Pennsylvania Climate Action Plan 2021

Cover Photo(s) TBD

December 2020

pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION

Pennsylvania Climate Action Plan 2021

Initial Draft

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For More Information

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Acknowledgements

- Support and input from CCAC and other state agencies (list specifically).
- This report and the analyses contained within it were prepared by the Pennsylvania DEP with support from ICF, Penn State University and Hamel Environmental Consulting.

Commented [D1]: Note for CCAC: This draft is a work in progress. We are aiming to keep all content for your review to streamline the process for you. Therefore, some pieces are more fleshed out than others at this point. We welcome feedback on any piece of the CAP.

Disclaimer

- This material is based upon work supported by the United States Department of Energy, Office of Energy Efficiency and Renewable Energy, under State Energy Program Award Number DE-EE0008293.

For More Information

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

- ~5 pages long (could be longer if intended to be the "pullout" or the booklet used for public and stakeholders. Likely no more than 10 pages.
- High-level overview of each primary section in the main report
- Present key results and takeaways
- Use key graphics from report
- Design to be a standalone version of the broader plan

1 INTRODUCTION

- ~4-6 pages long
- Explain how the climate is changing and affecting Pennsylvania
- Explain that the purpose of the CAP is to mitigate Pennsylvania's contribution to climate change and adapt to it simultaneously

1.1 Act 70 and EO 2019-1

The Pennsylvania Climate Change Act of 2008 (Act 70) requires the Department of Environmental Protection (DEP) to compile an annual greenhouse gas (GHG) inventory for Pennsylvania's emissions, to develop a voluntary GHG registry, and to conduct a climate action plan (CAP) and impact assessment (IA). Act 70 also establishes a Climate Change Advisory Committee (CCAC) to advise DEP during the development of an impacts assessment and climate change action plan. Working with the CCAC, DEP has prepared a series of climate action plans and GHG mitigation strategies since Act 70's creation in 2008.

Act 70 Requirements:

- Compile annual GHG inventory
- Develop a voluntary registry of GHG emissions
- Conduct a Climate Action Plan and Impact Assessment
- Establish a Climate Change Advisory Committee

Executive Order 2019-1:

- Set GHG reduction targets of 26% by 2025 and 80% by 2050 (from 2005 levels)
- Reestablished the GreenGov Council

Additionally, in 2019, Governor Tom Wolf issued Executive Order 2019-1 (EO 2019-01), which established a goal of achieving a 26% reduction of net GHG emissions statewide by 2025 from 2005 levels, and an 80% reduction by 2050 from 2005 levels. These goals are in line with the goals of the Paris Agreement.[1] EO 2019-01 also includes a "Lead by Example" provision for the state government that re-established the GreenGov Council to encourage the state to incorporate environmentally sustainable practices into the Commonwealth's policy and planning decisions.

DEP is tasked with responding to EO 2019-01 and implementing policies that will achieve Pennsylvania's GHG reduction targets. This updated 2021 Climate Action Plan satisfies the EO 2019-01 requirements by proposing a list of GHG reduction strategies that, if implemented successfully, will enable Pennsylvania to reduce its future GHG emissions and achieve its stated goals.

1.2 Pennsylvania's Evolving Climate Planning Efforts

Since the initial CAP and IA were developed in 2009, Pennsylvania's approach to addressing climate change has evolved as science and technology continue to mature and the Commonwealth's context and needs change. While some key climate and energy policies such as the Alternative Energy Portfolio Standard (AEPS) and Act 129 were in place when the

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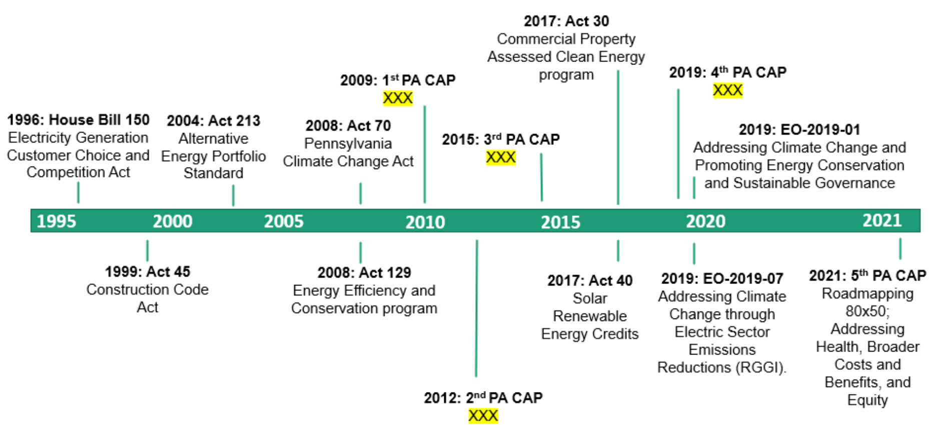
[1] The stated goal of the Paris Agreement is "to limit global warming to well below 2 degrees Celsius, preferably to 1.5 degrees Celsius, compared to pre-industrial levels." Details on the Paris Agreement can be found on the UNFCCC website, available here: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement#:~:text=The%20Paris%20Agreement's%20central%20aim,further%20to%201.5%20degrees%20Celsius.

first CAP was published (see Figure 1), the CAP process is an important method that allows DEP to map out how hallmark policies and programs will continue to evolve, and to determine how new programs can lead to further GHG reductions and increased resiliency, to the benefit of all Pennsylvanians. In some cases, past CAPs have helped lay the foundation for new programs that are being developed now, most notably Pennsylvania participating in the Regional Greenhouse Gas Initiative (RGGI) and developing the Pennsylvania Commercial Property Assessed Clean Energy (C-PACE) Program,[2] and ongoing industrial energy assessments.[3]

This 2021 Pennsylvania Climate Action Plan is the fifth iteration of the CAP. It builds on previous plans and includes the latest science on the impacts of climate change, the newly established near- and long-term emission reduction goals for the Commonwealth, new and expanded strategies to reduce GHG emissions and prepare for the impacts of climate changes, and the consideration of additional elements like public health and equity.

Figure 1. Pennsylvania's Evolving Climate Planning and Implementation Efforts

Commented [HD2]: Note this is a working concept for now.



[2] See: https://www.dep.pa.gov/Business/Energy/OfficeofPollutionPrevention/FinancialOptions/Pages/C-PACE.aspx.

[3] See: https://www.dep.pa.gov/Business/Energy/OfficeofPollutionPrevention/State-Energy-Plan/Pages/Energy-Assessments.aspx.

1.3 Pennsylvania's Current Climate Context

- Describe the general climate
- Describe how climate is changing (borrow from IA)
- Explain how impacts are already emerging
- Explain how the current and projected climactic changes inform the development of the CAP
- Describe how the state is accelerating climate action and commitments
  - GreenGov activities
  - Other activities
- Include overview of PA's energy context and emphasize that PA is an energy economy
  - Include metrics like energy exports, $ value
  - Mention RGGI context

Current climate change impacts

Could include a text box to highlight some of the key trends and changes, including extreme weather events, economic losses, health impacts, etc.

1.3.1 Risks to Pennsylvanians

- Mention how climate change impacts present a risk to the vitality of Pennsylvania residents, local governments, and industries
- Detail the implications of the risks
- Describe how these risks can be opportunities to improve related development goals like better health outcomes, improved equity, or shifting economic opportunities

1.3.2 The Effects of COVID-19

- Address the obvious
- Explain how COVID-19 has affected the state's economy, healthcare systems, education, etc.
  - Reference the PA Clean Jobs report and latest PA info from BW Research
- Describe how it affected the development of this CAP

How anticipated federal changes may influence Pennsylvania's climate efforts

List out a few key anticipated changes and how they may affect this plan and Pennsylvania's environmental and economic context.

1.4 The CAP Development Process

- Outline the overall approach, include a figure showing the timeline and interaction with the IA and the CCAC, based on placeholder Figure 2
- Emphasize it was an iterative process

- Describe stakeholder engagement efforts and results, e.g., with CCAC
- Describe engagement with other state agencies, e.g., the EJ office and Office of Natural Resources
- Indicate how their needs and feedback were considered and incorporated.

Figure 2. Overview of CAP Process

1.5 Report Contents

- Brief roadmap of the report
- Bullet out each main section with 1-2 lines describing its purpose and content

2 PENNSYLVANIA'S GREENHOUSE GAS INVENTORY, FORECAST, AND CURRRENT GHG REDUCTION EFFORTS

Pennsylvania's latest greenhouse gas (GHG) inventory provides a snapshot of GHG emissions in the Commonwealth at a given point in time. This inventory is used to track progress towards reducing GHGs over time and forms the basis of the business as usual (BAU) emissions scenario. The BAU scenario projects what emissions in Pennsylvania would be if only the current GHG reduction policies and programs are implemented.

2.1 Current GHG Emissions

The GHG inventory process, summarized below in Figure 3, is used to create a consistent inventory that can be compared over time, regardless of the year it represents. DEP developed Pennsylvania's most recent GHG Inventory in 2020, using data from 2017, using the EPA's State Inventory Tool (SIT), an Excel-based tool that follows a standardized process to generate state-level emission estimates. The SIT was used to develop GHG emission estimates for intervals from 2000 through 2017, the last year for which data was available as of the publication of this report. Emissions from the following sectors were included in the inventory: residential, commercial, industrial, transportation, electricity production, agriculture, waste management, and forestry and land use.

Figure 4 shows a breakdown of 2017 GHG emissions in Pennsylvania by sector.

Figure 5 provides a summary of historical GHG emissions in Pennsyvlania by sector.

Figure 3. Example of the inventory development process

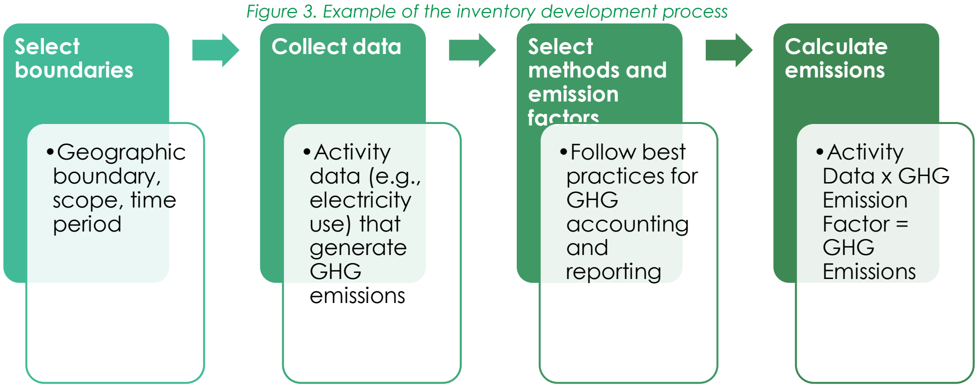
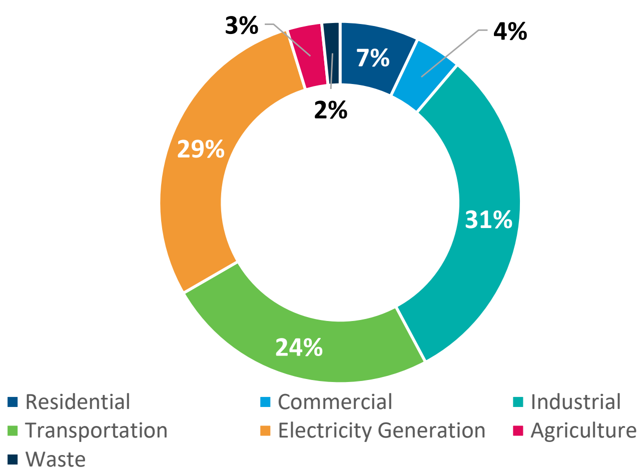
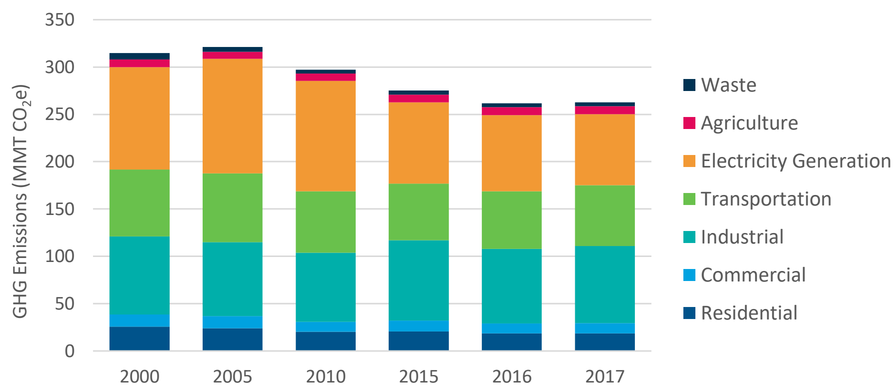


Figure 4. Pennsylvania 2017 GHG Emissions by Sector



Commented [HD3]: Note for the CCAC: DEP is looking to be consistent in sector terminology between the inventory, BAU and mitigation analysis. We have heard feedback around potentially splitting fugitive emissions from oil and gas systems out separately, maybe also industrial energy and process emissions. Can the CCAC please provide a list of sectors you would like to see represented in the final sector list?

Figure 5. Pennsylvania Historical GHG Emissions by Sector (MMT CO_2e)



Total statewide gross GHG emissions in 2017 were 262.7 $MMTCO_2e$. Pennsylvania's Land Use, Land-Use Change and Forestry (LULUCF) sector acts as a carbon sink for GHG emissions, sequestering 29.5 MMT CO_2e of carbon in 2017 and bringing net emissions down to 233.2 $MTCO_2e$. 2017 net emissions are 18.7% lower than 2005 levels, which were 286.8 MMT CO_2e. These reductions get Pennsyslvaina about two thrids towards its 2025 GHG redction goals of 26% by 2025.

Gross vs. Net Emissions:

"Gross emissions" includes only source categories with positive emissions, while "net emissions" include source categories with both positive and negative emissions. For Pennsylvania, net emissions are equal to gross emissions plus negative emissions from forestry and land use.

Emissions have declined since 2005 in the majority of sectors, with the exception of industrial emissions and very slight incresaes in agricultural emissions. As of 2017, industrial emissions have overtaken electricity production as the highest-emitting sector, with transportation the third highest emitting sector and then residential and commerical fuel use. Together, these sectors make up 95% of total GHG emissions in Pennsyslvania.

- **Industrial:** Industrial emissions make up the largest percentage of Pennsylvania's emissions at 31%, and have increased 4% above 2005 levels to 81.4 $MMTCO_2e$ in 2017. The majority of industrial emissions result from the combustion of fossil fuels, contributing 47.8 $MMTCO_2e$ of the 81.4 $MMTCO_2e$ total emissions from industrial processes. Key emitting industries in Pennsylvania include natural gas production and refining, coal mining, cement and metals manufacturing, for example.
- **Electricity Production:** The next largest sector, electricity production, saw a 7% decrease in emissions from 2016 to 2017, and a 38% decrease in emissions since 2005. This decrease is mainly a result of decreased electricity generation from coal being offset by increases in natural gas generation, efficiency improvements as a result of Act 129, and alternative and renewable energy sources being used for electricity production as a result of the AEPS.

Coal-based electricity generation has decreased from producing 56% of Pennsylvania's electricity in 2005 to 22% in 2017. Nuclear power is now the largest source of electricity generated in Pennsylvania as of 2017, providing 39% of all electricity. Figure 6 shows a breakdown of electricity generated in Pennsylvania in 2017 by fuel type.

Carbon dioxide equivalence and global warming potential explained

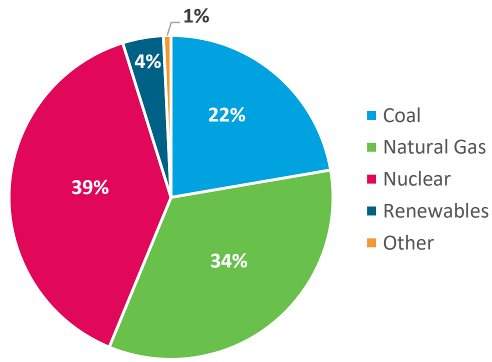
Carbon dioxide equivalence (CO_2e) is a measure used to compare the emissions from various GHGs based upon their global warming potential (GWP). GWPs allow for the comparison of the potential global warming impact of different GHGs by measuring the relative atmospheric warming effect of one ton of a GHG relative to the emissions of one ton of CO_2, accounting for differences in time. GWPs for each GHG are assessed in each of the International Panel on Climate Change's (IPCC) comprehensive climate change Assessment Reports. The IPCC has completed five assessment cycles. GWP values for the IPCC's Fourth Assessment Report (AR4) are commonly used in reporting, and the U.S. National GHG Inventory currently these values to develop emission estimates.

For example, the AR4 GWP for CH_4 is 25, indicating that one metric ton (MT) of CH_4 has a warming potential equivalent to 25 MT of CO_2. It is standard practice to report GHG inventory emissions in $MTCO_2e$. Error! Reference source not found. displays GWP values from the Fourth Assessment Report for CO_2, CH_4, and N_2O.

Table 1. Fourth Assessment Report GWPs

GHG	AR4 GWP
CO_2	1
CH_4	25
N_2O	298

Figure 6. 2017 Electricity Generation by Fuel Type



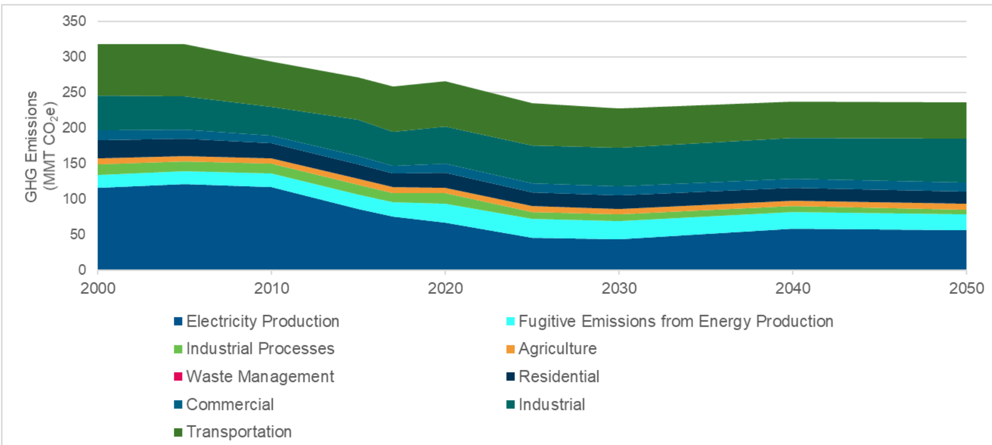
- **Transportation:** In 2017 GHG emissions from the transportation sector were 64.3 $MMTCO_2e$. The majority of these emissions were from personal vehicles that use gasoline. Since 2005, transportation emissions have decreased 11%, mainly attributable to increased fuel efficiency standards over time.
- **Residential and Commercial:** Residential and commerical emissions are a result of the direct use of fuels (not including electricity) in homes, busineses, and other larger buildings. Emissions from the residential and commerical sectors have decreased 20 % since 2005, likely a result of both fuel switching to lower emitting fuels to heat spaces, for example, and efficiency improvements as a result of both Act 129 (e.g., XX) and technology improvements over time (e.g., ENERGY STAR certified products).

2.2 BAU Overview

Pennsylvania's BAU scenario used the most recent Pennsylvania GHG Inventory as a starting point and projects GHG emissions through 2050 under the current GHG reduction policies and programs being implemented. The BAU serves as a benchmark for Pennsylvania's GHG reduction planning by providing emissions estimates that can be compared against emissions estimates for selected GHG reduction strategies.

Figure 7 below shows BAU emissions estimates by sector, from 2018 through 2050 (years 2000 – 2017 are actual emissions). Under the BAU scenario, Pennsylvania's emissions are projected to be 242.67 $MMTCO_2e$ in 2050, a 25% decrease from 2005 levels (323.57 MMT CO_2e), excluding carbon sinks.

Figure 7: BAU Emissions by Sector, 2000-2050 (MMTCO₂e)



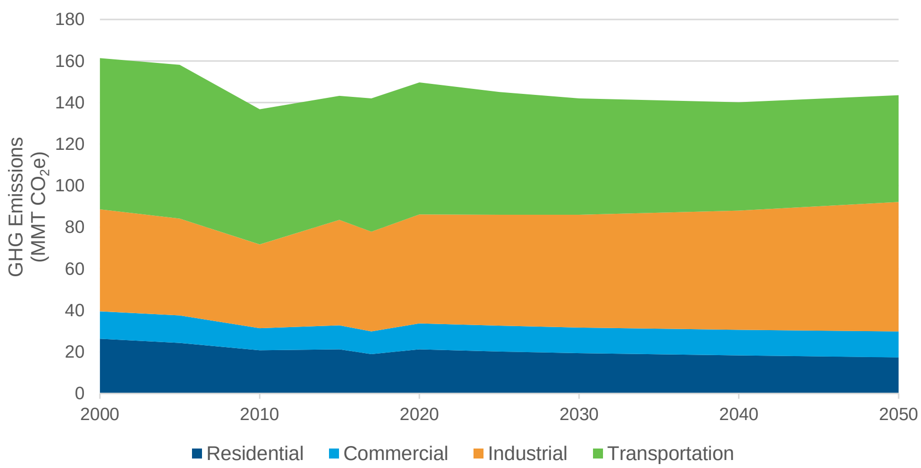
Under the BAU scenario, Pennsylvania may achieve its 2025 reduction goal, but will not meet the 2050 80% reduction goal from 2005. 2025 emissions are projected to be 239.8 MMTCO_2e, a 26% decrease from 2005 emissions (323.6 MMTCO_2e), which is the target set in EO 2019-01. However, BAU emissions are projected to increase slightly beyond 2025. 2050 emissions are projected to be 242.7 MMTCO_2e with no additional policy changes, a 25% decrease below 2005 levels.

The projected decrease in emissions in 2050 is driven largely by the trends described above, and as a result of policies that are currently being implemented at the state-level to reduce energy consumption and use lower-carbon fuels for electricity generation in place of fossil fuels, such as Act 129, the AEPS, and RGGI. The projected decrease in emissions in 2050 is driven largely by lower emissions associated with electricity generation as a result of reduced electricity generation and lower-emitting fuel used to generate electricity as a result of the AEPS and RGGI. Total in-state electricity generation is projected to decrease from 220,997 GWh in 2020 to 162,027 GWh in 2050. Emissions from electricity generation are projected to be 55.7 MMTCO_2e in 2050, a 54% decrease from 120.97 MMTCO_2e of emissions in 2005.

Emissions from direct fuel consumption, which make up the largest percentage of emissions in Pennsylvania (55% in 2020), are projected to decrease by 9%, from 158.1 MMTCO_2e in 2005 to 143.6 MMTCO_2e in 2050. The decrease in emissions from direct fuel consumption is driven by decreases in the residential, commercial, and transportation sectors. These decreases are based on projections from the Annual Energy Outlook (AEO) Reference Case (2020). Industrial emissions from direct fuel consumption are projected to increase from 46.7 MMTCO_2e in 2005 to 62.4 MMTCO_2e in 2050.

Figure 8 shows projected emissions from direct fuel consumption (non-electricity) by sector through 2050. Emissions from electricity consumption are not included in the BAU totals as that would results in double-counting with the emissions from electricity production included.

Figure 8: Emissions from Direct Fuel Consumption (Non-Electricity) by Sector, 2000-2050



Fugitive emissions from energy production, which includes CH_4 emissions from coal mining and natural gas and oil systems, are projected to decrease from 27.5 $MMTCO_2e$ in 2020 to 23.0 $MMTCO_2e$ in 2050, in part as a result of increased regulation on VOCs from oil and natural gas sources, which provides co-benefits of reduced methane emissions at the state level (25 PA. CODE CHS. 121 AND 129) and continued decreases in coal production driven by market preferences.

Agricultural emissions very slightly increase across the time series, increasing slightly from 7.6 $MMTCO_2e$ in 2005 to 7.7 $MMTCO_2e$ in 2050. Waste emissions remain fairly constant across the time series, decreasing slightly from 5.1 MMT CO_2e in 2005 to 4.6 $MMTCO_2e$ in 2020 and then increasing to 6.1 $MMTCO_2e$ in 2050 due to increases in both municipal solid waste and wastewater emissions.

2.2.1 Methodology

The BAU scenario is built on a few key datasets to estimate GHG emissions, based on activity data, trends, and policies within the Commonwealth of Pennsylvania. The BAU estimates do not include additional GHG reduction strategies beyond the policies and programs already in place as of September 2020. This scenario uses the following sources for a majority of the input data:

- **EPA's State Inventory Tool (SIT)**: The SIT is used for non-energy projections, including agriculture and waste. SIT provides a combination of population-based forecasts with other state-specific data.
- **State Energy Data System (SEDS)**: Datasets from SEDS are used to provide activity data at the state-level that can be disaggregated by sector. SIT incorporates SEDS data to estimate historical energy consumption and production data.
- **Energy Information Administration (EIA)**: Data from EIA's Annual Energy Outlook (AEO) are used for projections of future emissions. AEO estimates are forecasted at the regional level; these estimates are applied to the state-specific datasets to project energy production and consumption trends.

- **State-specific data**: Specific resources developed or collected within the Commonwealth and DEP include:
    - MOVES (on-road transportation modeling)
    - Act 129 reports
    - Alternative Energy Portfolio Standard (AEPS) compliance reports
    - Distributed solar data
    - Biofuel production data
    - Vehicle registration data
    - U.S. Department of Energy's CHP Installation Database that ICF maintains (contains locational information on CHP systems, loads, etc.)

In addition to these datasets, the BAU also relies on data from ICF's Integrated Planning Model (IPM) to model the electricity sector through 2050.[4]

See Appendix B for additional information about the methodology used to develop the BAU.

PA Policies Informing the BAU Scenario:

- **Act 129** – Act 129 requires PA's seven electric distribution companies (EDCs) to reduce energy use within their service territory.
- **Alternative Energy Portfolio Standard (AEPS)** – AEPS sets targets for the amount of electricity supplied by PA's EDCs that must come from renewable sources.
- **Regional Greenhouse Gas Initiative (RGGI)** – By joining RGGI, Pennsylvania is obligated to reduce their GHG emissions in coordination with other member states.
- **HFC Phaseout** – PA will phase out HFCs in accordance with EO 2019-1.
- **Oil and Gas Regulations** – Control measures on VOC emissions from oil and natural gas sources will provide co-benefits including reduced methane emissions.

2.3 Pennsylvania's Ongoing Climate Efforts and Commitments

- Limit to 1 page
- Describe climate-related laws, e.g., Act 40, AEPS, etc., but be wary of making it too much of a history lesson
    - Can cite CEP report
- Describe key efforts and how they are built on in this CAP, including:
    - Green Gov Council – also include solar purchase for state buildings
    - RGGI (also include graphic)
    - Methane regulations
    - HFC policy
    - TCI
    - MD/HD MOU
    - EV Roadmap (and potential update)
    - Driving PA Forward
    - AFIG
    - CPACE expansion
    - Green Bank
    - Act 129 Phase IV
    - DEP's Local Climate Action Program

[4] ICF's Integrated Planning Model (IPM®) 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. Additional information about IPM can be found here: https://www.icf.com/technology/ipm.

- Efforts of other PA agencies, e.g., DCNR's adaptation plan and PennDOT's vulnerability study
- Can borrow content from recent DEP CEPP report for energy efforts
- Formation of PA Climate Leadership Academy

3 OPPORTUNITIES FOR REDUCING GHG EMISSIONS IN PENNSYLVANIA

- ~40 pages long
- Introductory paragraph describing section

3.1 GHG Reduction Analysis Approach

- Brief outline of steps, as presented below
- Include a process graphic explaining the approach visually
- Describe any overarching key assumptions

3.1.1 Process to Identify Potential Strategies

- The strategies presented in this report are based on five main sources:
    - DEP's knowledge of trending and common strategies used across the state
    - Feedback from the Climate Change Advisory Committee (CCAC)
    - A review of the 2018 Climate Action Plan, including letters from the CCAC
    - A review of the 2021 DEP Clean Energy Programs Plan
    - A review of public survey data from DEP on the 2018 Climate Action Plan
    - ICF's knowledge of trending and common strategies used across the country

3.1.2 Prioritization Process and Criteria Descriptions

- Developed prioritization criteria and weights collaboratively with DEP and CCAC
- Criteria include:
    - GHG reduction magnitude
    - ease of implementation (legal, institutional)
    - initial investment required
    - cost effectiveness
    - air quality benefits
    - public health benefits
    - resilience benefits
    - environmental justice and equitable implementation benefits
- Each potential strategy was evaluated on the criteria and given a score

3.1.3 Prioritized Strategies

- After strategies were scored, DEP reviewed the potential strategies and selected a subset that were most aligned with the Commonwealths goals, needs, and interests. Of these, DEP worked with ICF to determine which strategies could be modeled for GHG reductions, costs and benefits based on available data.
- The table below summarizes the selected strategy names and descriptions, identifies whether a strategy is quantified or not, as well as the expected implementation timeframe of each.
    - Time frames are defined as follows:
        - Near-term: 1 to 5 years
        - Mid-term: 5 to 10 years
        - Long-term: 10+ years
- All strategies are described in greater details in the following sections.

Table 3-1. Summary of GHG Reduction Strategies by Sector

Sector	GHG Reduction Strategy	Expected Implementation Timeframe	Quantified GHG Reductions, Costs and Benefits
(Residential and Commercial) Buildings	Support Energy Efficiency through Building Codes	Near-term	Yes
Buildings	Residential and Commercial Energy Efficiency Improvements (Electricity)	Near-term	Yes
Buildings	Residential and Commercial Energy Efficiency Improvements (Gas)	Near-term	Yes
Buildings	Incentivize Building Electrification	Long-term	Yes
Buildings	Introduce State Appliance Efficiency Standards	Mid-term	No
Buildings	Take actions to promote and advance C-PACE financing and other tools for NZB and high-performance buildings	Near-term	No
Transportation	Reduce Vehicle Miles Traveled for Single-Occupancy Vehicles	Short-term	Yes
Transportation	Implement the MHDV MOU	Long-term	Yes
Transportation	Increase Adoption of Light Duty Electric Vehicles	Mid-term	Yes
Transportation	Implement a Low Carbon Fuel Standard	Mid-term	Yes
Industrial	Increase Industrial Energy Efficiency	Near-term	Yes
Fuel Supply	Increase Production and Use of Biogas/Renewable Gas	Mid-term	Yes
Fuel Supply	Incentivize and increase use of distributed Combined Heat and Power (CHP)	Near-term	Yes
Fuel Supply	Reduce Methane Emissions Across Oil and Natural Gas Systems	Mid-term	Yes
Electricity Generation	Maintain Nuclear Generation at Current Levels	Near-term	Yes
Electricity Generation	Create a carbon emissions free grid	Long-term	Yes
Agriculture	Use Programs, Tools, and Incentives to Increase Energy Efficiency for Agriculture	Near-term	Yes
Agriculture	Provide Trainings and Tools to Implement Agricultural Best Practices	Mid-term	Yes

LULUCF	Land Management for Natural Sequestration and Increased Urban Green Space	Mid-term	Yes
Waste	Reduce food waste	Near-term	No
Waste	Reduce waste generated by citizens and businesses and expand beneficial use of waste	Near-term	No

3.1.4 GHG Reduction Accounting Approach

- Build on the GHG inventory and BAU, with specifics for power sector and CHP and DG
- Sample language: ICF analyzed each of the recommended mitigation actions to include estimated GHG reductions for all actions and implementation costs and savings for a selection of actions. Similar to the BAU, ICF uses a GHG accounting approach quantifying emissions from all electricity generated in Pennsylvania, whether consumed in state or exported. By employing a holistic accounting framework, ICF avoided overlapping GHG reductions from different sectors and mitigation actions (i.e., "double counting").
- Discuss layering of strategies and interactions between them
- Define metrics used

3.1.5 Other Analysis Elements Approaches

3.1.5.1 Economic Benefits and Costs

- Describe how strategies may have economic benefits
- Explain economic modeling methodology and metrics
- Allude to the economic results being included in each strategy
- Define metrics used

3.1.5.2 Co-Benefits and Costs

- Describe what co-benefits are and connect them to GHG reduction strategies
- Co-benefits can include improved air quality, health outcomes, equity, and more
- Some may be direct co-benefits, others may be indirect
- Explain how considering and quantifying co-benefits provides a more holistic approach and better informs decision-making
- Describe approaches to identifying and quantifying co-benefits
- Define metrics used
- High potential for graphics to describe the concept

3.1.5.3 Equity

- Define equity and connect the concept to GHG reduction strategies
- Describe how strategies can improve equity
- Describe how equity was considered and integrated into the strategies
- Define metrics used

3.2 Pennsylvania's Pathway to 2050

- List key takeaways upfront
- Summary of quantitative and qualitative impacts on metrics across all sectors and strategies:
    - energy use,
    - GHG reduction potential,
    - air quality,
    - health,
    - equity, and
    - economic effects
- Indicate progress toward achieving 2025 and 2050 GHG reduction goals
- Note any high-impact results
- Include cumulative results and accompanying charts/table (examples below)
- E.g., a graphic that breaks down reductions by sector for the BAU as compared to the 80x50 scenario
- E.g., a "story-telling chart" showing different pathway options (last example), this can also be reiterated in the implementation section to talk about phasing, or built on in some way there

3.3 Buildings Sector

- Define the sector and its scope
- Describe the context of the sector in Pennsylvania
- Note that this is for residential and commercial buildings
- Clearly state that we are only reporting these electricity emissions for informational purposes from res/com—we will report costs, but we are not attributing electric emissions here.

3.3.1 GHG Reduction Strategies

- Introductory paragraph explaining this section will outline recommended strategies to reduce GHG emissions
- Summary of quantitative and qualitative metrics for sector and by strategy: energy, GHG reduction potential, air quality benefits, health benefits, equity, and economic benefits
- Overview of strategies and overall expected results of implementing them
- E.g., there are X strategies, which include 1, 2, and 3. Together, it is projected that they will reduce emissions in the building sector by X amount by X year
- Include stacked chart showing annual GHG reductions compare to BAU for 2025 and 2050 (show reductions as negative)
- Include table that lists each strategy and the annual GHG reduction in 2025, in 2050, and the cost/tCO2 Reduced
- Present each strategy separately using the strategy template (outlined below)

Residential and Commercial Energy Efficiency Improvements (Electricity)

Commented [D4]: This is an example of text and length for a strategy.

Annual GHG Emissions Reduced in 2025	XXX,XXX $MTCO_2e$
Annual GHG Emissions Reduced in 2050	XXX,XXX $MTCO_2e$
Cost/(Benefit) per ton of GHG reduced	XXX,XXX $MTCO_2e$
Net Present Value	$XXX/$MTCO_2e$
Gross State Product	$XXX million
Disposable Income	$XXX million
Jobs	X,XXX jobs
Air Quality	X
Public Health	X
Social Equity	X

This strategy includes several actions to improve residential and commercial energy efficiency. These include requiring increased residential and commercial energy efficiency improvements targeted at kWh savings, either within the existing framework of or a modified framework of Act 129 (e.g., increasing savings targets and removing spending caps).

For Act 129, this could include increasing the low- to moderate-income (LMI) share of spending and reforming cost-effectiveness tests to support more LMI focus, and adding climate mitigation and resilience benefits to cost effectiveness tests.

To enhance Act 129 effectiveness and increase savings, incentives and education should leverage programs like Low Income Home Energy Assistance Program (LIHEAP) and Weatherization Assistance Program (WAP).

Environmental benefits and costs

- GHG reductions
- NPV per ton of GHG reduced

Economic benefits and costs

- NPV
- Jobs
- Disposable income
- Gross State Product (GSP)

Social benefits and costs

- Air quality: Reduced energy use from this strategy could lead to improved air quality through reduced point source emissions and improved local air quality from reduced use of on-site fuels to generate electricity.
- Public health: Improved air quality leads to improved public health.
- Environmental justice and equity: Improving air quality from point source emissions can lead to improved health outcomes in the surrounding communities, reducing disproportionate impacts from pollution. However, many environmental justice or low-income communities would not be benefited financially by this strategy.
- Resiliency: Reduced outages provided by enhanced resiliency allows critical facilities to continue operation, improves productivity, and increases economic output. Low-income, elderly, and disabled populations are often the most vulnerable in disasters and accompanying power outages and thus can greatly benefit from resiliency power projects and systems.
- Costs: Using cost effectiveness tests, programs can be designed to maximize energy cost benefits and program efficacy. Energy Efficiency helps lower energy bills and can be a

hedge against uncertainty associated with fuel price changes. Local utilities can also benefit through a reduced need to invest in electricity infrastructure.

Implementation Considerations

- Describe necessary actions to implement the strategy
  - Include a likely timeframe for implementation
- Describe actors and partners
  - Include what level(s) of government would implement and specifically who would be responsible for implementing
  - State government
- Offer considerations or actions to ensure equitable implementation and outcomes
- Describe equity considerations
  - Many environmental justice or low-income communities would not be financially benefited by this strategy, and careful implementation would be required to avoid increasing financial burdens and disparities (for example, expansion of programs like LIHEAP).
- Discuss phasing
- Note challenges and opportunities to implementation
  - Describe possible challenges to implementing the strategy, e.g., political will, economic challenges, behavior change
  - Describe possible solutions to overcome challenges
  - Describe any opportunities and how to best take advantage of them
- Note any enabling technologies

3.4 Transportation Sector

- Define the sector and its scope
- Describe the context of the sector in Pennsylvania

3.4.1 Strategies

- Introductory paragraph explaining this section will outline recommended strategies to reduce GHG emissions
- Summary of quantitative and qualitative metrics for sector and by strategy: energy, GHG reduction potential, air quality benefits, health benefits, equity, and economic benefits
- Overview of strategies and overall expected results of implementing them
- E.g., there are X strategies, which include 1, 2, and 3. Together, it is projected that they will reduce emissions in the building sector by X amount by X year
- Include stacked chart showing annual GHG reductions compare to BAU for 2025 and 2050 (show reductions as negative)
- Include table that lists each strategy and the annual GHG reduction in 2025, in 2050, and the cost/tCO2 Reduced
- Present each strategy separately using the strategy template

3.5 Industrial Sector

- Define the sector and its scope
- Describe the context of the sector in Pennsylvania

3.5.1 Strategies

- Introductory paragraph explaining this section will outline recommended strategies to reduce GHG emissions
- Summary of quantitative and qualitative metrics for sector and by strategy: energy, GHG reduction potential, air quality benefits, health benefits, equity, and economic benefits
- Overview of strategies and overall expected results of implementing them
- E.g., there are X strategies, which include 1, 2, and 3. Together, it is projected that they will reduce emissions in the building sector by X amount by X year
- Include stacked chart showing annual GHG reductions compare to BAU for 2025 and 2050 (show reductions as negative)
- Include table that lists each strategy and the annual GHG reduction in 2025, in 2050, and the cost/tCO2 Reduced
- Present each strategy separately using the strategy template

3.6 Fuel Supply Sector

- Define the sector and its scope
- Describe the context of the sector in Pennsylvania

3.6.1 Strategies

- Introductory paragraph explaining this section will outline recommended strategies to reduce GHG emissions
- Summary of quantitative and qualitative metrics for sector and by strategy: energy, GHG reduction potential, air quality benefits, health benefits, equity, and economic benefits
- Overview of strategies and overall expected results of implementing them
- E.g., there are X strategies, which include 1, 2, and 3. Together, it is projected that they will reduce emissions in the building sector by X amount by X year
- Include stacked chart showing annual GHG reductions compare to BAU for 2025 and 2050 (show reductions as negative)
- Include table that lists each strategy and the annual GHG reduction in 2025, in 2050, and the cost/tCO2 Reduced
- Present each strategy separately using the strategy template

3.7 Electricity Generation Sector

- Define the sector and its scope
- Describe the context of the sector in Pennsylvania

3.7.1 Strategies

- Introductory paragraph explaining this section will outline recommended strategies to reduce GHG emissions
- Summary of quantitative and qualitative metrics for sector and by strategy: energy, GHG reduction potential, air quality benefits, health benefits, equity, and economic benefits
- Overview of strategies and overall expected results of implementing them
- E.g., there are X strategies, which include 1, 2, and 3. Together, it is projected that they will reduce emissions in the building sector by X amount by X year
- Include stacked chart showing annual GHG reductions compare to BAU for 2025 and 2050 (show reductions as negative)
- Include table that lists each strategy and the annual GHG reduction in 2025, in 2050, and the cost/tCO2 Reduced
- Present each strategy separately using the strategy template

3.8 Agricultural Sector

- Define the sector and its scope
- Describe the context of the sector in Pennsylvania

3.8.1 Strategies

- Introductory paragraph explaining this section will outline recommended strategies to reduce GHG emissions
- Summary of quantitative and qualitative metrics for sector and by strategy: energy, GHG reduction potential, air quality benefits, health benefits, equity, and economic benefits
- Overview of strategies and overall expected results of implementing them
- E.g., there are X strategies, which include 1, 2, and 3. Together, it is projected that they will reduce emissions in the building sector by X amount by X year
- Include stacked chart showing annual GHG reductions compare to BAU for 2025 and 2050 (show reductions as negative)
- Include table that lists each strategy and the annual GHG reduction in 2025, in 2050, and the cost/tCO2 Reduced
- Present each strategy separately using the strategy template

3.9 Land Use and Forestry (LULUCF) Sector

- Define the sector and its scope
- Describe the context of the sector in Pennsylvania

3.9.1 Strategies

- Introductory paragraph explaining this section will outline recommended strategies to reduce GHG emissions
- Summary of quantitative and qualitative metrics for sector and by strategy: energy, GHG reduction potential, air quality benefits, health benefits, equity, and economic benefits
- Overview of strategies and overall expected results of implementing them
- E.g., there are X strategies, which include 1, 2, and 3. Together, it is projected that they will reduce emissions in the building sector by X amount by X year
- Include stacked chart showing annual GHG reductions compare to BAU for 2025 and 2050 (show reductions as negative)
- Include table that lists each strategy and the annual GHG reduction in 2025, in 2050, and the cost/tCO2 Reduced
- Present each strategy separately using the strategy template

3.10 Waste Sector

- Define the sector and its scope
- Describe the context of the sector in Pennsylvania

3.10.1 Strategies

- Introductory paragraph explaining this section will outline recommended strategies to reduce GHG emissions
- Summary of quantitative metrics for sector and by strategy: energy, GHG reduction potential, air quality benefits, health benefits, equity, and economic benefits
- Overview of strategies and overall expected results of implementing them
- Present each strategy separately using the strategy template

3.11 Enabling Technologies

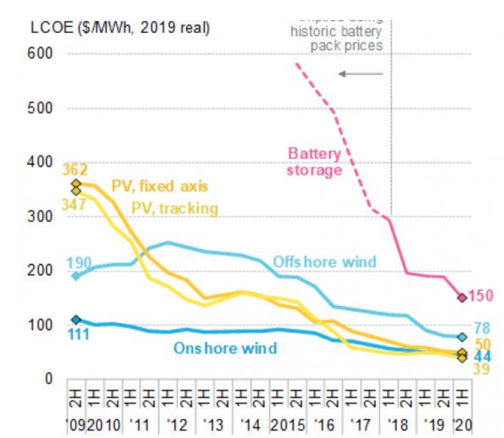
The strategies outlined above will rely on existing and future technologies. Leveraging technologies will allow the Commonwealth to more effectively implement the proposed GHG reduction strategies, typically by optimizing performance, reducing overall implementation costs, and/or by reducing GHG emissions at a greater level than possible through alternative technologies or in the absence of technology. Seven key enabling technologies were identified by, including:

- Incentivizing grid-level battery storage;
- Power-to-gas and blue and green hydrogen;
- Carbon capture, utilization, and sequestration (CCUS);
- Direct Air Capture (DAC);
- Peak energy load and balancing strategies;
- Carbon offsets; and
- Disruptive digital technologies.

A description of each is provided below, as well as short explanation of how the technology is relevant to Pennsylvania in particular.

Encourage and incentivize battery storage at the grid level

Figure 9 Global Levelized Cost of Energy (LCOE) of battery storage technology relative to renewable energy generation technologies.



Battery technology costs have dropped significantly in recent years, and battery energy storage systems will continue to gain traction as new technologies facilitate aggregation and grid optimization in wholesale markets. Batteries can be paired with other forms of renewable energy, including wind and other variable energy resources, to enhance the value of specific projects. They can also serve as standalone projects in the grid to provide added peak capacity to areas, and can potentially serve as an alternative to new or upgraded transmission lines.

Grid-scale storage is still relatively new in the U.S. In addition to providing capacity to the grid, it also serves a role in smaller grid services such as frequency regulation. Costs for battery storage have dropped in recent years and are expected to continue to drop an additional 40-80% by 2050.[5] See Figure 9 for recent battery price information.[6] Lithium-ion technologies are the leading energy storage solutions; however, several other technologies are under investigation for grid-scale applications

[5] Cole, Wesley, and A. Will Frazier. 2020. "Cost Projections for Utility-Scale Battery Storage: 2020 Update." Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-75385. https://www.nrel.gov/docs/fy20osti/75385.pdf.

[6] Energy Storage News. 2020. "BloombergNEF: 'Already cheaper to install new-build battery storage than peaking plants.'" Accessed December 15, 2020. Available at: https://www.energy-storage.news/news/bloombergnef-lcoe-of-battery-storage-has-fallen-faster-than-solar-or-wind-i

including lead-acid, redox flow, and molten salt.[7] While battery storage is currently the leading technology, fly wheels and fuel cell storage using hydrolysis are emerging technologies that have the ability to offer similar storage services to the grid.

Why it matters for Pennsylvania: Pennsylvania's electricity markets are operated by PJM, the independent service operator for the Mid-Atlantic region, and PJM's market rules govern capacity and frequency regulation markets. As the Pennsylvania grid mix continues to change, battery storage will play an important role in providing capacity for peak load days. Even without the addition of solar and wind, battery storage could provide 6-8% of PJM's Annual Peak.[8] With large additions of solar and wind electricity generation sources, a larger percentage can be anticipated. This enabling technology can be paired with the AEPS.

Some states, such as California, Virginia, and Massachusetts, have gone a step further and promoted battery storage technologies through direct incentives or portfolio standard type policies. These policies have been set to require a certain capacity of storage by a target year and are often passed in combination with renewable energy targets and portfolio standards. As Pennsylvania's AEPS is set to plateau in 2021, battery storage policy solutions may be helpful to explore as a way of reducing costs and carbon emissions in the state.

Analyze the potential role of power-to-gas (P2G) and blue and green hydrogen across sectors in meeting Pennsylvania's goals

Alternatives to natural gas have the potential to provide lower carbon thermal energy for a variety of different uses. Power-to-gas (P2G), blue hydrogen, and green hydrogen are emerging technologies that are already being used throughout the world and have the potential to continue to grow in the coming decades. Hydrogen fuel emits zero emissions when consumed and can be produced from a variety of resources, including natural gas and biomass. Hydrogen can be produced via electrolysis using electricity. The use of a zero-carbon electricity source, such as renewables or nuclear energy, creates zero carbon hydrogen fuel, also known as green hydrogen. The use of biomass and natural gas to create hydrogen is known as blue hydrogen. P2G uses electricity to produce gaseous fuels, most notably gas, syngas, and LPG alternatives.

Why it matters for Pennsylvania: Hydraulic fracturing has led to a boom in natural gas extraction in Pennsylvania, providing wide access to a low-cost fuel used for electricity generation, industrial uses, and building heat for Pennsylvania businesses and homes. As the Commonwealth looks to a low-carbon emissions future, continued investment in alternative fuels are expected as they are anticipated to grow in their cost effectiveness and versatility. Both hydrogen and P2G are promising fuels that can be created using electricity, and both fuels have the potential to displace hydraulically fractured or conventional gas, thus altering the gaseous fuels marketplace.

The potential to create, store, and distribute hydrogen in Pennsylvania using excess electricity generated from nuclear, in-state solar, and planned offshore wind projects could be a unique and important opportunity. These alternative fuels can be especially effective in difficult to

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[7] Grid-Scale Battery Storage: Frequently Asked Questions. Accessed December 3, 2020 https://www.nrel.gov/docs/fy19osti/74426.pdf.

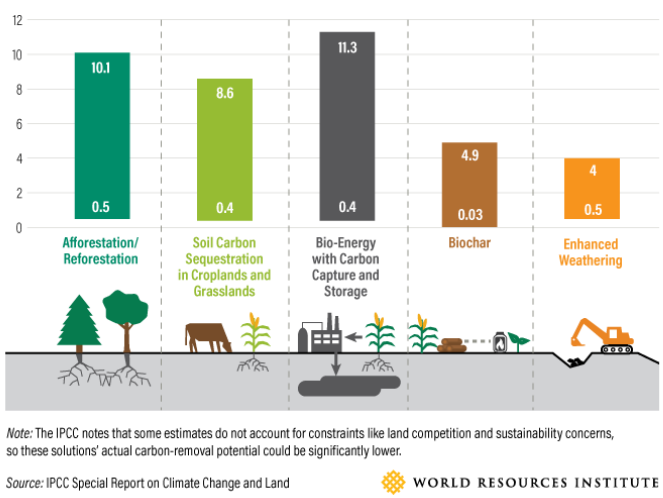
[8] Denholm, Paul, Jacob Nunemaker, Pieter Gagnon, and Wesley Cole. 2019. The Potential for Battery Energy Storage to Provide Peaking Capacity in the United States. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-74184. https://www.nrel.gov/docs/fy19osti/74184.pdf.

decarbonize industrial sectors that require high temperature processes, such as steel refining or food production, or for use as fuels for a variety of heavy-duty or off-road vehicles.

Analyze the potential role of carbon capture, utilization, and sequestration in meeting Pennsylvania's goals

Carbon capture utilization and sequestration (CCUS) is a broad category of technologies that generally capture CO_2 emissions from fossil fuel combustion source points (e.g., coal-fired power plants, industrial flue stacks) to prevent CO_2 from entering the atmosphere. Capturing emissions at source points is the most efficient means of capture as that is where there is the greatest concentration of CO_2—more than 90% of emissions can be captured this way.[9] There are a variety of technologies for capturing CO2, including absorption, adsorption, membranes, and others. Once captured, CO_2 is typically transported via pipeline to be permanently sequestered in geologic rock formations or reused in industrial processes and products such as enhanced oil recovery (EOR). Federal incentives such as the 45Q tax credit are making CCUS technologies more financially feasible, spurring commercial growth in the sector. While the technology is effective and proven, there are not many commercial-scale CCUS projects. However, as the technology continues to develop, costs decline, and demand grows, CCUS is poised to grow significantly over the coming years.

Figure 10. IPCC's Estimate Potential of Various Carbon Removal Approaches (gigatonnes of CO2e/year of carbon removal by 2050. Source: WRI.



In addition to manmade technologies, CO_2 can also be captured and stored through natural land-based carbon removal approaches that capture CO_2 in soils, biomass, and oceans. Soils, biomass, and oceans are known as carbon sinks because they extract CO_2 from the atmosphere rather than emit it. There are several strategies to increase the sequestration of CO_2 by these sinks, including reforestation and afforestation, enhanced soil carbon uptake, biochar, enhanced weathering, and bioenergy with carbon capture and storage (BECCS). The IPCC released its *Climate Change and Land* special report in 2019 that analyzed the sequestration potential of these strategies, the results of which are shown in Figure 10. Afforestation/reforestation and BECCS were found to have the greatest potential, though BECCS is still very much in the early stages of development. Land-based sequestration strategies mush be balanced with competing land and resource uses.

[9] C2ES. N.d. "Carbon Capture." Accessed December 3, 2020. Available at: https://www.c2es.org/content/carbon-capture/.

Why it matters for Pennsylvania: The Commonwealth has a potential sequestration capacity of 88.5 gigatons, enough to store hundreds of years of CO_2 emissions, primarily due to the deep saline formations underground.[10] Additionally, as a major oil and gas producer, it has vast potential to use CCUS technologies for EOR, and in October 2020, Pennsylvania joined a multi-state commitment to establish a regional CO_2 transport infrastructure, signaling its intent to commit to scaling up CCUS.[11] Together, these factors indicate that the Commonwealth is well-placed to implement CCUS technologies that can offer significant economic and climate benefits. Furthermore, Pennsylvania electricity generators, fossil fuel producers and processors, and high-emitting industries could incorporate CCUS technology as a solution for achieving statewide GHG emission reduction goals while preserving a viable fossil fuel-based energy industry. CCUS is expected to play a critical role in achieving GHG reduction goals, but to date, CCUS technologies have had low market penetration due to high costs, lack of policy support, and perceived risks.

Pennsylvania's large land area offers significant potential for land-based sequestration solutions, but must be balanced with competing land uses such as agriculture, recreation, and urban zones.

Provide resources and education on Direct Air Capture

One solution to climate change is to supplement GHG mitigation efforts by directly removing already existing atmospheric CO_2. Direct Air Capture (DAC) systems capture CO_2 from the ambient air through a variety of different techniques. DAC systems differ from other carbon capture techniques because CO_2 in the atmosphere is only present at low concentrations. DAC systems force air through a highly volatile chemical solution or filter that removes the CO_2 from the air. The resulting capture solution or sorbent is processed to isolate the CO_2 and then reestablished through a variety of different chemical and energy intensive processes. Captured CO_2 can be either permanently sequestered or utilized for products such as carbonated beverages or biofuels. Recent estimates indicate the current technology costs range from $300–600/tCO_2$.[12] DAC is considered to be among the most expensive carbon capture technologies, and can be as much as three times more expensive than carbon capture at point sources.

Though some forms of DAC can be traced back to the 1930s, the technology has not yet reached commercial scale due to several factors, but primarily due to high energy demand and high production and operating costs. (However, there are a few existing pilot projects that claim to achieve commercial scale.) However, over the last 10 years, several businesses and research institutions have made significant advances to reduce the costs and improve the efficiency of DAC technologies. DAC has increasingly gained attention as a tool against climate change as it is becoming clearer that to meet midcentury emissions and global warming goals, the world will likely have to remove existing atmospheric CO_2 in addition to

[10] C2ES. 2020. "Carbon capture offers dual economic and climate opportunities in Pennsylvania." Accessed December 3, 2020. Available at: https://www.c2es.org/2020/06/carbon-capture-offers-dual-economic-and-climate-opportunities-in-pennsylvania/.

[11] Pennsylvania Department of Community and Economic Development (DCED). 2020. "Pennsylvania Joins 6 States in Commitment to Plan for CO2 Transport Infrastructure." Accessed December 3, 2020. Available at: https://dced.pa.gov/newsroom/pennsylvania-joins-6-states-in-commitment-to-plan-for-co2-transport-infrastructure/.

[12] Innovation for Cool Earth Forum (ICEF). (2018). *Direct Air Capture of Carbon Dioxide.* Available at: https://www.globalccsinstitute.com/wp-content/uploads/2020/06/JF_ICEF_DAC_Roadmap-20181207-1.pdf.

mitigating future emissions. As technology advances, costs fall, and the demand to capture CO_2 increase, DAC is likely to play a larger role in the coming decades. Providing current resources and education to energy providers and regulators, local businesses, academic and research institutions, and other interested stakeholders may better enable the adoption of DAC technology.

Why it matters for Pennsylvania: Some emissions sources like transportation and cement production are especially hard to decarbonize and will continue to create significant emissions, potentially for decades. DAC systems can be installed in the Commonwealth to help offset the emissions from those sources until they are decarbonized. DAC can also be integrated into the Commonwealth's larger CCUS strategy and infrastructure, notably the recent multi-state CO2 transportation project. DAC requires significant energy inputs, though as a major energy producer, this may not prevent the Commonwealth from adopting DAC technology.

Implement peak load and balancing strategies

Peak load management is a series of technologies and markets that are implemented to reduce strain on the electricity grid. Electricity is a very versatile fuel; however, it needs to be used exactly as it is generated. Flexible grids help solve this challenge as they are capable of handling grid disruption events or high electricity usage peaks by changing energy loads. Managing peak loads and balancing the grids reduces costs for customers by allowing the system to be more efficient. In the future, managing peak loads may play a bigger role as more renewable electricity comes online and provides variable resources.

Presently, grid interruptions occur when sudden power plant shutdowns or large transmission lines outages occur; however, larger load management issues may occur in the future. Load management technologies and markets can help mitigate these challenges. Time of use rates provide economic incentives to electricity customers to use electricity in ways that match grid availability. Dual fuel heat pumps use natural gas to support electricity heat pumps and reduce electricity peaks that could occur in winter months.

Beyond technology, load management programs may also increase the flexibility of grid systems. Load management system provide incentives for building operators and occupants to reduce their usage at key times through advanced HVAC systems or plug load management. Increased EV deployment allows for vehicle batteries to play a role in grid balancing by charging during off-peak times, and one day may potentially provide services to the grid through a vehicle-to-grid connection during critical events.

Why it matters for Pennsylvania: Many Pennsylvania businesses already participate in peak load and balancing strategies through either PJM markets or their local utility. These programs reduce overall costs to operate the grid and can provide revenue to participants. As Pennsylvania's electricity grid changes and a higher penetration of variable sources like wind and solar are incorporated, load management of grid peaks will become increasingly important to provide a resilient energy system. As load management programs grow in sophistication, regulators and legislators may also need to address rate structures to ensure that load balancing does not hurt small businesses and low-income residents.

Analyze the potential role of carbon offsets in meeting Pennsylvania's goals

Carbon offsets provide organizations and government bodies the opportunity to offset their carbon footprint by purchasing a certificate that states that a certain amount (usually 1 $MTCO_2e$) of carbon will be or has been sequestered through some action. The system can be thought of in an accounting framework in which an organization emits carbon through its actions that results in a "carbon credit," which it balances out by purchasing a carbon offset, or "carbon debit." Carbon offsets are provided through either formal carbon offset markets like RGGI, or by a second party that takes some action—often planting trees or installing renewable energy infrastructure—that will sequester carbon permanently or for a very long time. An organization often pursues carbon offsets when the cost of the offset is cheaper than directly reducing its own carbon footprint. Individuals can also purchase offsets. For example, many purchase carbon offsets to cover emissions that results from plane travel. Carbon offsets are relatively cheap, typically ranging from \$3-15/$MTCO_2$.

There are several critical requirements that carbon offsets must meet: they must be verified as legitimate (i.e., a trusted third-party verifies the offset action will truly reduce emissions), "additional," (i.e., the activity would not have been taken without the purchase of the offset), and that the offset remains valid long-term (i.e., the planted tree will not be cut down right after the offset is issued). Carbon offsets have long been criticized for not fully meeting these criteria, and their long-term efficacy remains unconfirmed. Further criticisms point to concerns about equity and that emissions are not prevented.

Why it matters for Pennsylvania: There are two different carbon offset markets that are applicable to Pennsylvania: the formal carbon offset market under RGGI, and the smaller, voluntary market. As RGGI evolves and grows, the carbon offset market will likely expand in kind, and as a RGGI member, the Commonwealth could benefit by either buying or selling offsets, depending on which is more beneficial. As a state with a relatively large population and land area and large forested areas, Pennsylvania is better positioned to provide carbon offsets than many of its neighbors.

Provide resources and education on disruptive digital technologies

Digital technologies, enabled through the Internet of Things (IoT) and high-speed networks such as 5G (fifth generation cellular technology standards), are disrupting traditional business models and standard industry processes. IoT allows everyday objects to connect to the internet and transmit data (e.g., smart thermostats); widespread application of IoT necessitates a high-speed 5G network to exchange data, implement updates, and track performance, and 5G is currently being rolled out nationwide. Artificial intelligence and advanced algorithms are increasingly built into smart and digital technologies for improved optimization, which is expected to continue to make great strides in the coming years. The potential costs, barriers to implementation, and impacts of digital technologies vary greatly based on the scale and scope of application, yet they will undoubtedly reshape the energy sector over the next decade.

The energy sector has historically been an early adopter of digital solutions and has already seen digital technologies penetrate and disrupt energy system supply and demand, from smart metering to distributed grid optimization. Energy end-use sectors such as transport systems, buildings, and industrial plants have already adopted some disruptive digital technologies, including autonomous cars, smart home systems, and 3-D printing processes. Energy companies and utilities are expected to increasingly invest in disruptive technologies to revolutionize remote automation capabilities, real-time automation, and hazard and maintenance sensing ability. Drivers for technology change include targeted education and key changes in regulations or rules that affect market conditions can also stimulate the installation or economic viability of certain technologies. These technologies have applications in all sectors of the CAP.

Why it matters for Pennsylvania: Disruptive digital technologies have the potential to significantly enhance Pennsylvania's energy sector by improving efficiency and optimization. Integrating 5G and IoT into energy generation and transmission can potentially reduce operation costs and energy bills, lessen negative environmental impacts, and mitigate GHG emissions. Energy demand will also shift due to increased connectivity, and the Commonwealth must improve its capability to respond and adapt to the changing demand.

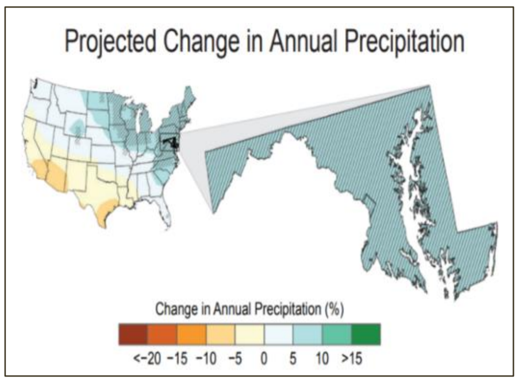
4 THE IMPACTS OF CLIMATE CHANGE IN PENNSYLVANIA AND ONGOING ADAPTATION EFFORTS

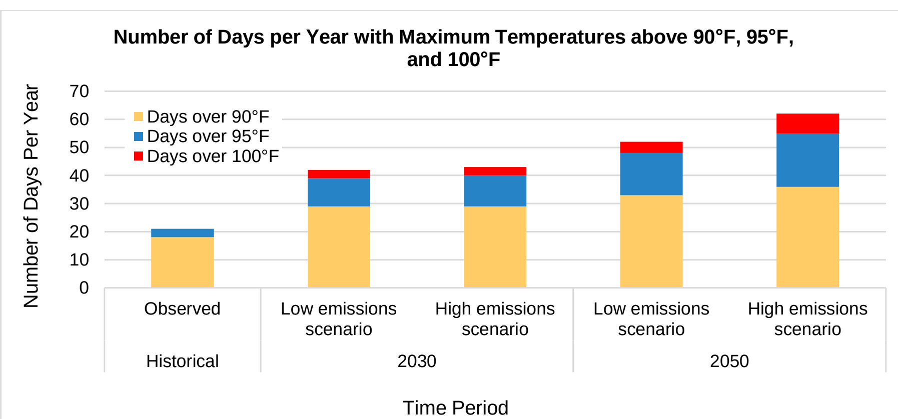
- ~5 pages long
- Introductory paragraph

4.1 Summary of Priority Risks and Impacts from IA

- Summarize key results of IA
- Include a table
- Describe each priority risk and impact briefly
- Include maps and charts to help visualize results (examples to right and below)

Figure 11. Projected percent change in annual precipitation in the mid-21st century, relative to late 20th century levels, under a high emissions scenario.





4.2 Ongoing Adaptation Efforts

- Summarize current adaptation efforts broadly
- Describe specific efforts, by sector or focus area

5 OPPORTUNITIES TO ADAPT TO THE IMPACTS OF CLIMATE CHANGE IN PENNSYLVANIA

- ~15-25 pages long, depending on number of strategies and pathways
- Introductory paragraph describing section
- Reference efforts in the IA

5.1 Approach

- Outline basic approach
- Include process diagram figure

5.1.1 Identification Process of Potential Strategies and Adaptation Pathways

- The strategies presented in this memorandum are based on four main sources, for each of the priority risks identified in the IA:
    - Feedback from the Climate Change Advisory Committee (CCAC)and various Commonwealth agencies
    - A review of the 2018 Climate Action Plan, including addendum letters from the CCAC
    - A review of public survey data from DEP on the 2018 Climate Action Plan
    - ICF's knowledge of relevant and common strategies used across the country

5.1.2 Developing Adaptation Pathways

- For each priority risk, the CAP outlines an "adaptation pathway" to manage that risk over time. Adaptation pathways outline a series of steps, including options and decision points over time. For example, pathways may include a handful of near-term, "no regrets" strategies, and then options for medium- and longer-term strategies and criteria for deciding between options in the future.
- Each pathway consists of several adaptation strategies, organized by timeline and tipping points that would prompt implementation of the strategy.
- Emphasize pathways in a descriptive graphic that shows monitoring of tipping points and the anticipated responses
- Describe how pathways are connected to strategies

5.1.3 Identifying Costs and Benefits

- Present identified costs and benefits
- Explain how they result from the strategies
- Mention economic costs and benefits, but also social, equity, and environmental

5.2 Adaptation Pathways

- Set up the section

5.2.1 Pathway Descriptions

- For each pathway, include:
    - Description and Purpose
    - Decision points and thresholds

- Costs and benefits

6 IMPLEMENTING CLIMATE ACTION IN PENNSYLVANIA

- ~15 pages long
- Introductory paragraph describing section

6.1 Challenges and Opportunities

- Pull from challenges identified in GHG strategy reduction section to identify key challenges
- Explain possible solutions to overcome challenges
- Explain possible opportunities and how they could prove fruitful
- Discuss potential methods to take advantage of opportunities
- Talk about potential uses of RGGI revenues (generally) or potential stimulus revenues

6.2 Implementation Principles

- Describe best practices to implement strategies
- Strategy implementation will align with the Guiding Principles and Best Practices for EPO Planning and Programming (PA Energy Programs Office 2020):
    - Enhance collaboration between government and stakeholders.
    - Consider the needs of vulnerable communities and the effects of actions on equity, access, and inclusion.
    - Enhance the marketing of programs and communication of results.
    - Conduct program impact assessments.
    - Create a program tracker.
    - Integrate energy assurance and resilience in planning efforts.
- Touch on institutional arrangements that exist and could be leveraged, identify any gaps in arrangements
- Discuss monitoring and tracking considerations

6.3 Equitable and Beneficial Implementation

- Explain how implementation should be designed to ensure the outcomes and benefits are equitable and improve the lives of all Pennsylvanians
- Talk about potential uses of RGGI revenues (generally) or potential stimulus revenues

6.3.1 Creating jobs and economic opportunity

- Explain how implementing the identified strategies will create jobs and economic opportunities
- Describe how proper implementation can maximize the amount of jobs and economic benefits

6.3.2 Addressing health

- Explain how human health is influenced by the local climate and how the climate adaptation strategies and GHG reduction strategies will improve human health

6.3.3 Addressing equity barriers

- Explain what equity barriers exist and potential solutions to overcome barriers.

6.4 Key Steps and Stakeholders for Implementation

- Describe high-level steps and stakeholders that are most critical for implementing adaptation and GHG reduction strategies
- Add a timeline graphic showing phasing of GHG reduction strategies
- Add a timeline graphic showing phasing of adaptation strategies
- Indicate potential or actual roles of stakeholders to implement the CAP

APPENDIX A – KEY TERMS

- Glossary
- Acronyms

APPENDIX B – METHODOLOGY DETAILS

BAU Methodology

The BAU was developed through a series of steps that mostly align with the BAU approach ICF used for the 2018 Pennsylvania CAP update and the Energy Assessment Report. The exceptions to this methodology and data sources are noted below. The primary methodological steps undertaken were as follows:

1. Compiled and integrated historical energy and emissions data, primarily from the Energy Information Administration (EIA) State Energy Data System (SEDS), the Environmental Protection Agency State Inventory Tool (SIT), and state-specific data sources. Section 2.2.1 provides an overview of these data sources in more detail.
2. Projected future activity primarily using the EIA Annual Energy Outlook (AEO) Reference Case, making adjustments to align AEO and SEDS geographies. While SEDS data are provided at the state level, AEO data are forecasted at the regional level. To account for this geographical discrepancy, DEP and ICF applied the AEO regional growth rate for a particular energy resource to the historical SEDS data to project Pennsylvania Commonwealth-level energy resource data. Other projection methods, such as those based on state-specific regulations on oil and gas methane emission controls and HFC phaseouts, were incorporated as described below.
3. Adjusted historical and future activity data to ensure consistency, capture available Pennsylvania-specific data, address existing data gaps, and incorporate the analysis team's expert input using resources such as ICF's Integrated Planning Model (IPM).
4. Applied emission factors when available to estimate GHG and criteria air pollutant emissions.

GHG Accounting Methods

The BAU assessment followed the GHG accounting methods applied within the existing state GHG inventory. Notably, the BAU estimates and incorporates emissions from electricity generation in total emissions estimates for the Commonwealth. Emissions from electricity consumption (e.g., from the residential and commercial sectors) are reported for informational purposes. This is consistent with the request from the CCAC and will make accounting for policies, such as the Regional Greenhouse Gas Initiative, more transparent and consistent. It will also allow for consistent future goal tracking using the SIT. Data for the SIT and other resources were adjusted and aligned with state-specific data, where available and feasible.

Base and Projection Years

The BAU scenario incorporated activity and emissions data through 2050. DEP and ICF modeled the BAU starting in 2005, as this is the baseline year for Pennsylvania's 80x50 GHG reduction goal. Historical data for 2000 - 2005 are also shown to provide a consistent timeseries for the entire 21st century. The last year for which SIT data were available is 2017. Projections that relied on SIT data were developed annually, starting in 2018, for each year through 2050. Emission categories that used other datasets, such as the AEO, were projected beginning in the most recent year of available data (in most cases this was 2019).

Sector Approach and Data Sources

The following sections outline the approaches and accompanying data sources used in to develop historic BAU estimates and projections.

Transportation

DEP and ICF used transportation fuel use data from SEDS and emission factors from the SIT to analyze historical transportation emissions. Transportation fuel use growth rates from AEO were used to project fuel use and then emissions (applying appropriate emission factors) through 2050. This data was supplemented with state-specific data and assumptions for required production and use levels for biodiesel. Emissions associated with electricity use were not included in total emissions but reported separately for informational purposes.

Residential and Commercial Buildings

Historical building energy consumption data were pulled from SEDS, along with emission factors from the SIT, to calculate past GHG emissions. The analysis team used AEO data and trends, along with historical data, to project residential and commercial building energy use through 2050. Emissions associated with electricity use were not included in total emissions but reported separately for informational purposes.

Industrial

Similar to the residential and commercial sectors, industrial sector energy use and emissions were taken from SEDS and the SIT. To project activity and emissions, AEO growth trends and related emission factors were applied. Emissions associated with electricity use were not included in total emissions but reported separately for informational purposes.

HFC emissions were extrapolated based on the HFC phaseout regulations that requires GHG emissions reductions of 26% below 2005 levels by 2025 and 80% below 2005 levels by 2050. These targets align with the statewide emission reduction goals established by Governor Tom Wolf in EO 2019-1.

Oil and Gas Systems

Historical natural gas and crude oil data are available from SEDS; future natural gas and crude oil production (and therefore emissions) were estimated using a mix of sources. To determine future production of natural gas and crude oil in Pennsylvania, the analysis team used historical SEDS data and ICF's Integrated Planning Model (IPM) to project future generation from oil and gas sources. Fugitive GHG emissions estimates from oil and natural gas production were based on estimates from the SIT, which were adjusted based on a proposed rule from DEP that would reduce the amount of methane emitted through control measures aimed at limiting emissions from volatile organic compounds (VOCs).

Renewable and Alternative Energy (Non-Electricity)

Biogas (including agricultural waste, wastewater, and landfill gas) estimates are only available for the industrial sector in the EIA data sources. DEP and ICF therefore relied on biogas supply/consumption information from a mix of sources, including EPA's Landfill Methane Outreach Program (LMOP) and AgSTAR project databases, a listing of wastewater sites in Pennsylvania (WEF 2015), and a database of CHP projects maintained by ICF. This information is readily available and was compiled by ICF through its work with the American Gas Foundation to assess renewable gas supply in the United States. Projections for these sources were based on outputs from the IPM.

Electricity Generation

Historical electricity generation was pulled from SEDS, along with emission factors. Future annual electricity load projections (aggregated for all sectors) were then fed into IPM, which projected future generation mixes and emissions through 2050. The analysis team worked to align historical SEDS data and future IPM projections to ensure consistency.

Waste and Wastewater

Both waste and wastewater emissions reflect non-energy sources in the BAU, as the SIT does not allocate emissions from electricity consumption in these sectors. The BAU model does not include CO_2 from landfills in waste emissions estimates, as this is considered biogenic.

For wastewater, similar to waste, the BAU model does not include biogenic CO_2 from treatment plants. The BAU projects wastewater emissions from increased flows due to population growth and landfill waste emissions from the historic activity data and projected waste disposal totals.

Agriculture

Agriculture emissions were estimated using the SIT Agriculture module. Projections for the agricultural sector include CH_4, N_2O, and CO_2 emissions using data from the SIT.

LULUCF

ICF estimated net carbon sequestration/emissions from LULUCF using data from the SIT, this is based on data from the US Forest Service. Projections for LULUCF were held constant to latest year of available data for the BAU. Additional changes on forest cover and natural sequestration may be addressed through the GHG reduction analysis.

BAU Results

The BAU res presented in Table B-1.

Table B-1 Pennsylvania GHG emissions (MMTCO$_2$e) by sector

Sector	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	%
Residential	26	24	20	20	17	20	22	21	19	19	7%
Commercial	13	13	11	10	9	11	11	12	11	11	4%

Industrial	82	78	73	73	74	83	87	85	79	81	31%
Transportation	71	73	65	63	62	61	61	60	61	64	24%
Electricity Production	108	121	117	111	105	103	97	86	81	75	29%
Agriculture	8	8	8	8	8	8	8	8	8	8	3%
Waste Management	7	5	4	4	4	4	4	4	4	4	2%
Total (Gross Emissions)	**315**	**321**	**297**	**289**	**279**	**290**	**291**	**275**	**262**	**263**	**100%**
Forestry and Land Use	(26)	(35)	(31)	(30)	(31)	(30.5)	(30)	(30)	(29)	(30)	-
Total (Net Emissions)	**289**	**287**	**266**	**258**	**248**	**260**	**261**	**246**	**232**	**233**	**-**

Note: Totals may not sum due to rounding.

Greenhouse Gas Reduction Strategy Methodology

The analysis team used methods and tools similar to what were used to conduct the 2018 CAP analysis with a few exceptions. The analysis was primarily conducted using Excel-based tools, the exception being the use of the IPM model for the electricity sector analysis. ICF also made a few changes to the GHG accounting approach, including accounting for electricity sector generation emissions (pulling out any electricity related emissions from end use sectors) and applying marginal emission factors (i.e., using emission factors more specific to the fuel/technology to better characterize the change of emissions) where appropriate to estimate reductions. As part of the GHG reduction analysis, where feasible, ICF also estimated changes in air quality emissions (e.g., NO_x and SO_x) at the state level.

Buildings Sector

Buildings 1: Support Energy Efficiency Through Building Codes

Description

- Adopt the most current building codes, enforce existing codes, encourage local adoption of stretch codes, and educate and train code officials and inspectors on code enforcement.

Method, Data and Key Assumptions

- **Residential Energy Savings:** Using ICF's Energy Code Calculator,[13] the analysis team assumed an International Energy Conservation Code (IECC) 2015 base code and then implemented projected future IECC code versions every six years through 2050. The analysis team also reviewed the 2021 IECC code and considered what aspects to integrate in the analysis. This implementation timeframe was based on the actual time it took to adopt the 2015 codes in Pennsylvania.[14] The team assumed 90% code compliance for all new construction homes with a 30-year measure life, based on requirements set in 2009 SEP grants.[15] New home projections were provided by Pacific Northwest National Laboratory.[16] This approach delivers both electricity and natural gas savings.
- **Commercial Energy Savings:** Again, using ICF's Code Calculator, the team assumed an American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 2007 base code and implement projected future ASHRAE code versions every six years through 2050. The team assumes 90% code compliance for all new construction,

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[13] The Energy Codes calculator is a proprietary tool that estimates changes in energy use based on assumed updates to building codes for new construction.

[14] In May 2018 Pennsylvania moved ahead with adopting the 2015 model International Energy Conservation Code commercial and residential energy codes, while incorporating some select improvements from the 2018 model code. These changes will go into effect in October of 2018. https://www.dli.pa.gov/ucc/Documents/rac/UCC-RAC2015-Code-Review-Report.pdf.

[15] During the 2009-12 Recovery act period, SEP grants came with a condition that all states set plans to achieve 90% code compliance. A DOE field study for PA shows close to 90% compliance: https://www.energycodes.gov/sites/default/files/documents/Pennsylvania_Residential_Field_Study.pdf.

[16] 19 Pacific Northwest National Laboratory. (PNNL). 2014. Utility Savings Estimator. Accessed on July 13, 2018. Available at https://www.energycodes.gov/resource-center/utility-savings-estimator.

renovations, and additions with a 30-year measure life. New commercial square foot projections were provided by Pacific Northwest National Laboratory. This approach delivers both electricity and natural gas savings.

- **Strategy Layering:** This strategy was applied prior to any other building energy strategy.
- **Emissions Accounting:** Emissions savings as a result of building electrification appear in two places—emissions related to electricity consumption are accounted for in the electricity generation sector and emissions related to displaced gas or fossil use appear in the buildings sector. Emissions from electricity consumed by residential and commercial buildings are reported for informational purposes only and are not included in emissions totals. These informational emission reductions were calculated using marginal emission factors for the grid over time.

Applicable Emission Factors

- **GHG:** GHG emission factors for electricity come from IPM. ICF calculated a blended gas supply emission factor over time based on the available supply of renewable natural gas (see Fuel Supply 1 measure) and overall gas demand across the state. Other fuel emission factors come from the U.S. Inventory and 2006 IPCC Guidelines for National Greenhouse Gas Inventories (consistent with the State Inventory Tool).
- **Air Quality:** Air Quality emissions factors for electricity come from IPM. Emissions factors for natural gas, coal, fuel oil and other fuels come from EPA AP-42 Fifth Edition Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources; and Emission Factor Supporting Documentation for the Final Mercury and Air Toxics Standards. Mercury Air Toxic Standards (MATS).

Buildings 2: Residential and Commercial Energy Efficiency Improvements (Electricity)

Description

- Either within the existing Act 129 framework or a modified framework (e.g., increase savings targets and remove spending caps), require increasing residential and commercial energy efficiency improvements targeted at kWh savings.
- For Act 129, consider increasing the low- to moderate-income (LMI) share of spending and reforming cost-effectiveness tests to support an increased LMI focus, and add climate mitigation and resilience benefits to cost-effectiveness tests.
- Energy savings could also be achieved through other incentives and education by leveraging programs like Low Income Home Energy Assistance Program (LIHEAP) and Weatherization Assistance Program (WAP).

Method, Data, and Key Assumptions

- **Residential Electricity Savings:** Based on the Pennsylvania Statewide Evaluator's (SWE) Energy Efficiency Potential Study for Pennsylvania, the analysis team applied the calculated maximum achievable potential energy savings from 2021-2050 (1.5%). Historical evidence suggests this potential estimate can be achieved. The analysis team assumed a measure lifetime of 10 years.
- **Commercial Electricity Savings:** Again, using the SWE's study, the analysis team applied the maximum achievable potential from 2021-2025 (0.8%) followed by 1.0%annual incremental savings for years 2026-2050. The team assumed a measure lifetime of 10 years. Accelerated progress will be demonstrated for a portion of buildings that are subject to local legislation (benchmarking and building performance) and voluntary programs (2030 District, CPACE, financing programs).
- **Strategy Layering:** SWE's study will serve as the base source for modeling savings in the residential and commercial sector. Accelerated progress for a subset of buildings will be layered on top of the base strategies. This strategy is expected to impact any portion of energy use (representative of buildings) not already impacted by Buildings Strategy #1.
- **Emissions Accounting:** Emissions savings as a result of energy efficiency improvements that affect electricity consumption are accounted for in the electricity generation sector (reduced generation = reduced emissions). Emissions from electricity consumed by residential and commercial buildings are reported for informational purposes only and not included in emissions totals. These informational emission reductions will be calculated using marginal emission factors for the grid over time.

Applicable Emission Factors

- **GHG:** GHG emission factors and emissions come from ICF's Integrated Planning Model (IPM).
- **Air Quality:** Air quality emission factors come from IPM (NO_x and SO_x).

Buildings 3: Residential and Commercial Energy Efficiency Improvements (Gas)

Description

- Create a new energy efficiency program focused on reducing gas consumption.
- The program description will match voluntary gas demand side management (DSM) programs already in place with some Pennsylvania gas utilities, but will be considered a statewide program.
- Ensure that the new program includes a LMI share of spending, reforms cost-effectiveness tests to support increased LMI focus, and reforms climate mitigation and resilience benefits to cost-effectiveness tests.

Method, Data and Key Assumptions

- **Residential Gas Savings:** Using an American Council for an Energy-Efficient Economy (ACEEE) Energy Efficiency Resource Standard (EERS) policy brief,[17] the analysis team applied the Massachusetts EERS target of 1.1%annual incremental natural gas savings from 2020-2025 followed by 1.0%from 2026-2050. The team assumed a measure lifetime of 10 years. The analysis team will also review data from the PUC and in rate filings related to voluntary gas programs to determine if adjustments to the assumptions should be made.
- **Commercial Gas Savings:** The analysis team used the same approach used for residential gas savings, with savings percentages mirroring electricity.
- **Strategy Layering:** Accelerated progress for a subset of buildings will be layered on top of the base strategies. This strategy is expected to impact any portion of energy use (representative of buildings) not already impacted by Building Strategy #1.
- **Emissions Accounting:** Emissions savings as a result of energy efficiency improvements that affect energy consumption are accounted for in the buildings sector.

Applicable Emission Factors

- **GHG:** The analysis team calculated a blended gas supply emission factor over time based on the available supply of renewable natural gas (see Fuel Supply 1) and overall gas demand across the state.
- **Air Quality:** Air quality emissions factors for gas combustion are from the EPA AP-42 Fifth Edition Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources; and Emission Factor Supporting Documentation for the Final Mercury and Air Toxics Standards. Mercury Air Toxic Standards (MATS).

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[17] ACEEE. 2020. "Energy Efficiency Resource Standard." Accessed December 15, 2020. Available at: https://www.aceee.org/toolkit/2020/02/energy-efficiency-resource-standard.

Buildings 4: Incentivize Building Electrification

Description

- Incentivize building electrification (e.g., heating and hot water). As part of this strategy, specific attention will be focused on where and how this can be applied in Pennsylvania, particularly for the residential and commercial sectors.
- Create a new energy efficiency program focused on beneficial electrification, possibly modeled on the New York Clean Heat program. Incentivize converting fuel oil and natural gas to electricity in existing buildings and electrification of entire new buildings where there are large natural gas infrastructure costs or where fuel oil is the alternative.

Method, Data and Key Assumptions

- **Method:** The analysis team applied an average annual energy savings potential for residential and commercial buildings to evaluate energy consumption (natural gas, and fuel oil) reductions from electrification of existing buildings. For new buildings, the team evaluated the amount of displaced energy consumption. The team assumed that a to-be-defined share of residential and commercial buildings will be retrofitted with electric heating at least (potentially also hot water heating and cooking) by 2050, and that a to-be-defined share of new residential and commercial buildings will be all-electric by 2050.
- **Strategy Layering:** This strategy is applied after Building Strategy #1, 2, and 3.
- **Emissions Accounting:** Emissions savings or increases as a result of building electrification appear in two places—emissions related to kWh are accounted for in the electricity generation sector and emissions related to displaced gas or fossil use appear in the buildings sector. Emissions from electricity consumed by residential and commercial buildings are reported for informational purposes only and not included in emissions totals. These informational emission reductions were calculated using marginal emission factors for the grid over time.

Applicable Emission Factors

- **GHG:** GHG emission factors for electricity come from IPM. The analysis team calculated a blended gas supply emission factor over time based on the available supply of renewable natural gas (see Fuel Supply 1 measure) and overall gas demand across the state. Other fuel emission factors are from the U.S. GHG Inventory and 2006 IPCC Guidelines for National Greenhouse Gas Inventories (consistent with the State Inventory Tool).
- **Air Quality:** Air Quality emissions factors for electricity come from IPM. Emissions factors for natural gas, coal, fuel oil and other fuels are from EPA AP-42 Fifth Edition Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources; and Emission Factor Supporting Documentation for the Final Mercury and Air Toxics Standards. Mercury Air Toxic Standards (MATS).

Transportation Sector

Transportation 1: Reduce Vehicle Miles Traveled for Single-Occupancy Vehicles

Description

- Reduce vehicle miles traveled (VMT) for single-occupancy vehicles by implementing travel demand strategies such as shifting travel time, mode choice, and route, and increasing the frequency of telecommuting. These efforts would be paired with land-use and development policies that promote sustainable transportation modes (walking, biking, transit, carpool) and development in existing population centers.

Method, Data and Key Assumptions

- **VMT Reduction:** The analysis team used an overall VMT reduction target of 3.4% by 2030 and 7.5% of total VMT from BAU by 2050. This estimate is based on the draft Pennsylvania Energy Assessment Report prepared in 2018,[18] as well as Pennsylvania-specific runs of the EPA's Motor Vehicle Emission Simulator (MOVES), U.S. Energy Information Administration's (EIA) Annual Energy Outlook 2018, and Federal Highway Administration VMT projections.[19]
- **Strategy Layering:** The reductions from this strategy were accounted for before Transportation strategies 2 and 3.
- **Emissions Accounting:** Changes in electricity consumption are accounted for in the electricity generation sector and then reported out for informational purposes here (similar to buildings). Other fuel reduction and related emission reductions are represented in this strategy.

Applicable Emission Factors

- **GHG:** GHG emission factors are from the State Inventory Tool Mobile CO2FFC Module. Electricity emission factors are from ICF's IPM.
- **Air Quality:** Air quality emission factors are ICF-developed factors based on MOVES runs provided by DEP.

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[18] Pennsylvania Department of Environmental Protection (DEP). 2018. Draft Report: Energy Assessment Report for the Commonwealth of Pennsylvania.

[19] Federal Highway Administration (FHWA). 2018. FHWA Forecasts of Vehicle Miles Traveled (VMT): Spring 2018. Accessed July 3, 2018. Available at: https://www.fhwa.dot.gov/policyinformation/tables/vmt/vmt_forecast_sum.pdf

Transportation 2: Implement the MHDV MOU

Description

- Implement the medium- and heavy-duty vehicles memorandum of understanding (MHDV MOU) with the goal of reaching net zero emissions from MHDVs by 2050, of which the State of Pennsylvania is a co-signatory.[20] This target would be achieved through a mix of fuel switching to electric and other alternative fuel vehicles such as fuel cell electric vehicles (FCEV), and would eliminate vehicles that have a disproportionate impact on air quality due to diesel emissions and/or that have a relatively low fuel economy. Potential actions (as stated in the MOU) may include:
    - Financial vehicle and infrastructure incentives.
    - Non-financial vehicle and infrastructure incentives.
    - Actions to encourage public transit and public fleets to deploy zero emission MHDVs.
    - Effective infrastructure deployment strategies.
    - Funding sources and innovative financing models to support incentives and other market-enabling programs.
    - Leveraging environmental and air quality benefits associated with the adoption of the California Advanced Clean Trucks rule under Section 177 of the Clean Air Act.
    - Coordinated outreach and education to public and private MHDV fleet managers.
    - Utility actions to promote zero emission MHDVs, such as electric distribution system planning, beneficial rate design and investment in "make-ready" charging infrastructure.
    - Measures to foster electric truck use in densely populated areas.
    - Addressing vehicle weight restrictions that are barriers to zero emission MHDV deployment.
    - Uniform standards and data collection requirements.

Method, Data and Key Assumptions

- **Method:** 30% of medium- and heavy-duty vehicles will be alternative fuel vehicles by 2030, and 100% will be by 2050, aligning with Pennsylvania's commitment in the MHDV MOU. MOVES data was used to determine the breakdown of vehicle type and to calculate displaced fuel consumption due to changes in vehicle type. The CALSTART Zero-Emission Technology Inventory (ZETI) tool[21] was used to identify vehicles that already have zero-emission versions available, and Pennsylvania will prioritize those vehicle types for reaching the 2030 goal.
- **Strategy Layering:** This measure used Transportation Strategy #1 as a baseline to avoid double-counting emissions reductions.
- **Emissions Accounting:** Changes in electricity consumption are accounted for in the electricity generation sector and then reported out for informational purposes here (similar to the buildings strategies). Other fuel reductions and related emission reductions are represented in this strategy.

[20] Multi-State Medium- and Heavy-Duty Zero Emission Vehicle Memorandum of Understanding. Available here: https://ww2.arb.ca.gov/sites/default/files/2020-07/Multistate-Truck-ZEV-Governors-MOU-20200714.pdf

[21] https://globaldrivetozero.org/tools/zero-emission-technology-inventory/

Applicable Emission Factors

- **GHG:** GHG emission factors are from the State Inventory Tool Mobile CO2FFC Module. Electricity emission factors come from ICF's IPM.
- **Air Quality:** Air quality emission factors are ICF-developed emission factors based on MOVES runs provided by DEP.

Transportation 3: Increase Adoption of Light-Duty Electric Vehicles

Description[22]

- Increase adoption of light-duty electric passenger vehicles (including private and municipal fleet vehicles) by following the EV Roadmap, using a ZEV mandate, providing education and outreach, and offering additional or modified incentives through AFIG, AFV, and the Driving Pennsylvania Forward program. This strategy will include approaches for reaching low-income communities, multi-family units, and workplaces.

Method, Data and Key Assumptions

- **EV Market Penetration**: EVs will represent 20%of the light-duty market share by 2030, rising to 70%by 2050. The target is based on the Pennsylvania DEP Pennsylvania Electric Vehicle Roadmap report, with consideration for the current market share.
- **Strategy Layering:** This measure will use Transportation Strategy #1 as a baseline to avoid double-counting emissions reductions.
- **Emissions Accounting:** Changes in electricity consumption are accounted for in the electricity generation sector and then reported out for informational purposes here (similar to the buildings sector). Other fuel reductions and related emission reductions are represented in this strategy.

Applicable Emission Factors

- **GHG:** GHG emission factors are from the State Inventory Tool Mobile CO2FFC Module. Electricity emission factors come from ICF's IPM.
- **Air Quality:** Air quality emission factors are ICF-developed factors based on MOVES runs provided by DEP.

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[22] https://www.dep.pa.gov/Business/Air/Volkswagen/Pages/Driving-PA-Forward-Grant-and-Rebate-Awards.aspx

Transportation 4: Implement a Low Carbon Fuel Standard (LCFS)

Description

- This program would focus on decreasing the carbon intensity of transportation fuels and provide an increased supply and range of alternative fuels through a system of credits, similar to the California LCFS Program.[23] This would expand on the ethanol and biodiesel requirements already in place in Pennsylvania.

Method Data and Key Assumptions

- **Energy Savings:** As part of this strategy, changes in fuel consumption and associated emissions from fuel switching to i) renewable diesel, ii) natural gas (i.e., compressed natural gas (CNG)), and iii) electricity from gasoline and diesel are estimated. Annual changes in fuel consumption were estimated by linearly interpolating reductions in carbon intensity of the fuel mix in accordance with the 8% and 20% carbon intensity reduction targets by 2030 and 2040, respectively. The analysis team assumed total fuel consumption to be equivalent to BAU fuel consumption.
- **Strategy Layering:** This is the final measure to be implemented, and reductions from other transportation strategies are layered into baseline fuel consumption used to model the LCFS.
- **Emissions Accounting:** Changes in electricity consumption are accounted for in the electricity generation sector and then reported out for informational purposes here (similar to the buildings sector). Other fuel reduction and related emission reductions are represented in this strategy.

Applicable Emission Factors

- **GHG:** GHG emission factors are from the State Inventory Tool Mobile CO2FFC Module. Electricity emission factors come from ICF's IPM.
- **Air Quality:** Air quality emission factors are taken from ICF-developed factors based on MOVES runs provided by DEP.

[23] https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard/about

Industrial Sector

Industrial 1: Increase Industrial Energy Efficiency

Description

- Leverage existing programs from DEP (e.g., the Energy Efficiency, Environment, and Economics [E4] Initiative) and the types of actions outlined in the new Pennsylvania Clean Energy Plan. This will include a focus on specific industries, or sizes of industries, but also leverage broader tools such as virtual trainings and expanded partnerships to reach smaller and hard to access industries.

Method, Data and Key Assumptions

- **Energy Savings:** Using the Pennsylvania Statewide Evaluator's (SWE) Energy Efficiency Potential Study for Pennsylvania,[24] the analysis team applied the calculated maximum achievable potential from 2020-2025 (1.2%) followed by the average incremental annual maximum achievable potential (1.2%) from 2016-2025 for years 2026-2050 for electricity.
- **Natural Gas Savings:** Based on a 2009 Georgia Tech meta-review of efficiency potential studies,[25] the analysis team applied the natural gas average annual energy efficiency potential for the industrial sector of 0.6%from 2020-2050. This strategy is assumed to have a lifetime of 10 years.
- **Strategy Layering:** Reductions from this strategy were applied after Fuels Supply Strategy #2 (increased CHP).
- **Emissions Accounting:** Emissions savings as a result of energy efficiency improvements are accounted for in the industrial sector.

Applicable Emission Factors

- **GHG:** GHG emission factors for electricity come from IPM and other relevant sources or were calculated using assumptions from onsite generation projects. The analysis team also accounted for reduced electricity emissions that result from combined heat and power (CHP) generation and updated the emissions factor for CHP as more projects come online. The team calculated a blended gas supply emission factor over time based on the available supply of renewable natural gas (see Fuel Supply Strategy #1) and overall gas demand across the state. Other fuel emission factors come from the U.S. Inventory and 2006 IPCC Guidelines for National Greenhouse Gas Inventories (consistent with the State Inventory Tool).
- **Air Quality:** Air Quality emissions factors for electricity come from IPM. Emissions factors for natural gas, coal, fuel oil, and other fuels come from EPA AP-42 Fifth Edition Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources; and Emission Factor Supporting Documentation for the Final Mercury and Air Toxics Standards. Mercury Air Toxic Standards (MATS).

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[24] Statewide Evaluation Team. 2015. Energy Efficiency Potential Study for Pennsylvania. Prepared for the Pennsylvania Public Utility Commission. Accessed on July 3, 2018. Available at: http://www.puc.pa.gov/pcdocs/1345079.pdf.

[25] Georgia Institute of Technology. 2009. Meta-Review of Efficiency Potential Studies and Their Implications for the South. Accessed July 13, 2018. Available at: https://smartech.gatech.edu/handle/1853/30189.

Fuel Supply

Fuel Supply 1: Increase Production and Use of Biogas/Renewable Gas

Description

- This strategy would increase the production and use of biogas/renewable gas from sources such as coal mines, agriculture, wastewater, and landfills. This strategy would consider the potential for renewable gas and specific applications within Pennsylvania and regionally across a number of feedstocks, as identified in the 2019 American Gas Foundation renewable natural gas (RNG) report, Penn State University's RNG analysis, and ICF's PA RNG database. Fuels will be supplied through the existing pipeline network.

Method, Data, and Key Assumptions

- **Potential for RNG:** Based on the analysis team's evaluation for the American Gas Foundation in 2019, there are various feedstock options for considering biogas and renewable gas in Pennsylvania. These options and their potential are listed below. The potentials are maximum, and the analysis team applied criteria to reduce the amount of supply available by 2050 and also phase in availability over the 2020 to 2050 time period. In particular, thermal gasification feedstocks are not available in the analysis team's modeling until 2030.

Total (Bcf)	PA Total
Animal Manure	56.4
Food Waste	3.8
Landfill Gas	60.9
WRRFs	4.0
Anaerobic Digestion sub-total	125.2
Agriculture Residue	14.4
Energy Crops	74.5
Forestry Residue	7.5
MSW	33.3
Thermal gasification sub-total	129.7
Total	254.8

- **Uses of RNG:** The analysis team assumed that some feedstocks for RNG will be used in direct CHP applications, but that the majority of available RNG supply will be injected into the pipeline to decarbonize the gas supply in Pennsylvania or in the power sector if a feedstock already qualifies as an eligible Tier 1 or Tier 2 AEPS resource. As a first step, the analysis team considered RNG use for CHP; landfill gas will not be used for CHP and some portion of anaerobic digester gas will be used for CHP (most likely at water resource recovery facilities (WRRFS) and large farms). The remainder of available RNG will be used for both the power sector (as available and picked up through IPM modeling (see Electric Generation #2) and distributed proportionally across the end use sectors of residential and commercial buildings, industrial, and transportation based on total gas btu need.
- **Strategy Layering:** This action interacts with Electricity Generation Strategy #2 (carbon-free grid), Fuel Supply #2 (CHP), and all strategies that result in continued natural gas use (i.e., the industrial, residential, commercial, and transportation sectors).

- **Emissions Accounting:** GHG emissions reductions for this strategy are reflected in end use sectors and the power sector, as well as for Fuel Supply Strategy #3, which could focus on reduction of methane emissions from distribution systems for gas.

Applicable Emission Factors

- **GHGs:** The analysis team assumed that RNG is carbon neutral.
- **Air Quality:** The team used the Argonne National Laboratory's GREET Model to determine air quality emission factors for biogas/renewable natural gas.

Fuel Supply 2: Incentivize and Increase Use of Distributed Combined Heat and Power (CHP)

Description

- Incentivize and increase the use of distributed CHP with microgrids, particularly for high-value applications such as industrial applications or building campus-style settings.

Method, Data and Key Assumptions

- **Energy:** While most CHP systems use natural gas, they are substantially more efficient than separate heat and utility-delivered electricity. With the improved efficiency, there is a net reduction in fossil fuel consumption when CHP is implemented, provided that marginal grid generators are using fossil fuels. In the BAU case, current and planned CHP installations from ICF's CHP Installation Database are maintained through 2050. Other cases evaluate CHP potential and expected adoption according to economic factors, utility incentives, and technical potential for new CHP installations in Pennsylvania, referenced from ICF's CHP Technical Potential Database.
- **Strategy Layering:** This strategy will be applied after the Industrial energy efficiency strategy and Fuel Supply #1 (Bio/Renewable Gas).
- **Emissions Accounting:** Emissions savings appear in two places—emissions related to kWh are accounted for in the electricity generation sector, and emissions related to displaced gas or fossil use appear in the buildings sector. Emissions from electricity consumed by residential and commercial buildings are reported for informational purposes only and not included in emissions totals. These informational emission reductions are calculated using marginal emission factors for the grid over time.

Applicable Emission Factors

- **GHG:** GHG emission factors for electricity will come from IPM. The analysis team calculated a blended gas supply emission factor over time based on the available supply of renewable natural gas (see Fuel Supply 1 measure) and overall gas demand across the state. Other fuel emission factors come from the U.S. Inventory and 2006 IPCC Guidelines for National Greenhouse Gas Inventories (consistent with the State Inventory Tool).
- **Air Quality:** Air Quality emissions factors for electricity come from IPM. Emissions factors for natural gas, coal, fuel oil and other fuels come from EPA AP-42 Fifth Edition Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources; and Emission Factor Supporting Documentation for the Final Mercury and Air Toxics Standards. Mercury Air Toxic Standards (MATS). As applicable biogas air quality factors will also be used (see Fuel Supply 1).

Fuel Supply 3: Reduce Methane Emissions Across Oil and Natural Gas Systems

Description

- This strategy would reflect and go beyond what expected methane reductions will be related to the VOC regulations. This strategy could also consider similar regulations or strategies, as they may interact with increased renewable gas supply.

Method, Data and Key Assumptions

- Under development in coordination with Pennsylvania Air Quality program staff

Electricity Generation

Electricity Generation 1: Maintain Nuclear Generation at Current Levels

Description

- Implement a policy to maintain nuclear generation at current levels. This would assume an 80-year lifetime extensions for plants currently in operation; all plants currently in operation would stay online through 2050 at least with this extension.

Method, Data and Key Assumptions

- **Energy:** For the BAU, the analysis team assumed that Three Mile Island closes in 2019 as a firm retirement. BAU nuclear generation levels are held constant after these plants are closed. To model a policy action that restores these units to service for the study period, their capacity and generation are added back to the PJM fleet. To balance the overall electricity generation totals over the years (i.e., to not create new generation on top of the business-as-usual scenario), the team assumed that nuclear electricity generation displaces coal and natural gas electricity generation in future years.
- **Strategy Layering:** This action is applied before Electricity Generation Strategy #2 (carbon-free grid).
- **GHG Accounting:** GHG emission accounting for this strategy used IPM Reference Case output as a baseline, and projected GHG reductions from maintaining nuclear as a source of electricity generation at current levels.

Applicable Emission Factors

- **GHGs:** GHG emission factors come from IPM.
- **Air Quality:** Air quality emission factors come from IPM.

Electricity Generation 2: Create a Carbon Emissions Free Grid

Description

- Increase Alternative Energy Portfolio Standard (AEPS) to be a 100% AEPS, Tier 1 targets and the solar carve out with be expanded and additional eligible sources will be added including nuclear, storage, and fossil with carbon capture and sequestration; Tier 2 sources will be maintained as part of the portfolio of options to meet the 100% target. This will also likely include strategies to expand the development of solar and wind projects across the Commonwealth, such as legislation to help develop a robust solar industry both at the distributive- and grid-level (PA Solar Future), and strategies that increase the value of solar renewable energy credits (SRECs). It would focus on the AEPS and other complementary legislation and programs, all aimed at increasing renewable and alternative electricity at grid scale.

Method, Data and Key Assumptions

- **Method:** The team used IPM to determine the generation through 2050 that will result in a clean grid (100% AEPS requirement by 2050), based on several constraints:
    - The solar carve out is assumed to be in line with the Finding Pennsylvania's Solar Future Plan initially, and then will go beyond it in 2030 through 2050.
    - Generation for other eligible renewables from 2020 through 2050 were developed using IPM.
    - All solar Alternative Energy Credits (AECs) for solar and Tier 2 resources are assumed to come from in-state generation, as required through legislation. DEP may consider limiting additional resources in-state in the modeling should additional reductions be needed to achieve a state-wide 80% reduction by 2050.

- **Strategy Layering:** This action is applied after Electricity Generation Strategy #1 (maintain nuclear generation at current levels). This action interacts with other CAP actions that impact electricity use (e.g., buildings, transportation, and CHP), as the electricity consumption emission factor will change from grid changes in the Commonwealth.
- **GHG Accounting:** GHG emission accounting for this strategy used IPM Reference Case emissions as a baseline and projected GHG reductions in Pennsylvania from transitioning to a clean grid.

Applicable Emission Factors

- **GHGs:** GHG emissions come from IPM.
- **Air Quality:** Emissions for NO_x and SO_2 come from IPM.

Agriculture

Agriculture 1: Use Programs, Tools, and Incentives to Increase Energy Efficiency for Agriculture

Description

- Offer programs, tools, and incentives to increase energy efficiency for agricultural end uses such as refrigeration, ventilation, and lighting. This strategy will build off recent EnSave report and strategies.

Method, Data and Key Assumptions

- **Baseline Farm Energy Use:** Annual baseline farm energy consumption used data from a report by EnSave titled "Energy Use, Energy Savings, and Energy Efficiency Policy Recommendations for Pennsylvania Agriculture."[26] The report provides estimates for annual electricity and fuel usage for dairy, beef, poultry, swine, orchard, greenhouse, and crop farming. These estimates are based on EnSave's Farm Energy Audit Tool (FEAT) database. This baseline was disaggregated from the EIA BAU data to ensure alignment and to prevent double counting.
- **Energy Efficiency Measures:** EnSave's report provides a list of recommended energy efficiency strategies from which the analysis team selected strategies that have the most potential for energy savings and emission reductions. Examples of potential strategies include: implementing LED lighting and lighting controls, high efficiency circulation fans, high efficiency scroll compressors, wall insulation, and compressor heat recovery systems.
- **GHG Accounting:** Emissions savings as a result of energy efficiency improvements that affect electricity consumption are accounted for in the electricity generation sector (reduced generation = reduced emissions). Emissions from electricity consumed by farms were reported for informational purposes only and are not included in total emissions reductions. These informational emission reductions were calculated using marginal emission factors for the grid over time.
- **Strategy Layering:** This strategy does not require any layering.

Applicable Emission Factors

- **GHG:** GHG emission factors for electricity come from IPM and other relevant sources or be calculated using assumptions from onsite generation projects. The analysis team also accounted for reduced electricity emissions that result from combined heat and power (CHP) generation and updated the emissions factor for CHP as more projects come online. The analysis team calculated a blended gas supply emission factor over time based on the available supply of renewable natural gas (see Fuel Supply 1 measure) and overall gas demand across the state. Other fuel emission factors come from the U.S. Inventory and 2006 IPCC Guidelines for National Greenhouse Gas Inventories (consistent with the State Inventory Tool).
- **Air Quality:** Air Quality emissions factors for electricity come from IPM. Emissions factors for natural gas, coal, fuel oil, and other fuels come from EPA AP-42 Fifth Edition Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources; and Emission Factor Supporting Documentation for the Final Mercury and Air Toxics Standards. Mercury Air Toxic Standards (MATS).

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[26] EnSave report "Energy Use, Energy Savings, and Energy Efficiency Policy Recommendations for Pennsylvania Agriculture."

Agriculture 2: Provide Trainings and Tools to Implement Agricultural Best Practices

Description

- Provide trainings and tools to implement agricultural best practices, such as those focused on no-till farming practices, integrated farm management and conservation planning, and soil management. Practices could include rotational grazing, silvopasture, and organic and regenerative agricultural methods.
- Research crops that will be most appropriate for future climate conditions.

Method, Data and Key Assumptions

- **Total Acres Planted**: The analysis team assumed the total agricultural acres planted in Pennsylvania will increase by approximately 2% annually based on the U.S. Department of Agriculture (USDA) Pennsylvania Tillage Survey statistics for 2013 and 2014.
- **Acres Planted by Crop**: The team assumed that the percent of acres planted by crop is consistent with the average percent of acres planted by crop from 2011 to 2017, as obtained from the USDA National Agricultural Statistics Service QuickStats database.[27]
- **Tillage Adoption**: The team assumed conventional tillage acres will transition to reduced tillage acres, and reduced tillage acres will transition to no-tillage acres.[28]
    - **No-Till Adoption:** According to USDA's Pennsylvania Tillage Survey statistics, no-till acres increased by approximately 8.5% from 2013 to 2014. The analysis team conservatively assumed no-till acres in Pennsylvania will increase by approximately 6% annually based on the slower, historical trend of no-till adoption. The team also assumed that no-till adoption will reach a maximum of 98% of acres planted by 2024.
    - **Reduced Till Adoption:** According to USDA Pennsylvania Tillage Survey statistics, reduced till acres decreased by approximately 16% from 2013 to 2014. For this analysis, the team assumed this trend will continue through 2018. After 2018, reduced till acres will decrease by approximately 30,000 acres annually until no-till adoption reaches 98% of total acres planted in 2024. After 2024, the share of reduced till acres will remain constant at approximately 1% of total acres planted.
    - **Conventional Till:** Conventional till acres were assumed to equal the difference between total acres planted, no-till acres, and reduced till acres.
- **Carbon Sequestration:** Emission reductions by crop/tillage practice for USDA's Northeast region come from the USDA's "Greenhouse Gas Mitigation Options and Costs for Agricultural Land and Animal Production within the United States" report. Emission reductions by crop/tillage practice are based on Pennsylvania's average share of acres planted by crop from 2011 to 2017. This was considered and layered with LULUCF Strategy #1.
- **Changes in Yield:** Changes in yield by crop/tillage practice for USDA's Northeast region come from USDA's "Greenhouse Gas Mitigation Options and Costs for Agricultural Land and Animal Production within the United States" report. Changes in yield by crop/tillage

[27] https://quickstats.nass.usda.gov/ Accessed July 4, 2018.

[28] In 2013, farmland comprised 16.6% conventional till acres, 21.5% reduced till acres, and 61.9% no till acres comprised. USDA. 2015. Tillage Practices with Updated Alfalfa Seedings and Final Acreages. Accessed July 3, 2018/. Available online at: https://www.nass.usda.gov/Statistics_by_State/Pennsylvania/Publications/Survey_Results/tillage%202014%20jan%2020125.pdf.

practice are based on Pennsylvania's average share of acres planted by crop from 2011 to 2017.

- **Changes in Production and Revenue**: The analysis team multiplied estimates of reduced yield by the projected estimates of conventional, reduced, and no-till acres in Pennsylvania to obtain reduced production estimates. The team multiplied production by weighted revenue (dollars per short ton of production).
- **Energy Savings**: The team estimated fuel savings by applying USDA regional estimates of fuel consumption ($/acre) for various tillage practices to the projected estimates of conventional, reduced, and no-till acres in Pennsylvania. The analysis team assumed diesel, natural gas, liquefied petroleum gas (LPG), motor gasoline, and kerosene represented 73, 23, 2, 3, and <1% of consumption on a BTU basis, respectively, based on consumption data for the Agriculture economic sector from U.S. EPA's 1990-2016 Inventory of U.S. Greenhouse Gas Emissions and Sinks. These values were updated with the most recent U.S. Inventory data.
- **Strategy Layering:** This strategy does not require any layering.

Applicable Emission Factors

- GHG and air quality emission factors are based on estimates from USDA's "Greenhouse Gas Mitigation Options and Costs for Agricultural Land and Animal Production within the United States" report and other state-specific sources, where applicable. The team used emission factors from the U.S. GHG Inventory and IPCC guidance as needed.

LULUCF

Land Use 1: Land Management for Natural Sequestration and Increased Urban Green Space

Note: The analysis team is working with DCNR and Penn State University to further develop and refine the methodology below.

Description

- Expand forest and crop lands and improve soil management to sequester carbon naturally. This includes increasing urban green space.

Method, Data and Key Assumptions

- **Land-Use Assessment:** The project team identified a comprehensive assessment of Pennsylvania's land cover to determine what land-cover types are found in Pennsylvania and how they are distributed. This land-cover data provided the project team with a baseline for developing land-use strategies that maximize the amount of carbon sequestration.
- **Forest Carbon and Urban Trees:** The U.S. Forest Service published a report in April 2020 that summarizes the amount of CO_2 emissions and removals from forest land, woodlands, and urban trees at the state-level. This publication served as a starting point for determining how much carbon is currently being sequestered by forest and urban tree cover in Pennsylvania.[29]
- **DCNR Climate Change Mitigation and Adaptation Plan:** Pennsylvania's Department of Conservation and Natural Resource (DCNR) published a Climate Change Mitigation and Adaptation Plan in June 2018 that highlights major vulnerabilities Pennsylvania's natural and managed lands face, and outlines specific strategies to address them.[30] The actions focused on carbon sequestration were especially useful for identifying the list of reduction strategies for this CAP. Some of these strategies include:
    - Increasing forest carbon stocks by increasing forest coverage and avoiding conversion of forest to non-forest uses.
    - Decreasing forest carbon loss by adjusting timber harvesting intensities and rotations.
    - Utilizing durable wood-based products whenever possible in construction projects.
- **Cropland and Soil Management:** Although forests and urban trees are typically the largest land-based stock of carbon, croplands also have the potential to store significant quantities of carbon. The project team worked with Penn State to identify potential land management practices that could be easily modeled in the analysis framework. Additionally, the project team ensured that this strategy does not overlap with Agriculture Strategy #2.

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[29] Greenhouse gas emissions and removals from forest land, woodlands, and urban trees in the United States, 1990-2018. Resource Update FS-227. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 5 p. https://doi.org/10.2737/FS-RU-227.

[30] Pennsylvania DCNR Climate Change Mitigation and Adaptation Plan (2018). https://www.dcnr.pa.gov/Conservation/ClimateChange/Pages/default.aspx

- **Emissions Accounting:** GHG emission accounting for this strategy will use the estimates from the State Inventory Tool (SIT) as a baseline and project CO_2 reductions from the proposed changes in land-use practices.

Applicable Emission Factors

- GHG and Air Quality emission factors are based on the State Inventory Tool's LULUCF module. If possible, the project team will identify more state-specific factors.

Adaptation Strategy Methodology

- 1-page methodological details and detailed results for each adaptation action or flexible pathway.