Waste	GWh	2,582	3,295	3,231	3,394	4,131	60%
Landfill Gas Methane	GWh	1,621	1,648	1,648	1,648	1,648	2%
Digesters – Wastewater	GWh	40	40	40	40	40	0%
Digesters – Ag Waste	GWh	32	36	40	44	60	91%
Total Capacity	**MW**	**3,313**	**4,320**	**4,540**	**4,770**	**5,868**	**77%**
Utility-Scale Solar PV	MW	37	205	403	600	1,389	3687%
Building-Scale Solar PV	MW	197	551	575	600	699	255%
Hydroelectric	MW	920	1,011	1,011	1,011	1,052	14%
Wind	MW	1,334	1,662	1,662	1,670	1,818	36%
Wood and Biogenic Waste	MW	619	680	677	677	696	12%
Landfill Gas Methane	MW	195	198	198	198	198	2%
Digesters – Wastewater	MW	9	9	9	9	9	0%
Digesters – Ag Waste	MW	4	4	5	5	7	91%
Total Energy Consumption[a]	**BBtu**	**54,538**	**62,321**	**61,695**	**63,450**	**71,365**	**31%**
Utility-Scale Solar PV	BBtu	NA	NA	NA	NA	NA	N/A
Building-Scale Solar PV	BBtu	NA	NA	NA	NA	NA	N/A
Hydroelectric	BBtu	NA	NA	NA	NA	NA	N/A
Wind	BBtu	NA	NA	NA	NA	NA	N/A
Wood and Biogenic Waste	BBtu	28,236	35,713	35,040	36,748	44,478	58%
Biogas	BBtu	26,302	26,608	26,655	26,701	26,887	2%

	Unit	2015	2020	2025	2030	2050	Change from 2015 to 2050
Expenditures	**$ Million**	**$72.50**	**$104.96**	**$105.51**	**$114.29**	**$144.56**	**99%**
Utility-Scale Solar PV	$ Million	NA	NA	NA	NA	NA	N/A
Building-Scale Solar PV	$ Million	NA	NA	NA	NA	NA	N/A
Hydroelectric	$ Million	NA	NA	NA	NA	NA	N/A
Wind	$ Million	NA	NA	NA	NA	NA	N/A
Wood and Biogenic Waste	$ Million	$72.50	$104.96	$105.51	$114.29	$144.56	99%
Biogas	$ Million	NE	NE	NE	NE	NE	N/A
GHG Emissions	**$MtCO_2e$**	**25,496**	**25,793**	**25,838**	**25,883**	**26,063**	**2%**
Utility-Scale Solar PV	$MtCO_2e$	NA	NA	NA	NA	NA	N/A
Building-Scale Solar PV	$MtCO_2e$	NA	NA	NA	NA	NA	N/A
Hydroelectric	$MtCO_2e$	NA	NA	NA	NA	NA	N/A
Wind	$MtCO_2e$	NA	NA	NA	NA	NA	N/A
Wood and Biogenic Waste	$MtCO_2e$	-	-	-	-	-	N/A
Biogas	$MtCO_2e$	25,496	25,793	25,838	25,883	26,063	2%
SO_2 Emissions	**MT**	**947**	**1,138**	**1,123**	**1,167**	**1,367**	**44%**
Utility-Scale Solar PV	MT	NA	NA	NA	NA	NA	N/A
Building-Scale Solar PV	MT	NA	NA	NA	NA	NA	N/A
Hydroelectric	MT	NA	NA	NA	NA	NA	N/A
Wind	MT	NA	NA	NA	NA	NA	N/A
Wood and Biogenic Waste	MT	706	893	876	919	1,112	58%
Biogas	MT	241	245	247	248	255	6%
NO_x Emissions	**MT**	**5,125**	**6,173**	**6,140**	**6,421**	**7,664**	**50%**
Utility-Scale Solar PV	MT	NA	NA	NA	NA	NA	N/A
Building-Scale Solar PV	MT	NA	NA	NA	NA	NA	N/A
Hydroelectric	MT	NA	NA	NA	NA	NA	N/A
Wind	MT	NA	NA	NA	NA	NA	N/A
Wood and Biogenic Waste	MT	3,727	4,714	4,625	4,851	5,871	58%
Biogas	MT	1,398	1,459	1,514	1,570	1,793	28%
Hg Emissions	**MT**	**-**	**-**	**-**	**-**	**-**	**N/A**
Utility-Scale Solar PV	MT	NA	NA	NA	NA	NA	N/A

	Unit	2015	2020	2025	2030	2050	Change from 2015 to 2050
Building-Scale Solar PV	MT	NA	NA	NA	NA	NA	N/A
Hydroelectric	MT	NA	NA	NA	NA	NA	N/A
Wind	MT	NA	NA	NA	NA	NA	N/A
Wood and Biogenic Waste	MT	NE	NE	NE	NE	NE	N/A
Biogas	MT	NE	NE	NE	NE	NE	N/A

[a] There may be some overlap of energy consumption between electricity generation and other sectors due to the addition of energy consumption from small CHP units to the electricity generation sector. Any overlap would represent a small percentage of total consumption.
"NA" indicates that the value is not applicable.
"NE" indicates that the value was not estimated.

Table 47: Projected Electricity Generation from Traditional Nuclear and Related Environmental and Economic Factors

	Unit	2015	2020	2025	2030	2050	Change from 2015 to 2050
Total Electricity Generation	GWh	80,517	59,546	60,058	60,044	48,955	-39%
Total Capacity	MW	10,322	7,828	7,897	7,898	6,383	-38%
Total Energy Consumption	BBtu	842	623	628	628	512	-39%
Expenditures	$ Million	602	337	343	343	226	-62%
GHG Emissions	$MTCO_2e$	NA	NA	NA	NA	NA	N/A
SO_2 Emissions	MT	NA	NA	NA	NA	NA	N/A
NO_x Emissions	MT	NA	NA	NA	NA	NA	N/A
Hg Emissions	MT	NA	NA	NA	NA	NA	N/A

"NA" indicates that the value is not applicable.

Historical Energy Imports and Exports

Table 48: Historical Energy Imports and Exports by Fuel Type

	Unit	2000	2005	2010	2015	Change from 2005 to 2015
Electricity						
Production	GWh	724,240	784,979	830,641	768,259	-2%
Consumption	GWh	456,681	505,908	508,265	499,325	-1%
Imports	GWh	-	104	2,623	1,933	1763%
Exports	GWh	176,156	180,367	232,864	187,419	4%

	Unit	2000	2005	2010	2015	Change from 2005 to 2015
Fossil Fuels						
Coal						
Production	BBtu	1,741,490	1,589,354	1,336,164	1,113,859	-30%
Consumption	BBtu	1,497,705	1,480,449	1,300,283	868,442	-41%
Net Imports	BBtu	(243,785)	(108,905)	(35,882)	(245,417)	125%
Natural Gas[a]						
Production	BBtu	156,171	176,540	600,849	5,128,439	2805%
Consumption	BBtu	706,874	656,276	847,123	1,278,409	95%
Imports	BBtu	2,468,602	2,176,857	2,431,721	554,746	-75%
Exports	BBtu	1,934,299	1,636,349	2,125,245	4,440,236	171%
Crude Oil						
Production	BBtu	8,700	14,268	18,769	39,979	180%
Consumption	BBtu	1,213,230	1,254,075	1,023,918	971,918	-22%
Net Imports	BBtu	1,204,530	1,239,807	1,005,149	931,939	-25%
Coal Mine Methane						
Production	BBtu	79.1	951.6	1,426.6	1,426.6	50%
Consumption	BBtu	79.1	951.6	1,426.6	355.6	-63%
Net Imports	BBtu	-	-	-	(1,071.0)	N/A
Renewable and Alternative Fuels						
Landfill Gas Methane						
Production	BBtu	3,303	5,928	17,744	25,535	331%
Consumption	BBtu	3,303	5,928	17,744	25,535	331%
Net Imports	BBtu	-	-	-	-	N/A
Biodiesel						
Production	BBtu	-	1,287	2,574	3,070	139%
Consumption	BBtu	3,338	3,690	3,258	3,589	-3%
Net Imports	BBtu	3,338	2,403	684	519	-78%
Ethanol						
Production	BBtu	-	-	-	9,319	N/A
Consumption	BBtu	1,107	4,741	39,684	38,759	718%
Net Imports	BBtu	1,107	4,741	39,684	29,441	521%

[a] Natural gas exports exceeding production from 2000 to 2010. This is likely due to pipeline passthrough volumes through Pennsylvania being counted as both imports and exports.

Future Energy Imports and Exports Trends

Table 49: Projected Energy Imports and Exports by Fuel Type

	Unit	2015	2020	2025	2030	2050	Change from 2015 to 2050
Electricity							
Production	GWh	768,259	784,291	795,048	811,520	909,924	18%
Consumption	GWh	499,325	490,310	499,967	493,857	496,899	0%
Imports	GWh	1,933	1,933	1,933	1,933	1,933	0%
Exports	GWh	187,419	213,972	213,458	237,062	331,915	77%
Fossil Fuels							
Coal							
Production	BBtu	1,113,859	978,922	989,396	910,803	858,355	-23%
Consumption	BBtu	868,442	946,249	959,752	949,798	849,667	-2%
Net Imports	BBtu	(245,417)	(32,672)	(29,644)	38,995	(8,688)	-96%
Natural Gas							
Production	BBtu	5,128,439	6,594,754	7,219,480	7,744,559	10,194,872	99%
Consumption	BBtu	1,278,409	1,382,976	1,395,540	1,440,084	1,804,193	41%
Imports	BBtu	554,746	527,009	499,272	471,534	360,585	-35%
Exports	BBtu	4,440,236	5,738,787	6,323,211	6,776,009	8,751,264	97%
Crude Oil							
Production	BBtu	39,979	47,687	45,074	42,921	79,254	98%
Consumption	BBtu	971,918	949,894	887,680	821,445	791,086	-19%
Net Imports	BBtu	931,939	902,207	842,606	778,524	711,831	-24%
Coal Mine Methane							
Production	BBtu	1,426.6	1,426.6	1,426.6	1,426.6	1,426.6	0%
Consumption	BBtu	355.6	299.2	275.8	265.3	252.5	-29%
Net Imports	BBtu	(1,071.0)	(1,127.4)	(1,150.8)	(1,161.3)	(1,174.1)	10%
Renewable and Alternative Fuels							
Landfill Gas Methane							
Production	BBtu	25,535	25,795	25,795	25,795	25,795	1%
Consumption	BBtu	25,535	25,795	25,795	25,795	25,795	1%
Net Imports	BBtu	-	-	-	-	-	N/A
Biodiesel							
Production	BBtu	3,070	3,349	3,349	3,349	3,349	9%
Consumption	BBtu	3,589	3,587	3,584	3,397	3,486	-3%
Net Imports	BBtu	519	238	235	48	137	-74%
Ethanol							
Production	BBtu	9,319	9,319	9,319	9,319	9,319	0%
Consumption	BBtu	38,759	40,549	42,557	41,885	65,972	70%
Net Imports	BBtu	29,441	31,230	33,238	32,566	56,653	92%

Appendix B. Detailed Resource Potential Data

Table 50: Energy Conservation Potential by Sector and Fuel Type and Related Environmental Factors Compared to BAU Consumption

	Unit	Annualized Economic Potential					Economic Potential	Technical Potential
		2018	2020	2025	2030	2050		
BAU Electricity Consumption	**BBtu**	**487,765**	**490,310**	**499,967**	**493,857**	**496,899**	**NA**	**NA**
Total Energy Conservation Potential – Electricity	**BBtu**	**10,892**	**18,014**	**22,949**	**22,977**	**22,185**	**23,748**	**54,741**
Residential	BBtu	7,728	12,688	12,105	11,994	11,350	12,688	21,971
Commercial	BBtu	2,227	3,741	7,536	7,527	7,335	7,559	25,657
Industrial	BBtu	938	1,585	3,308	3,457	3,501	3,501	7,112
Transportation	BBtu	NE	NE	NE	NE	NE	NE	NE
BAU Electricity Consumption	**GWh**	**142,956**	**143,702**	**146,532**	**144,742**	**145,634**	**NA**	**NA**
Total Energy Conservation Potential – Electricity	**GWh**	**3,194**	**5,283**	**6,730**	**6,738**	**6,506**	**6,964**	**16,053**
Residential	GWh	2,266	3,721	3,550	3,517	3,328	3,721	6,443
Commercial	GWh	653	1,097	2,210	2,207	2,151	2,217	7,524
Industrial	GWh	275	465	970	1,014	1,027	1,027	2,086
Transportation	GWh	NE	NE	NE	NE	NE	NE	NE
BAU Natural Gas Consumption	**BBtu**	**921,843**	**944,789**	**957,577**	**977,929**	**1,141,014**	**NA**	**NA**
Total Energy Conservation	**BBtu**	**13,048**	**21,958**	**33,280**	**33,731**	**36,209**	**37,198**	**118,516**

	Unit	Annualized Economic Potential					Economic Potential	Technical Potential
		2018	2020	2025	2030	2050		
Potential – Natural Gas								
Residential	BBtu	6,602	10,986	10,822	10,728	10,022	11,010	21,933
Commercial	BBtu	946	1,592	3,215	3,309	4,109	4,109	30,333
Industrial	BBtu	5,500	9,380	19,243	19,693	22,078	22,078	66,250
Transportation	BBtu	NE	NE	NE	NE	NE	NE	NE
BAU Motor Gasoline Consumption	**BBtu**	**555,498**	**533,553**	**472,983**	**423,539**	**392,430**	**NA**	**NA**
Total Energy Conservation Potential – Motor Gasoline	**BBtu**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**
Residential	BBtu	NE	NE	NE	NE	NE	NE	NE
Commercial	BBtu	NE	NE	NE	NE	NE	NE	NE
Industrial	BBtu	NE	NE	NE	NE	NE	NE	NE
Transportation	BBtu	NE	NE	NE	NE	NE	NE	NE
BAU Diesel Consumption	**BBtu**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**
Total Energy Conservation Potential – Diesel	**BBtu**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**
Residential	BBtu	NE	NE	NE	NE	NE	NE	NE
Commercial	BBtu	NE	NE	NE	NE	NE	NE	NE
Industrial	BBtu	NE	NE	NE	NE	NE	NE	NE
Transportation	BBtu	NE	NE	NE	NE	NE	NE	NE
GHG Emissions Savings – Total for All Fuels	**$MtCO_2e$**	**2,136,092**	**3,552,839**	**4,807,767**	**4,835,403**	**4,862,183**	**5,121,754**	**13,547,950**

	Unit	Annualized Economic Potential					Economic Potential	Technical Potential
		2018	2020	2025	2030	2050		
Residential	$MtCO_2e$	1,374,565	2,264,725	2,178,747	2,159,046	2,036,181	2,266,034	4,076,408
Commercial	$MtCO_2e$	345,240	580,063	1,168,995	1,172,803	1,189,955	1,219,673	5,011,425
Industrial	$MtCO_2e$	416,287	708,050	1,460,025	1,503,554	1,636,047	1,636,047	4,460,117
Transportation	$MtCO_2e$	NE	NE	NE	NE	NE	NE	NE
SO2 Emissions Savings – Total for All Fuels	**MT**	**3,617**	**5,982**	**7,622**	**7,632**	**7,370**	**7,888**	**18,192**
NO_x Emissions Savings – Total for All Fuels	**MT**	**2,265**	**3,762**	**5,013**	**5,036**	**5,014**	**5,302**	**13,581**
Hg Emissions Savings – Total for All Fuels	**MT**	**0.1**	**0.1**	**0.2**	**0.2**	**0.1**	**0.2**	**0.4**

Note: “NE” indicates that the value was not estimated.

Table 51: Energy Efficiency Potential by Sector and Fuel Type and Related Environmental Factors Compared to BAU Consumption

	Unit	Annualized Economic Potential					Economic Potential	Technical Potential
		2018	*2020*	*2025*	*2030*	*2050*		
BAU Electricity Consumption	**BBtu**	**487,765**	**490,310**	**499,967**	**493,857**	**496,899**	**NA**	**NA**
Total Energy Efficiency Potential – Electricity	**BBtu**	**46,588**	**58,835**	**91,883**	**81,037**	**97,002**	**110,461**	**196,204**
Residential	BBtu	29,915	32,605	44,818	29,567	31,359	44,818	85,967
Commercial	BBtu	9,038	13,908	23,205	23,940	30,114	30,114	39,179
Industrial	BBtu	7,635	12,322	23,860	27,530	35,529	35,529	71,058
Transportation	BBtu	NE	NE	NE	NE	NE	NE	NE
BAU Electricity Consumption	**GWh**	**142,956**	**143,702**	**146,532**	**144,742**	**145,634**	**NA**	**NA**

	Unit	Annualized Economic Potential					Economic Potential	Technical Potential
		2018	*2020*	*2025*	*2030*	*2050*		
Total Energy Efficiency Potential – Electricity	**GWh**	**13,662**	**17,254**	**26,945**	**23,764**	**28,446**	**32,393**	**57,538**
Residential	GWh	8,773	9,562	13,143	8,671	9,196	13,143	25,210
Commercial	GWh	2,651	4,079	6,805	7,021	8,831	8,831	11,489
Industrial	GWh	2,239	3,614	6,997	8,073	10,419	10,419	20,838
Transportation	GWh	NE	NE	NE	NE	NE	NE	NE
BAU Natural Gas Consumption	**BBtu**	**921,843**	**944,789**	**957,577**	**977,929**	**1,141,014**	**NA**	**NA**
Total Energy Efficiency Potential – Natural Gas	**BBtu**	**71,774**	**92,474**	**145,948**	**120,861**	**151,118**	**195,824**	**356,730**
Residential	BBtu	42,017	45,795	62,948	34,598	31,698	62,948	117,889
Commercial	BBtu	17,917	27,571	46,000	31,749	32,545	46,000	65,090
Industrial	BBtu	11,840	19,108	37,000	54,514	86,876	86,876	173,751
Transportation	BBtu	NE	NE	NE	NE	NE	NE	NE
BAU Motor Gasoline Consumption	**BBtu**	**555,498**	**533,553**	**472,983**	**423,539**	**392,430**	**NA**	**NA**
Total Energy Efficiency Potential – Motor Gasoline	**BBtu**	**944**	**991**	**1,096**	**5,897**	**62,703**	**62,703**	**551,093**
Residential	BBtu	NE	NE	NE	NE	NE	NE	NE
Commercial	BBtu	NE	NE	NE	NE	NE	NE	NE
Industrial	BBtu	NE	NE	NE	NE	NE	NE	NE
Transportation	BBtu	944	991	1,096	5,897	62,703	62,703	551,093

	Unit	Annualized Economic Potential					Economic Potential	Technical Potential
		2018	*2020*	*2025*	*2030*	*2050*		
BAU Diesel Consumption	**BBtu**	**369,847**	**365,143**	**360,556**	**341,835**	**332,793**	**NA**	**NA**
Total Energy Efficiency Potential – Diesel	**BBtu**	NE	NE	NE	NE	NE	NE	NE
Residential	BBtu	NE	NE	NE	NE	NE	NE	NE
Commercial	BBtu	NE	NE	NE	NE	NE	NE	NE
Industrial	BBtu	NE	NE	NE	NE	NE	NE	NE
Transportation	BBtu	NE	NE	NE	NE	NE	NE	NE
GHG Emissions Savings – Total for All Fuels	**$MtCO_2e$**	**10,054,438**	**12,780,175**	**20,007,199**	**17,578,799**	**25,371,978**	**29,532,608**	**53,954,880**
Residential	$MtCO_2e$	6,196,831	6,754,034	9,283,912	5,755,997	5,839,112	9,283,912	17,656,011
Commercial	$MtCO_2e$	2,150,117	3,308,596	5,520,199	4,859,357	5,719,221	6,435,051	8,651,087
Industrial	$MtCO_2e$	1,639,839	2,646,518	5,124,553	6,540,674	9,318,570	9,318,570	18,637,141
Transportation	$MtCO_2e$	67,650	71,027	78,536	422,771	4,495,075	4,495,075	9,010,642
SO_2 Emissions Savings – Total for All Fuels	**MT**	**15,476**	**19,544**	**30,522**	**26,919**	**32,254**	**36,731**	**65,253**
NO_x Emissions Savings – Total for All Fuels	**MT**	**10,499**	**13,284**	**20,695**	**18,084**	**23,034**	**27,019**	**48,683**
Hg Emissions Savings – Total for All Fuels	**MT**	**0.3**	**0.4**	**0.6**	**0.5**	**0.6**	**0.7**	**1.3**

Note: “NE” indicates that the value was not estimated.

Table 52: Energy Production Potential for Fossil Fuels by Fuel Type and Related Economic and Environmental Factors

Fuel Type	Unit	Annualized Economic Potential					Economic Potential	Technical Potential
		2018	2020	2025	2030	2050		
BAU Fossil Fuel Consumption	**BBtu**	**3,928,778**	**3,966,838**	**3,967,135**	**3,945,116**	**4,241,188**	**NA**	**NA**
Production Potential								
Coal	BBtu	972,646	1,117,838	1,208,110	1,065,734	969,148	218,012,036	220,651,650
Crude Oil	BBtu	41,914	50,437	55,163	57,328	118,624	4,694,604	4,699,376
Natural Gas	BBtu	5,763,991	6,432,482	7,349,875	8,449,250	12,235,472	252,814,761	346,690,201
Propane	BBtu	72,858	81,308	92,904	106,800	154,658	4,250,375	4,254,545
Waste Coal	BBtu	114,066	114,066	114,066	114,066	114,066	3,992,294	5,033,810
Coal Mine Methane	BBtu	1,360	1,634	2,091	2,247	2,541	75,392	150,672
Production Prices Tied to Production Potential								
Coal	$/MMBtu	$2.70	$2.73	$2.91	$3.01	$3.49	$3.60	NA
Crude Oil	$/MMBtu	$19.36	$24.78	$31.04	$33.48	$40.41	$40.50	NA
Natural Gas	$/MMBtu	$2.56	$3.02	$3.78	$4.15	$5.78	$6.00	NA
Propane	$/MMBtu	$14.62	$18.20	$22.86	$26.60	$47.31	$47.40	NA
Waste Coal	$/MMBtu	$3.16	$3.16	$3.16	$3.16	$3.16	$3.16	NA
Coal Mine Methane	$/MMBtu	$3.14	$4.31	$6.95	$8.00	$10.23	$10.23	NA
Potential Greenhouse Gas Emissions from Consuming Fuels Produced								
Coal	$MtCO_2e$	89,667,665	103,052,824	111,374,963	98,249,342	89,345,140	20,098,397,411	20,341,741,782
Crude Oil	$MtCO_2e$	3,046,456	3,665,883	4,009,366	4,166,772	8,621,940	341,216,575	341,563,401
Natural Gas	$MtCO_2e$	306,101,471	341,602,237	390,321,167	448,704,374	649,774,764	13,425,935,367	18,411,267,618
Propane	$MtCO_2e$	4,528,117	5,053,275	5,773,968	6,637,623	9,612,030	264,161,474	264,420,647
Waste Coal	$MtCO_2e$	10,515,633	10,515,633	10,515,633	10,515,633	10,515,633	368,047,141	464,063,909
Coal Mine Methane	$MtCO_2e$	72,230	86,755	111,064	119,309	134,939	4,003,775	8,001,573
Potential Sulfur Dioxide Emissions from Consuming Fuels Produced								
Coal	MT	1,575,340	1,810,499	1,956,707	1,726,108	1,569,673	353,101,638	357,376,869

Fuel Type	Unit	Annualized Economic Potential					Economic Potential	Technical Potential
		2018	2020	2025	2030	2050		
Crude Oil	MT	432	518	562	579	1,198	47,417	47,465
Natural Gas	MT	1,526	1,703	1,946	2,237	3,239	66,931	91,784
Propane	MT	19	21	24	27	39	1,083	1,084
Waste Coal	MT	184,745	184,745	184,745	184,745	184,745	6,466,090	8,152,975
Coal Mine Methane	MT	0.4	0.4	0.6	0.6	0.7	20.0	39.9
Potential Nitrogen Oxides Emissions from Consuming Fuels Produced								
Coal	MT	328,829	377,915	408,434	360,300	327,646	73,704,838	74,597,231
Crude Oil	MT	4,479	5,149	4,973	4,485	8,723	345,206	345,557
Natural Gas	MT	239,070	266,796	304,846	350,444	507,483	10,485,845	14,379,460
Propane	MT	5,066	5,653	6,459	7,426	10,753	295,525	295,815
Waste Coal	MT	38,563	38,563	38,563	38,563	38,563	1,349,702	1,701,815
Coal Mine Methane	MT	56	68	87	93	105	3,127	6,249
Potential Mercury Emissions from Consuming Fuels Produced								
Coal	MT	1.4	1.6	1.7	1.5	1.4	311.4	315.2
Crude Oil	MT	0.1	0.1	0.1	0.1	0.2	6.4	6.4
Natural Gas	MT	0.7	0.7	0.8	1.0	1.4	29.0	39.8
Propane	MT	NE	NE	NE	NE	NE	NE	NE
Waste Coal	MT	0.2	0.2	0.2	0.2	0.2	5.7	7.2
Coal Mine Methane	MT	0.0002	0.0002	0.0002	0.0003	0.0003	0.0086	0.0173

Note: “NE” indicates that the value was not estimated. “NA” indicates that the value is not applicable.

Table 53: Energy Production Economic Potential for Fossil Fuels in Sectoral Equivalents by Fuel Type

Fuel Type	Unit	Annualized Economic Potential				
		2018	*2020*	*2025*	*2030*	*2050*
Production Potential						
Coal	BBtu	972,646	1,117,838	1,208,110	1,065,734	969,148
Crude Oil	BBtu	41,914	50,437	55,163	57,328	118,624
Natural Gas	BBtu	5,763,991	6,432,482	7,349,875	8,449,250	12,235,472
Propane	BBtu	72,858	81,308	92,904	106,800	154,658
Waste Coal	BBtu	114,066	114,066	114,066	114,066	114,066
Coal Mine Methane	BBtu	1,360	1,634	2,091	2,247	2,541
Residential Sector Equivalency – Share of BAU Sectoral Fuel Consumption for a Fuel Type that Could be Met by In-State Production						
Coal	% of BAU Consumption	NA	NA	NA	NA	NA
Crude Oil	% of BAU Consumption	43%	55%	67%	76%	226%
Natural Gas	% of BAU Consumption	2466%	2775%	3216%	3735%	5790%
Propane	% of BAU LPG Consumption	468%	536%	646%	778%	1329%
Waste Coal	% of BAU Consumption	NA	NA	NA	NA	NA
Coal Mine Methane	% of BAU Consumption	597%	717%	918%	986%	1115%
Commercial Sector Equivalency – Share of BAU Sectoral Fuel Consumption for a Fuel Type that Could be Met by In-State Production						
Coal	% of BAU Consumption	39871%	42371%	44065%	38929%	35892%
Crude Oil	% of BAU Consumption	99%	123%	139%	147%	322%
Natural Gas	% of BAU Consumption	3553%	3992%	4487%	4917%	5639%
Propane	% of BAU LPG Consumption	828%	926%	1030%	1145%	1467%
Waste Coal	% of BAU Consumption	NA	NA	NA	NA	NA

Fuel Type	Unit	Annualized Economic Potential				
		2018	*2020*	*2025*	*2030*	*2050*
Coal Mine Methane	% of BAU Consumption	859%	1032%	1321%	1419%	1605%
Industrial Sector Equivalency – Share of BAU Sectoral Fuel Consumption for a Fuel Type that Could be Met by In-State Production						
Coal	% of BAU Consumption	534%	629%	731%	727%	1349%
Crude Oil	% of BAU Consumption	46%	54%	55%	57%	107%
Natural Gas	% of BAU Consumption	1231%	1322%	1490%	1716%	2113%
Propane	% of BAU LPG Consumption	241%	263%	291%	340%	480%
Waste Coal	% of BAU Consumption	NA	NA	NA	NA	NA
Coal Mine Methane	% of BAU Consumption	285%	342%	437%	470%	532%
Transport Sector Equivalency – Share of BAU Sectoral Fuel Consumption for a Fuel Type that Could be Met by In-State Production						
Coal	% of BAU Consumption	NA	NA	NA	NA	NA
Crude Oil	% of BAU Consumption	5%	6%	8%	9%	18%
Natural Gas	% of BAU Consumption	10027%	9844%	10195%	9646%	9161%
Propane	% of BAU LPG Consumption	NA	NA	NA	NA	NA
Waste Coal	% of BAU Consumption	NA	NA	NA	NA	NA
Coal Mine Methane	% of BAU Consumption	2118%	2544%	3257%	3499%	3957%
Electricity Generation Sector Equivalency – Share of BAU Sectoral Fuel Consumption for a Fuel Type that Could be Met by In-State Production						
Coal	% of BAU Consumption	141%	144%	150%	131%	123%

Fuel Type	Unit	Annualized Economic Potential				
		2018	*2020*	*2025*	*2030*	*2050*
Crude Oil	% of BAU Consumption	2302%	2401%	2845%	3312%	6680%
Natural Gas	% of BAU Consumption	1135%	1269%	1450%	1591%	1672%
Propane	% of BAU LPG Consumption	NA	NA	NA	NA	NA
Waste Coal	% of BAU Consumption	146%	146%	146%	146%	146%
Coal Mine Methane	% of BAU Consumption	273%	328%	420%	451%	510%
Equivalency for All Sectors (Excluding Electricity Generation) - Share of BAU Sectoral Fuel Consumption for a Fuel Type that Could be Met by In-State Production						
Coal	% of BAU Consumption	527%	620%	719%	713%	1300%
Crude Oil	% of BAU Consumption	2%	3%	3%	3%	7%
Natural Gas	% of BAU Consumption	625%	681%	768%	864%	1072%
Propane	% of BAU LPG Consumption	130%	144%	163%	190%	273%
Waste Coal	% of BAU Consumption	NA	NA	NA	NA	NA
Coal Mine Methane	% of BAU Consumption	NA	NA	NA	NA	NA

Note: “NE” indicates that the value was not estimated. “NA” indicates that the value is not applicable.

Table 54: Energy Production Potential for Renewable and Alternative Fuels by Fuel Type and Related Economic and Environmental Factors

Fuel Type	Unit	Annualized Economic Potential					Economic Potential	Technical Potential
		2018	*2020*	*2025*	*2030*	*2050*		
BAU Renewable and Alternative Fuel Consumption	BBtu	141,067	147,646	149,257	148,995	179,862	NA	NA
Production Potential								
Landfill Methane	BBtu	25,859	26,087	26,695	27,358	29,008	29,008	32,349
Digesters – Wastewater	BBtu	679	722	838	966	1,602	1,602	1,602
Digesters – Ag Waste	BBtu	842	1,171	2,059	3,043	7,930	7,930	7,930
Biodiesel	BBtu	10,084	10,307	11,086	11,320	11,508	11,591	NE
Corn Ethanol	BBtu	47,945	50,233	55,702	60,706	51,510	60,706	NE
Cellulosic Ethanol	BBtu	9,779	18,120	31,443	34,066	35,771	40,461	NE
Biomass Solids – Low-Use Wood	BBtu	46,697	50,529	60,107	69,686	108,000	2,640,150	10,312,200
Production Prices Tied to Production Potential								
Landfill Methane	$/MMBtu	NE	NE	NE	NE	NE	NE	NA
Digesters – Wastewater	$/MMBtu	NE	NE	NE	NE	NE	NE	NA
Digesters – Ag Waste	$/MMBtu	NE	NE	NE	NE	NE	NE	NA
Biodiesel	$/MMBtu	$4.31	$4.31	$4.31	$4.31	$4.31	$4.31	NA
Corn Ethanol	$/MMBtu	$3.51	$3.51	$3.51	$3.51	$3.51	$3.51	NA
Cellulosic Ethanol	$/MMBtu	$10.99	$10.99	$10.99	$10.99	$10.99	$10.99	NA
Biomass Solids – Low-Use Wood	$/MMBtu	NE	NE	NE	NE	NE	NE	NA
Potential Greenhouse Gas Emissions from Consuming Fuels Produced								
Landfill Methane	$MtCO_2e$	25,067	25,288	25,877	26,520	28,119	28,119	31,358
Digesters – Wastewater	$MtCO_2e$	658	700	812	936	1,553	1,553	1,553
Digesters – Ag Waste	$MtCO_2e$	816	1,135	1,996	2,950	7,687	7,687	7,687
Biodiesel	$MtCO_2e$	0	0	0	0	0	0	NE
Corn Ethanol	$MtCO_2e$	0	0	0	0	0	0	NE
Cellulosic Ethanol	$MtCO_2e$	0	0	0	0	0	0	NE
Biomass Solids – Low-Use Wood	$MtCO_2e$	0	0	0	0	0	0	0

Fuel Type	Unit	Annualized Economic Potential					Economic Potential	Technical Potential
		2018	*2020*	*2025*	*2030*	*2050*		
Potential Sulfur Dioxide Emissions from Consuming Fuels Produced								
Landfill Methane	MT	30,975	31,248	31,977	32,771	34,747	34,747	38,749
Digesters – Wastewater	MT	814	865	1,003	1,157	1,919	1,919	1,919
Digesters – Ag Waste	MT	1,008	1,402	2,467	3,645	9,499	9,499	9,499
Biodiesel	MT	NE	NE	NE	NE	NE	NE	NE
Corn Ethanol	MT	8,146	8,202	8,171	7,899	3,579	4,218	NE
Cellulosic Ethanol	MT	1,662	2,958	4,613	4,433	2,485	2,811	NE
Biomass Solids – Low-Use Wood	MT	6,164	6,670	7,934	9,199	14,256	348,500	1,361,210
Potential Nitrogen Oxides Emissions from Consuming Fuels Produced								
Landfill Methane	MT	0	0	0	0	0	0	0
Digesters – Wastewater	MT	0	0	0	0	0	0	0
Digesters – Ag Waste	MT	0	0	0	0	0	0	0
Biodiesel	MT	NE	NE	NE	NE	NE	NE	NE
Corn Ethanol	MT	0	0	0	0	0	0	NE
Cellulosic Ethanol	MT	0	0	0	0	0	0	NE
Biomass Solids – Low-Use Wood	MT	0	0	0	0	0	0	0
Potential Mercury Emissions from Consuming Fuels Produced								
Landfill Methane	MT	NE	NE	NE	NE	NE	NE	NE
Digesters – Wastewater	MT	NE	NE	NE	NE	NE	NE	NE
Digesters – Ag Waste	MT	NE	NE	NE	NE	NE	NE	NE
Biodiesel	MT	NE	NE	NE	NE	NE	NE	NE
Corn Ethanol	MT	NE	NE	NE	NE	NE	NE	NE
Cellulosic Ethanol	MT	NE	NE	NE	NE	NE	NE	NE
Biomass Solids – Low-Use Wood	MT	NE	NE	NE	NE	NE	NE	NE

Note: “NE” indicates that the value was not estimated. “NA” indicates that the value is not applicable.

Table 55: Energy Production Economic Potential for Renewable and Alternative Fuels in Sectoral Equivalents by Fuel Type

Fuel Type	Unit	Annualized Economic Potential				
		2018	*2020*	*2025*	*2030*	*2050*
Production Potential						
Landfill Methane	BBtu	25,859	26,087	26,695	27,358	29,008
Digesters – Wastewater	BBtu	679	722	838	966	1,602
Digesters – Ag Waste	BBtu	842	1,171	2,059	3,043	7,930
Biodiesel	BBtu	10,084	10,307	11,086	11,320	11,508
Corn Ethanol	BBtu	47,945	50,233	55,702	60,706	51,510
Cellulosic Ethanol	BBtu	9,779	18,120	31,443	34,066	35,771
Biomass Solids – Low-Use Wood	BBtu	46,697	50,529	60,107	69,686	108,000
Transport Sector Equivalency – Share of BAU Sectoral Fuel Consumption for a Fuel Type that Could be Met by In-State Production						
Biodiesel	% of BAU Consumption	278%	287%	309%	333%	330%
Corn Ethanol	% of BAU Consumption	129%	129%	136%	150%	81%
Cellulosic Ethanol	% of BAU Consumption	33098%	58316%	96421%	106138%	70761%
Industrial Sector Equivalency –Production Potential						
Landfill Methane	% of BAU Consumption	101%	102%	105%	107%	114%
Digesters – Wastewater	% of BAU Consumption	166%	177%	205%	236%	392%
Digesters – Ag Waste	% of BAU Consumption	235%	327%	574%	849%	2212%
All Sectors – Production Potential						
Biomass Solids – Low-Use Wood	% of BAU Biomass Consumption from Forests	114%	123%	147%	170%	264%

Table 56: Electricity Generation Potential for Fossil Fuels by Fuel Type and Related Economic and Environmental Factors

Fuel Type	Unit	Annualized Economic Potential					Economic Potential	Technical Potential
		2018	*2020*	*2025*	*2030*	*2050*		
Electricity Generation Potential								
Coal	GWh	69,348	78,547	81,837	83,669	83,380	NA	NA
Natural Gas	GWh	69,307	69,948	69,861	84,327	116,123	NA	NA
Waste Coal	GWh	9,585	9,585	9,585	9,585	9,585	9,585	NE
Electricity Generation Capacity Potential								
Coal	MW	14,186	14,020	14,362	15,477	17,300	NA	NA
Natural Gas	MW	16,095	16,373	16,279	16,949	22,094	NA	NA
Waste Coal	MW	1,615	1,615	1,615	1,615	1,615	1,615	NE
Fuel Consumption for Potential Generation								
Coal	BBtu	716,754	819,767	879,386	928,896	1,007,963	NA	NA
Natural Gas	BBtu	505,186	507,109	506,423	593,478	754,140	NA	NA
Waste Coal	BBtu	114,066	114,066	114,066	114,066	114,066	114,066	NE
Generation Fuel Price								
Coal	$/MMBtu	$1.80	$1.84	$1.95	$2.02	$2.42	NA	NA
Natural Gas	$/MMBtu	$2.63	$3.30	$3.51	$3.72	$4.75	NA	NA
Waste Coal	$/MMBtu	$3.16	$3.16	$3.16	$3.16	$3.16	$3.16	NA
Greenhouse Gas Emissions								
Coal	$MtCO_2e$	66,077,071	75,573,827	81,070,096	85,634,370	92,923,459	NA	NA
Natural Gas	$MtCO_2e$	26,828,321	26,930,431	26,894,033	31,517,161	40,049,223	NA	NA
Waste Coal	$MtCO_2e$	10,515,633	10,515,633	10,515,633	10,515,633	10,515,633	10,515,633	NE
Sulfur Dioxide Emissions								
Coal	MT	112,319	127,218	132,546	135,513	135,046	NA	NA
Natural Gas	MT	18	19	18	22	31	NA	NA
Waste Coal	MT	15,524	15,524	15,524	15,524	15,524	15,524	NE

Fuel Type	Unit	Annualized Economic Potential					Economic Potential	Technical Potential
		2018	**2020**	**2025**	**2030**	**2050**		
Nitrogen Oxides Emissions								
Coal	MT	23,445	26,555	27,667	28,286	28,189	NA	NA
Natural Gas	MT	2,875	2,901	2,898	3,498	4,816	NA	NA
Waste Coal	MT	3,240	3,240	3,240	3,240	3,240	3,240	NE
Mercury Emissions								
Coal	MT	0.10	0.11	0.12	0.12	0.12	NA	NA
Natural Gas	MT	0.01	0.01	0.01	0.01	0.01	NA	NA
Waste Coal	MT	0.01	0.01	0.01	0.01	0.01	0.01	NE

Note: "NE" indicates that the value was not estimated. "NA" indicates that the value is not applicable.

Table 57: Electricity Generation Potential for Renewable and Alternative Fuels by Fuel Type and Related Economic Factors

Fuel Type	Unit	Annualized Economic Potential					Economic Potential	Technical Potential
		2018	**2020**	**2025**	**2030**	**2050**		
Electricity Generation Potential								
Utility-Scale Solar PV	GWh	7,083	11,783	23,533	35,282	82,281	82,281	1,105,862
Building-Scale Solar PV – Residential	GWh	652	1,025	1,959	2,892	6,625	6,625	26,567
Building-Scale Solar PV – Commercial	GWh	603	948	1,810	2,672	6,121	6,121	24,548
Hydroelectric	GWh	3,523	4,393	4,423	4,673	5,033	5,033	13,000
Wind	GWh	3,784	3,957	4,390	4,822	6,552	6,552	35,000
Landfill Methane	GWh	1,654	1,678	1,740	1,808	1,977	1,977	2,320
Digesters – Wastewater	GWh	66	70	81	94	156	156	156
Digesters – Ag Waste	GWh	70	98	172	254	662	662	662
Biomass Solids – Low-Use Wood	GWh	1,697	1,791	2,026	2,261	3,201	3,201	NA

Fuel Type	Unit	Annualized Economic Potential					Economic Potential	Technical Potential
		2018	*2020*	*2025*	*2030*	*2050*		
Electricity Generation Capacity Potential								
Utility-Scale Solar PV	MW	5,403	8,980	17,924	26,868	62,643	62,643	841,600
Building-Scale Solar PV – Residential	MW	526	808	1,513	2,219	5,042	5,042	20,218
Building-Scale Solar PV – Commercial	MW	486	746	1,398	2,050	4,658	4,658	18,682
Hydroelectric	MW	1,244	1,551	1,562	1,650	1,777	1,777	2,400
Wind	MW	1,662	1,789	2,107	2,425	3,696	3,696	12,000
Landfill Methane	MW	199	202	209	217	238	238	265
Digesters – Wastewater	MW	10	10	12	14	23	23	23
Digesters – Ag Waste	MW	8	12	21	31	80	80	80
Biomass Solids – Low-Use Wood	MW	NE	NE	NE	NE	NE	NE	NA
Fuel Consumption for Potential Generation								
Utility-Scale Solar PV	BBtu	NA	NA	NA	NA	NA	NA	NA
Building-Scale Solar PV – Residential	BBtu	NA	NA	NA	NA	NA	NA	NA
Building-Scale Solar PV – Commercial	BBtu	NA	NA	NA	NA	NA	NA	NA
Hydroelectric	BBtu	NA	NA	NA	NA	NA	NA	NA
Wind	BBtu	NA	NA	NA	NA	NA	NA	NA
Landfill Methane	BBtu	25,859	26,087	26,695	27,358	29,008	29,008	32,349
Digesters – Wastewater	BBtu	654	695	807	930	1,543	1,543	1,543
Digesters – Ag Waste	BBtu	800	1,112	1,956	2,891	7,533	7,533	7,533
Biomass Solids – Low-Use Wood	BBtu	17,793	18,779	21,243	23,707	33,565	33,565	NA

Fuel Type	Unit	Annualized Economic Potential					Economic Potential	Technical Potential
		2018	2020	2025	2030	2050		
Generation Fuel Price								
Utility-Scale Solar PV	$/MMBtu	$1.60	$1.60	$1.60	$1.60	$1.60	$1.60	NA
Building-Scale Solar PV – Residential	$/MMBtu	$3.00	$3.00	$3.00	$3.00	$3.00	$3.00	NA
Building-Scale Solar PV – Commercial	$/MMBtu	$3.00	$3.00	$3.00	$3.00	$3.00	$3.00	NA
Hydroelectric	$/MMBtu	$17.56	$17.66	$17.11	$16.91	$16.13	$16.13	NA
Wind	$/MMBtu	$1.74	$1.74	$1.74	$1.74	$1.74	$1.74	NA
Landfill Methane	$/MMBtu	NE	NE	NE	NE	NE	NE	NA
Digesters – Wastewater	$/MMBtu	NE	NE	NE	NE	NE	NE	NA
Digesters – Ag Waste	$/MMBtu	NE	NE	NE	NE	NE	NE	NA
Biomass Solids – Low-Use Wood	$/MMBtu	NE	NE	NE	NE	NE	NE	NE

Note: "NE" indicates that the value was not estimated. "NA" indicates that the value is not applicable.

Table 58: Electricity Generation Potential for Nuclear and Related Economic Factors

	Unit	Annualized Economic Potential					Economic Potential	Technical Potential
		2018	2020	2025	2030	2050		
Electricity Generation Potential	GWh	75,246	59,546	60,058	60,044	39,073	NA	NA
Electricity Generation Capacity Potential	MW	9,731	7,828	7,897	7,898	5,091	NA	NA
Fuel Consumption for Potential Generation	BBtu	787	623	628	628	409	NA	NA
Generation Fuel Price	$/MMBtu	$0.81	$0.81	$0.97	$1.07	$1.88	NA	NA

Note: "NA" indicates that the value is not applicable.

Table 59: Electricity Generation Potential for Combined Heat and Power and Related Economic Factors

	Unit	Annualized Economic Potential					Economic Potential	Technical Potential
		2018	2020	2025	2030	2050		
Electricity Generation Potential	GWh	16,255	17,129	19,356	21,641	31,357	31,357	66,160
Electricity Generation Capacity Potential	MW	2,889	3,005	3,301	3,604	4,895	4,895	10,462
Fuel Consumption for Potential Generation	BBtu	193,264	201,937	224,037	246,735	343,318	343,318	677,775
Generation Fuel Price	$/MMBtu	$5.71	$5.87	$6.29	$6.74	$8.90	NA	NA

Note: “NA” indicates that the value is not applicable.

Appendix C. Fossil Fuel Production Supply Curves Supporting the Resource Potential Analysis

Figure 40: Pennsylvania Supply Curve Generated for Coal

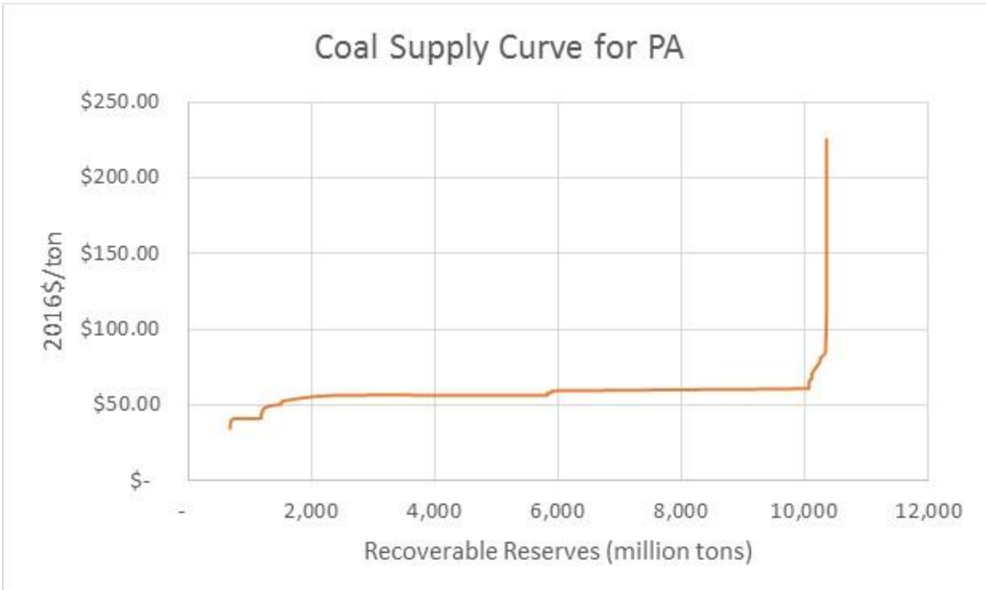


Figure 41: Pennsylvania Supply Curve Generated for Crude Oil and Lease Condensate

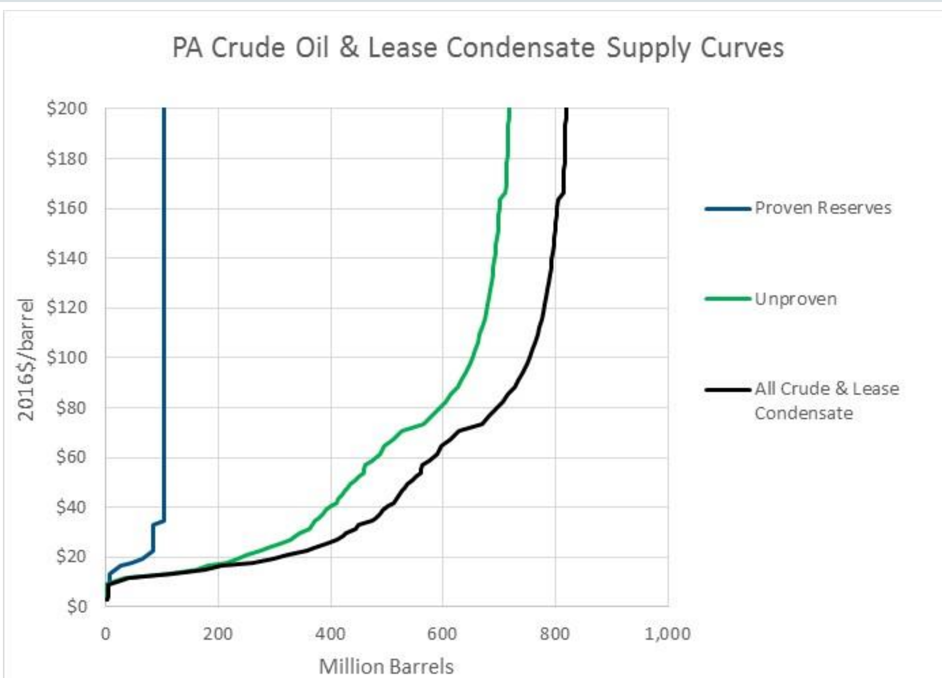


Figure 42: Pennsylvania Supply Curve Generated for Natural Gas

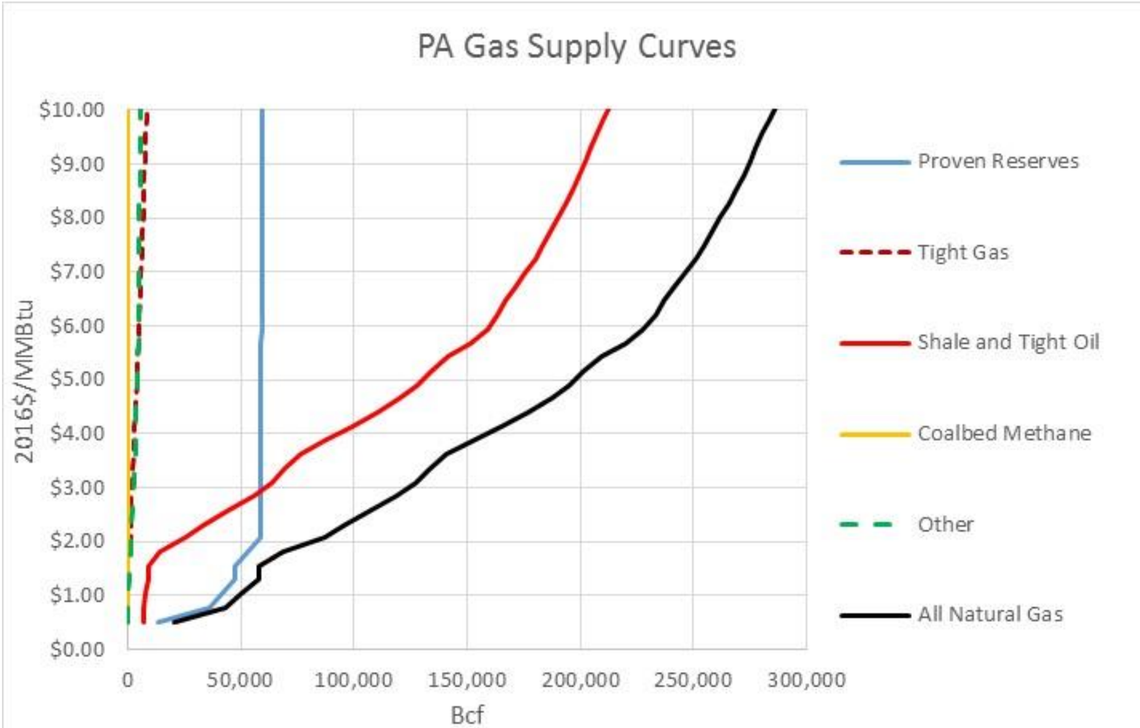
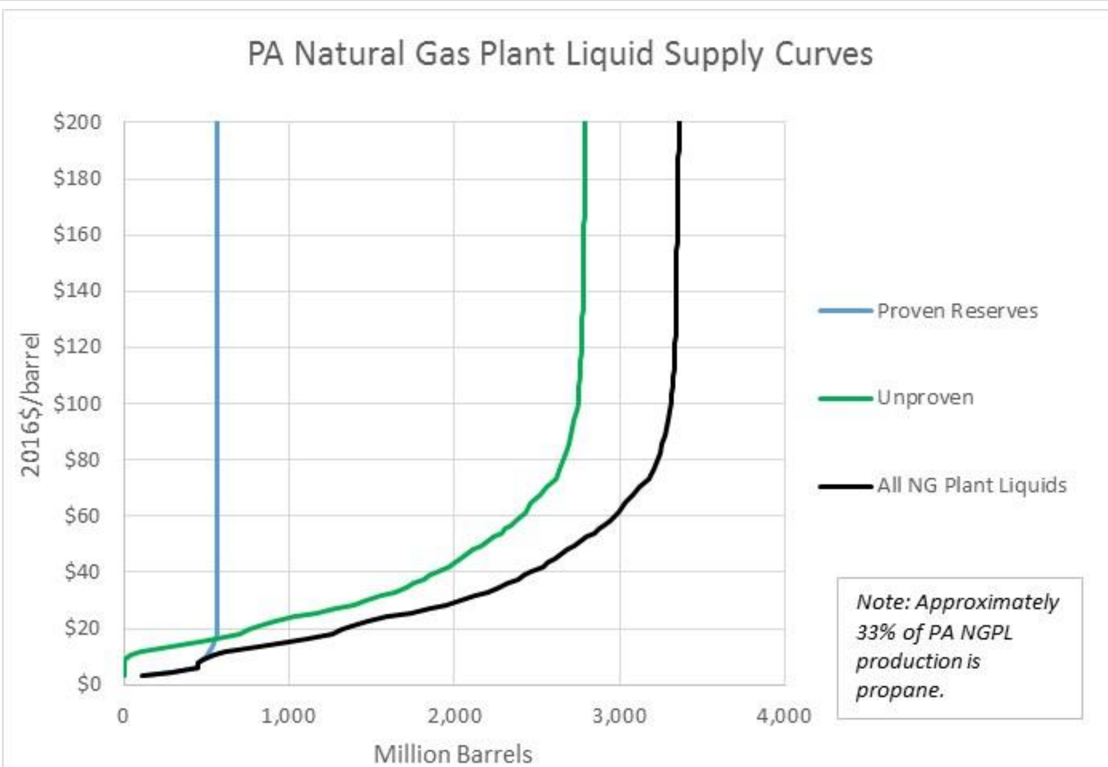


Figure 43: Pennsylvania Supply Curve Generated for Propane



Appendix D. Policies Considered in AEO Forecast

The BAU projections take into consideration all of the policies in EIA's Annual Energy Outlook (AEO), excluding the Clean Power Plan. The policies considered in the AEO forecast include the following:[37]

- ***Consolidated Appropriations Act of 2016***, which extended investment tax credits (ITCs) for renewable energy technologies, includes a 5-year extension for solar technologies which provides a 30 percent tax credit for solar through 2019, a 26 percent tax credit in 2020, a 22 percent tax credit in 2021, and expires after 2021
- ***Energy Improvement and Extension Act of 2008***, which extended and modified many of the clean energy tax credits for residential customers from the Energy Policy Act of 2005, including extending certain tax credits through 2016, removing the tax credit cap for certain technologies, increasing the tax credit cap for certain technologies, and expanding the tax credits to include additional technologies
- ***American Recovery and Reinvestment Act of 2009***, which provided energy efficiency and renewable energy funding at federal, state, and local levels; increased funding for weatherization; removed the 30 percent tax credit for renewable technologies; and increased the tax credit cap for energy-efficient improvements
- ***Energy Independence and Security Act of 2007***, which included several provisions that affect energy use, including standards for light bulbs and commercial equipment, requirements for energy efficiency measures in commercial and federal facilities, and a fuel economy credit trading program for vehicle manufacturers
- ***Energy Policy Act of 2005***, which established minimum efficiency standards for residential and commercial equipment, provided tax credits to producers and purchasers of energy efficiency and renewable energy equipment, and provided tax credits to builders of energy-efficient homes
- ***Energy Policy Act of 1992***, which established several equipment efficiency standards, as well as tax credits for solar technologies
- ***Clean Air Act Amendments of 1990***, which included several provisions that affect industrial facilities, including requirements related to process emissions, emissions related to hazardous or toxic substances, and sulfur dioxide emissions, as well as requirements for nitrogen oxide controls on existing major stationary sources
- ***Cross State Air Pollution Rule***, which addressed the interstate transport of air emissions from power plants by restricting emissions of sulfur dioxide and/or nitrogen oxide in 27 states and establishing allowance trading programs among states

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[37] For more detailed information on how the AEO forecast accounts for various policies, see the "Legislation and regulations" sections of "Assumptions to the Annual Energy Outlook 2017," available at: https://www.eia.gov/outlooks/aeo/assumptions/pdf/0554(2017).pdf.

- ***Maximum Achievable Control Technology for Industrial Boilers***, which regulated emissions of hazardous air pollutants, hydrogen chloride, mercury, dioxin/furan, carbon monoxide, and particulate matter from industrial, commercial, and institutional boilers
- ***Light-Duty Vehicle Combined Corporate Average Fuel Economy Standards*** and ***Heavy Duty Vehicle Combined Corporate Average Fuel Economy Standards***, which established GHG emissions and fuel consumption standards for different vehicle types and model years
- ***Emission Control Areas in North America and U.S. Caribbean Sea waters under the International Convention for the Prevention of Pollution from Ships***, which mandated decreased emissions and levels of airborne pollutants by designating specific portions of U.S., French, and Canadian waters as emission control areas
- ***Low-Emission Vehicle Program***, which established a fleet-averaged, emissions-based policy for smog-forming pollutants and set sales mandates for six categories of low-emission vehicles; the program was originally a California program with a provision that other states can opt in
- ***FERC Orders 888 and 88***, which were designed to bring low-cost power to consumers through competition, ensure continued power reliability, and provide for open and equitable transmission services
- ***State-Specific Renewable Programs and Energy Efficiency Resource Standards***, such as the Pennsylvania Alternative Energy Portfolio Standards Act (2004 Act 213) and Act 129[38]

[38] EIA does not explicitly model Act 129 provisions but does model broad energy efficiency improvements from policies in which Act 129 would be considered.